AN ONTOLOGICALLY FOUNDED AND GOVERNANCE-INTEGRATED INFORMATION DASHBOARD DESIGN METHOD

AHADI BIN HAJI MOHD NASIR

UNIVERSITI KEBANGSAAN MALAYSIA

AN ONTOLOGICALLY FOUNDED AND GOVERNANCE-INTEGRATED INFORMATION DASHBOARD DESIGN METHOD

AHADI BIN HAJI MOHD NASIR

THESIS SUBMITTED IN FULFILMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

INSTITUTE OF VISUAL INFORMATICS
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2025

KAEDAH MEREKA BENTUK PAPAN PEMUKA MAKLUMAT BERASASKAN ONTOLOGI YANG DIINTEGRASI DENGAN TADBIR URUS

AHADI BIN HAJI MOHD NASIR

TESIS YANG DIKEMUKAKAN UNTUK MEMPEROLEH IJAZAH DOKTOR FALSAFAH

INSTITUT VISUAL INFORMATIK
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2025

UNIVERSITI KEBANGSAAN MALAYSIA
The National University of Malaysia

PERAKUAN TESIS SARJANA / DOKTOR FALSAFAH
(DECLARATION OF MASTER / DOCTOR OF PHILOSOPHY THESIS)

A. MAKLUMAT PELAJAR/*STUDENT DETAILS*	
Nama *Name*	Ahadi bin Haji Mohd Nasir
No. Pendaftaran *Registration No.*	P127430
Fakulti/Institut *Faculty/Institute*	Institut Informatik Visual (IVI)
Program Pengajian *Program of Study*	~~Sarjana~~ / Doktor Falsafah | *~~Masters~~ / Doctor of Philosophy*
Tajuk Tesis *Thesis Title*	An Ontologically Founded and Governance-Integrated Information Dashboard Design Method
Mel-e/*Email*: p127340@siswa.ukm.edu.my	No. Telefon/*Tel No.*: 017-3995657

B. PERAKUAN / *DECLARATION*

Merujuk kepada Dasar Harta Intelek UKM 2018, **tesis adalah hak milik UKM** seperti keterangan dibawah:

4.2.1 Harta Intelek yang direka cipta oleh pelajar termasuk tesis dan semua hasil penyelidikan ditulis oleh Pelajar UKM dalam tempoh pengajiannya di UKM direka cipta, dibangunkan atau dihasilkan menggunakan kemudahan, bahan, dana, atau sumber lain adalah hak milik UKM melainkan dinyatakan sebaliknya dalam Dasar ini atau dipersetujui sebaliknya oleh UKM dan Pelajar/Penaja.

*Referring to the UKM Intellectual Property Policy 2018, **the thesis is the property of UKM** as described below:*

4.2.1 Intellectual property created by the student, including the thesis and all research output produced by the UKM Student during their studies at UKM, including designed, developed or produced output using facilities, materials, funds, or other resources are the property of UKM unless otherwise stated in this Policy or otherwise agreed by UKM and the Student/Sponsor.

	RAHSIA ***CONFIDENTIAL***	Mengandungi maklumat rahsia di bawah AKTA RAHSIA RASMI 1972 *Consisting of classified information under the OFFICIAL SECRETS ACT 1972*
	TERHAD ***RESTRICTED***	Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan *Consisting of RESTRICTED information which has been determined by the organisation/body where the research was conducted*
✓	**AKSES TERBUKA/ TIDAK TERHAD** ***OPEN ACCESS/ NON-RESTRICTED***	Saya membenarkan tesis ini diterbitkan secara akses terbuka, teks penuh atau dibuat salinan untuk tujuan pengajian, pembelajaran & penyelidikan sahaja *I give permission for this thesis to be published through open access, full text or copied only for study, learning, and research purposes.*

Bagi kategori Akses Terbuka/Tidak Terhad, saya membenarkan tesis (Sarjana/Doktor Falsafah) ini di simpan di Perpustakaan Universiti Kebangsaan Malaysia (UKM)* dengan syarat-syarat kegunaan seperti berikut:

For the Open Access/Non-Restricted category, I permit this (Master's/Doctoral) Thesis to be kept in the Universiti Kebangsaan Malaysia (UKM) Library with the following conditions:

1. Perpustakaan UKM mempunyai hak untuk membuat salinan untuk tujuan pengajian,pembelajaran, penyelidikan sahaja.

   UKM Library has the right to reproduce the thesis only for study, learning and research purposes.

2. Perpustakaan Universiti Kebangsaan Malaysia dibenarkan membuat satu (1) salinan tesis ini untuk tujuan pertukaran antara institusi pengajian tinggi dan mana-mana badan/ agensi kerajaan, tertakluk kepada terma dan syarat.

   UKM Library is allowed to make one (1) copy of this thesis for exchange purposes among higher education institutions and any government body/agency, subject to the terms and conditions.

Saya mengakui maklumat & tesis yang diberikan adalah benar & terkini.

I acknowledge the information & the thesis provided are correct & current.

Tandatangan Pelajar:
Student's Signature

Tarikh / Date: 26 Disember 2025

Saya memperakukan maklumat & tesis yang diberikan adalah benar & terkini.

I verify that the information & the thesis provided are correct & current.

Tandatangan Penyelia / *Supervisor's Signature*:

Nama / *Name*: **Prof. Madya Dr. Mohammad Nazir Ahmad**

Cop Rasmi / *Official Stamp*:

ASSOC. PROF. DR. MOHAMMAD NAZIR AHMAD
Institute of Visual Informatics,
Universiti Kebangsaan Malaysia (UKM)
43600, Bangi, Selangor
mnazir@ukm.edu.my

Tarikh / Date: 26 Disember 2025

C. PENGESAHAN FAKULTI/INSTITUT | *VERIFICATION OF FACULTY/INSTITUTE*

Tandatangan/*Signature*:
Nama/*Name*:
Tarikh/*Date*:
Cop Rasmi/*Official Stamp*:

MOHAMAD SALLEH SULIEMAN
Penolong Pendaftar Kanan
Institut Informatik Visual (IVI)
Universiti Kebangsaan Malaysia

**Kuatkuasa:15 Julai 2021

DECLARATION

I hereby declare that the work in this thesis is my own except for quotations, and summaries which have been duly acknowledged.

30 December 2025

AHADI BIN HAJI MOHD NASIR
P127430

ACKNOWLEDGMENT

Alhamdulillah, I am truly grateful for the opportunity to pursue this doctoral journey - a journey that has tested my limits, challenged my thinking, and reshaped my perspective as someone coming from the industry, not academia.

My heartfelt appreciation goes to Associate Professor Dr. Mohammad Nazir Ahmad, my supervisor, who not only guided this research but also introduced me to the nuances of academic thinking and scholarly writing. His mentorship has been pivotal in shaping my understanding of research, theory, and contribution to knowledge, things I would have never fully grasped on my own. I would also like to acknowledge Dr. Ely Salwana Mat Surin, my co-supervisor, for her support and contribution throughout this research process.

I am sincerely thankful to my employer, KDEB Waste Management, for the continuous support and the flexibility extended to me in balancing my professional responsibilities with the demands of this PhD journey. To my dedicated team in the Project Delivery and Subsidiary Management Department, and to my colleagues across KDEB Waste Management, KDEB Services, and KDEB ICI, thank you for your understanding, encouragement, and for always having my back throughout this journey.

To my family —my beloved wife, Nor Idayu Binti Ahmad, and my children, Muhammad Amjad, Muhammad Al-Fateh, Muhammad Aslam, and Amani —thank you for your endless patience, love, and prayers. To my late aunty, Hajah Noripah Binti Alias, who constantly encouraged me to pursue this PhD journey, my father, Haji Mohd Nasir Bin Haji Alias, and in loving memory of my late mother, Zaiton Binti Abdul Rahman, your sacrifices and values continue to inspire me. I am also grateful to my extended family, especially my brothers Ahsani and Ansar, as well as all relatives and in-laws who have continuously supported me with their encouragement and doa throughout this journey.

May this work be of benefit not only to those in the field, but also serve as a source of inspiration for my children, and a small contribution that brings value to others, InsyaAllah. May Allah bless us all. *Ameen*.

ABSTRACT

Information dashboards have become essential monitoring and decision-support tools in smart waste management systems, providing stakeholders with real-time operational insights to enhance efficiency and effectiveness. Despite their widespread adoption, existing dashboard design practices remain fragmented and ad hoc, with most studies focusing on domain-specific implementations using diverse approaches. Critically, no standardized Information Dashboard Design Method (IDDM) exists that integrates Information Governance (IG) principles or employs ontological approaches, resulting in inconsistent design practices, limited knowledge reuse, and insufficient attention to governance requirements such as data quality, compliance, and accountability. This research addresses this gap by developing the IDDM Canvas, an ontology-based method that embeds IG principles to enable a systematic, accountable, and reusable dashboard design approach that reduces reliance on ad hoc practices. The research employed Design Science Research Methodology (DSRM) and synthesized common elements from thirteen recent dashboard design studies into twelve core building blocks organized across three categories: Defining and Planning, Design and Visualization, and Testing and Improvement. These building blocks are governed by eight IG principles: Effectiveness, Transparency, Accountability, Quality, Integrity, Compliance, Security, and Availability, which are integrated within the Information Dashboard Design Ontology (IDDO). The IDDO was developed using the Unified Ontology Approach (UOA), a customized Ontology Development Methodology (ODM), and formalized using OntoUML grounded in the Unified Foundational Ontology (UFO). The IDDM Canvas operationalizes IDDO into a structured, governance-aware method demonstrated through the Intelligent Monitoring Recycle System (i-MORSYS), where two independent designers applied the IDDM Canvas to create operational and analytical dashboards on Tableau and Looker Studio. Evaluation through semi-structured interviews with the two designers and one waste management expert, analyzed using Braun and Clarke's thematic analysis, revealed positive outcomes across seven themes: Framework usability and learning experience, Enhanced design thinking and user-centricity, Comprehensive coverage with implementation gaps, Practical implementation challenges, Framework flexibility and adaptability, Recommendations for enhancement, and Overall assessment and adoption potential. Participants rated the framework's usefulness at 8.5/10, with all expressing willingness to adopt the method in future projects. This research contributes theoretically through the invention of IDDO and the improvement of dashboard design method through the IDDM Canvas, positioning both within the Design Science Research contribution matrix. Practically, the framework provides a reusable, standardized method bridging ad hoc design practices and governance-aware, systematic approaches. The integration of IG principles establishes a foundation for ensuring data quality, regulatory compliance, and organizational accountability. The framework's ontological foundation enables potential adaptation beyond waste management to other domains requiring governance-aware dashboard design. Future work includes developing iterative design support, operationalizing governance principles with actionable guidance, and exploring the IDDM Canvas's potential as input for AI-assisted dashboard generation tools.

KAEDAH MEREKA BENTUK PAPAN PEMUKA MAKLUMAT BERASASKAN ONTOLOGI YANG DIINTEGRASI DENGAN TADBIR URUS

ABSTRAK

Papan pemuka maklumat telah menjadi alat pemantauan dan sokongan keputusan yang penting dalam sistem pengurusan sisa pintar, dengan menyediakan maklumat operasi masa nyata kepada pihak berkepentingan bagi meningkatkan kecekapan dan keberkesanan perkhidmatan. Walaupun penggunaannya semakin meluas, amalan reka bentuk papan pemuka sedia ada masih dilakukan secara *ad hoc*, dengan kebanyakan kajian tertumpu kepada pelaksanaan khusus domain menggunakan pendekatan yang berbeza-beza. Secara kritikal, sehingga kini tiada kaedah reka bentuk papan pemuka maklumat (IDDM) yang standard, berasaskan ontologi, serta mengintegrasikan prinsip Tadbir Urus Maklumat (IG). Ketiadaan pendekatan sedemikian telah mengakibatkan ketidakseragaman amalan reka bentuk, keterbatasan penggunaan semula pengetahuan, dan kurangnya penekanan terhadap keperluan tadbir urus seperti kualiti data, pematuhan dan akauntabiliti. Kajian ini menangani jurang tersebut dengan membangunkan Kanvas IDDM, iaitu satu kaedah reka bentuk papan pemuka berasaskan ontologi yang mengintegrasikan prinsip IG bagi membolehkan pendekatan reka bentuk yang lebih sistematik, berakauntabiliti dan boleh digunakan semula, sekali gus mengurangkan kebergantungan terhadap amalan *ad hoc*. Kajian ini menggunakan Metodologi Penyelidikan Sains Reka Bentuk (DSRM) dan mensintesiskan elemen-elemen sepunya daripada tiga belas kajian reka bentuk papan pemuka terkini kepada dua belas blok binaan teras yang disusun dalam tiga kategori utama, iaitu Definisi dan Perancangan, Reka Bentuk dan Visualisasi, serta Pengujian dan Penambahbaikan. Kesemua blok binaan ini ditadbir oleh lapan prinsip IG, iaitu Keberkesanan, Ketelusan, Akauntabiliti, Kualiti, Integriti, Pematuhan, Keselamatan dan Ketersediaan, yang diintegrasikan dalam Ontologi Reka Bentuk Papan Pemuka Maklumat (IDDO). IDDO dibangunkan menggunakan Pendekatan Ontologi Bersepadu (UOA), iaitu satu Kaedah Pembangunan Ontologi (ODM) yang disesuaikan, dan diformalisasikan menggunakan OntoUML berasaskan *Unified Foundational Ontology* (UFO). Kanvas IDDM seterusnya mengoperasikan IDDO ke dalam satu kaedah reka bentuk berstruktur yang peka terhadap keperluan tadbir urus. Demonstrasi pelaksanaannya ditunjukkan melalui Sistem Pemantauan Kitar Semula Pintar (i-MORSYS), di mana dua pereka bebas menggunakan Kanvas IDDM untuk membangunkan papan pemuka operasi dan analitikal menggunakan platform *Tableau* dan *Looker Studio*. Penilaian dilakukan melalui temu bual separa berstruktur bersama dua pereka bebas tadi dan seorang pakar pengurusan sisa, dan dianalisis menggunakan analisis tematik *Braun* dan *Clarke.* Dapatan kajian menunjukkan hasil positif merentasi tujuh tema utama, iaitu kebolehgunaan kerangka dan pengalaman pembelajaran, peningkatan pemikiran reka bentuk dan orientasi pengguna, liputan menyeluruh dengan jurang pelaksanaan, cabaran pelaksanaan praktikal, fleksibiliti dan kebolehsuaian kerangka, cadangan penambahbaikan, serta penilaian keseluruhan dan potensi penerimaan. Para peserta menilai kegunaan kerangka ini pada skor purata 8.5 daripada 10, dan semua menyatakan kesediaan untuk menggunakannya dalam projek masa hadapan. Dari sudut sumbangan, kajian ini menyumbang secara teori melalui penciptaan IDDO dan penambahbaikan kaedah reka bentuk papan pemuka melalui Kanvas IDDM, dengan kedua-duanya diposisikan dalam matriks sumbangan Penyelidikan Sains Reka Bentuk. Dari segi praktikal, kerangka yang dicadangkan menyediakan satu kaedah reka bentuk yang

boleh digunakan semula dan diseragamkan, yang merapatkan jurang antara amalan *ad hoc* dan pendekatan reka bentuk yang sistematik serta berteraskan tadbir urus. Integrasi prinsip IG mewujudkan asas untuk memastikan kualiti data, pematuhan peraturan dan akauntabiliti organisasi. Asas ontologi yang digunakan turut membuka potensi peluasan aplikasi ke domain lain yang memerlukan reka bentuk papan pemuka berasaskan tadbir urus. Kajian masa hadapan dicadangkan untuk merangkumi sokongan reka bentuk lelaran, pengoperasian prinsip tadbir urus melalui panduan yang lebih mudah dilaksanakan, serta penerokaan potensi Kanvas IDDM sebagai input kepada alat penjanaan papan pemuka berasaskan kecerdasan buatan.

TABLE OF CONTENTS

		Page
DECLARATION		iii
ACKNOWLEDGEMENT		iv
ABSTRACT		v
ABSTRAK		vi
TABLE OF CONTENTS		viii
LIST OF TABLES		xiv
LIST OF FIGURES		xvii
LIST OF ABBREVIATIONS		xxi
CHAPTER I	**INTRODUCTION**	
1.1	Introduction	1
1.2	Research Background	4
1.3	Motivation	6
	1.3.1 Intersection of key areas	6
1.4	Problem Statement	7
1.5	Research Questions	6
1.6	Research Objectives	9
1.7	Research Scope	10
	1.7.1 Research strategy diagram	10
1.8	Thesis Outline	11
CHAPTER II	**LITERATURE REVIEW**	
2.1	Introduction	13
2.2	Information Dashboard Design (IDD): Background and Issues	14

	2.2.1	Design issues	15
	2.2.2	Common mistakes	16
	2.2.3	Design: Principles and practices	17
	2.2.4	Common dashboard: Elements and characteristics	18
	2.2.5	Towards unification: Principles, practices, and others	19
	2.2.6	Conclusion	20
2.3	Ontology		21
	2.3.1	What is ontology?	22
	2.3.2	Alternative knowledge representation approaches in information systems	23
	2.3.3	Why ontology	24
	2.3.4	Conclusion	25
2.4	Information Governance (IG)		26
	2.4.1	What is IG?	26
	2.4.2	IG for supporting IDD: Relationship	26
	2.4.3	Review of established IG models	27
	2.4.4	Conclusion	32
2.5	Proposing New Concepts in IDD		32
	2.5.1	IG as a theoretical framework for IDD	33
	2.5.2	The notion of the ontology of information dashboard	34
	2.5.3	The framework: Information dashboard design method based on IDDO	34
2.6	Related Work and Gap Analysis		36
	2.6.1	Discussion of related works	58
	2.6.2	Identified research gaps	66
2.7	Summary		67
CHAPTER III	**METHODOLOGY**		
3.1	Introduction		70
3.2	Research Paradigms in Information Systems		71
3.3	Design Science Research Methodology: An Overview		72
	3.3.1	Problem identification and motivation	79

	3.3.2	Objectives of a solution	79
	3.3.3	Design and development	80
	3.3.4	Demonstration and evaluation	80
	3.3.5	Communication	81
3.4	Design Science Research Methodology: An Application		81
	3.4.1	Problem identification and motivation	84
	3.4.2	Objective of a solution	84
	3.4.3	Design and development	85
	3.4.4	Demonstration and evaluation	86
	3.4.5	Communication	86
3.5	Research Design Diagram		87
3.6	Summary		90
CHAPTER IV	**TRANSFORMING ONTOLOGY INTO PRACTICAL APPLICATION: DESIGN AND DEVELOPMENT OF THE IDDM**		
4.1	Introduction		91
4.2	Establishing the Key Building Blocks for IDDO		92
	4.2.1	Key phases	93
	4.2.2	Design principles	94
	4.2.3	Best practices	95
	4.2.4	Key features	96
4.3	The Commonalities		97
4.4	The Building Blocks		99
	4.4.1	Purpose	104
	4.4.2	Audience	105
	4.4.3	Data source	106
	4.4.4	Data processing	107
	4.4.5	Style	108
	4.4.6	Visualization technique	109
	4.4.7	Layout	110
	4.4.8	Structure	111
	4.4.9	User interface	112
	4.4.10	Testing	112
	4.4.11	Evaluation	113
	4.4.12	Continuous improvement	114
	4.4.13	Conclusion	115

4.5	Categorizing the Building Blocks		116
	4.5.1	Defining and planning	117
	4.5.2	Design and visualization	117
	4.5.3	Testing and improvement	118
	4.5.4	Conclusion	119
4.6	IG as the Foundation of IDDO		120
	4.6.1	An overview of the established IG model	121
	4.6.2	An overview of diversification in IG principles	122
4.7	Derivation of Relevant IG Principles as the Foundational Governance of the IDDO		125
4.8	Applying Ontological Approach		130
	4.8.1	A snapshot of ontology development methods	131
	4.8.2	Ontology development method for IDDO	133
4.9	Designing and Developing the IDDO		135
	4.9.1	Identifying the scope and purpose	136
	4.9.2	Defining and identifying concepts	137
	4.9.3	Organizing concepts	138
	4.9.4	Defining properties and constraints	139
	4.9.5	Formalizing the ontology	155
4.10	Detailed IDDO Framework Components		162
	4.10.1	Implementing and testing	174
	4.10.2	Conclusion	177
4.11	Transforming the IDDO into the IDDM		177
4.12	Introducing the IDDM Canvas		178
4.13	Guidelines for Using the IDDM		182
4.14	Differentiating IDDM from Narrative Tools		185
4.15	Summary		187
CHAPTER V	**PUTTING IDDM CANVAS TO WORK: DEMONSTRATION AND EVALUATION IN REAL-WORLD SCENARIOS**		
5.1	Introduction		190

5.2	Demonstration Context: Intelligent Monitoring Recycle System (i-MORSYS)		194
	5.2.1	Overview of i-MORSYS	195
5.3	Applying The IDDM To i-MORSYS Dashboard Development		196
	5.3.1	Distinguishing operational and strategic dashboards in i-MORSYS	198
	5.3.2	Application scenario 1: i-MORSYS operational dashboard development	200
	5.3.3	Application scenario 2: i-MORSYS analytics dashboard development	215
5.4	Evaluation of the IDDM		234
	5.4.1	Evaluation methodology	234
	5.4.2	Evaluation findings	245
	5.4.3	Discussion of evaluation findings	257
	5.4.4	Summary of evaluation	259
5.5	Summary		260
CHAPTER VI	**RESEARCH ACHIEVEMENT, CONTRIBUTION, AND FUTURE WORK**		
6.1	Introduction		262
6.2	Research Achievements		263
	6.2.1	Achievement of research objective 1	263
	6.2.2	Achievement of research objective 2	264
	6.2.3	Achievement of research objective 3	265
6.3	Research Contribution		267
	6.3.1	Overview of artefacts developed	268
	6.3.2	Tree metaphor: A consolidated view of the research foundation and artefact outputs	271
	6.3.3	Design science research knowledge contribution framework	274
	6.3.4	Positioning the IDDM within design theory perspectives	283
6.4	Conclusion		285
6.5	Future Work		286

6.6	Summary	288
REFERENCES		290
APPENDICES		
Appendix A	Transcript of Interview - Dashboard Developer 1 (DD1)	311
Appendix B	Transcript of Interview - Dashboard Developer 2 (DD2)	322
Appendix C	Transcript of Interview - Waste Management Expert (WME)	334

LIST OF TABLES

Table No.		Page
Table 1.1	Thesis outline	12
Table 2.1	Index of related works	37
Table 2.2	Recent related studies in information dashboard design (IDD)	48
Table 2.3	Research gaps identified from related works analysis	66
Table 4.1	The basis for establishing the building blocks involves focusing on key phases, design principles, best practices, and key features	93
Table 4.2	The summary of commonalities in design principles and best practices	98
Table 4.3	The summary of commonalities in key phases and key features	99
Table 4.4	Derivation of key building blocks for the IDDO	102
Table 4.5	Categorization of the building blocks	117
Table 4.6	The summary of the category, its building blocks, and its description	119
Table 4.7	Summary of shared characteristics of the IGRM, IGIM and IGMM	121
Table 4.8	Summary of the IG principles in the previous study	123
Table 4.9	The proposed IG principles, the common design principles they align with, and a brief explanation	128
Table 4.10	ODM’s category and characteristics	132
Table 4.11	The strength of the UOA compared with existing ODMs	134
Table 4.12	Summary of defining and planning category properties	149
Table 4.13	Summary of design and visualization category properties	150
Table 4.14	Summary of testing and improvement category properties	151
Table 4.15	Summary of foundational governance category properties	153

Table 4.16	Key OntoUML stereotypes (Guizzardi 2005) used in IDDO formalization	161
Table 4.17	Summary of guidelines for using the IDDM	183
Table 5.1	A brief description of the two dashboard types developed using the IDDM	193
Table 5.2	Key features of i-MORSYS	195
Table 5.3	Comparison of operational and analytics dashboards in i-MORSYS	199
Table 5.4	Key design decisions for operational dashboard mock up implementations	203
Table 5.5	Comparison of operational dashboard mock-ups	212
Table 5.6	Alignment with information governance principles in operational dashboard	213
Table 5.7	Key design decisions for analytical dashboard implementations	219
Table 5.8	Comparison of analytical dashboard mock-ups	230
Table 5.9	Alignment with information governance principles in analytical dashboard	230
Table 5.10	Summary of IDDM evaluation methodology	238
Table 5.11	Respondent profiles	239
Table 5.12	Interview guide structure for dashboard designers	241
Table 5.13	Interview guide structure for waste management expert	242
Table 5.14	Six phases of thematic analysis by Braun and Clarke (2006)	244
Table 5.15	Framework usability assessment by respondents	246
Table 5.16	Impact of IDDM on design approach	247
Table 5.17	Framework completeness assessment	249
Table 5.18	Implementation challenges and mitigation strategies	251
Table 5.19	Framework flexibility assessment	252

Table 5.20	Enhancement recommendations summary	254
Table 5.21	Overall assessment and adoption likelihood	256
Table 5.22	Evaluation findings mapped to DSR criteria	258
Table 6.1	Summary of research objectives and achievements	266
Table 6.2	Summary of DSR knowledge contribution quadrants	275
Table 6.3	Artefact positioning within the DSR knowledge contribution matrix	277
Table 6.4	Levels of design knowledge and typical contributions	280
Table 6.5	Artefact positioning within levels of design knowledge	282

LIST OF FIGURES

Figure No.		Page
Figure 1.1	Intersection key areas	5
Figure 1.2	Research strategy diagram	11
Figure 2.1	Information Governance Reference Model (IGRM)	29
Figure 2.2	Information Governance Implementation Model (IGIM)	30
Figure 2.3	The IBM Information Governance Maturity Model (IGMM)	31
Figure 2.4	Kinds of ontologies, according to their level of dependence on a particular task or point of view	35
Figure 2.5	Summary of key papers, identified gaps, and knowledge contribution of this study	69
Figure 3.1	Information systems research framework	72
Figure 3.2	Seven guidelines for design science	73
Figure 3.3	DSRM process model	75
Figure 3.4	Design science research contribution types	76
Figure 3.5	Level of design knowledge	77
Figure 3.6	DSR schools of thoughts on Kernel Theory	78
Figure 3.7	The entire DSRM processes applied to the study context	83
Figure 3.8	Research design diagram based on DSRM	88
Figure 4.1	Combine view of commonalities of design principles, best practices, key phases and key features in the information dashboard	99
Figure 4.2	The key building blocks of the IDDO	101
Figure 4.3	Components for the derivation of IG Principles for IDDO	126
Figure 4.4	Commonalities in design principles	127
Figure 4.5	Suggested relevant IG principles as the foundational governance of the IDDO	128

Figure 4.6	Unified ontological approach (UOA)	134
Figure 4.7	The categorization of the IDDO	139
Figure 4.8	The initial conceptual framework of the IDDO	141
Figure 4.9	The refined IDDO framework	144
Figure 4.10	The categorization of the IDDO building blocks	148
Figure 4.11	Formalized IDDO framework	159
Figure 4.12	Fragment of the IDDO framework - purpose, audience, and governing IG principles	163
Figure 4.13	Fragment of the IDDO framework - audience, data source, user interface and governing IG principles	164
Figure 4.14	Fragment of the IDDO framework - data source, data processing and governing IG principles	165
Figure 4.15	Fragment of the IDDO framework – style, visualization technique, and governing IG Principles	167
Figure 4.16	Fragment of the IDDO framework – visualization technique, layout and governing IG principles	169
Figure 4.17	Fragment of the IDDO framework – layout, structure, and its governing IG principles	170
Figure 4.18	Fragment of the IDDO framework – structure, user interface and its governing IG principles	171
Figure 4.19	Fragment of the IDDO framework – testing, evaluation, continuous improvement and its governing IG principles	173
Figure 4.20	Syntactical validation results of the IDDO framework using the OntoUML plugin in visual paradigm	176
Figure 4.21	The IDDM base canvas template	179
Figure 4.22	The refined IDDM canvas template	181
Figure 4.23	IDDM canvas with embedded guidelines	184
Figure 5.1	The filled IDDM Canvas (DDB) for the i-MORSYS operational dashboard - Tableau implementation	201

Figure 5.2	The filled IDDM canvas (DDB) for the i-MORSYS operational dashboard – Looker Studio implementation	202
Figure 5.3	Tableau implementation of the i-MORSYS operational dashboard	205
Figure 5.3a	Collection status section	206
Figure 5.3b	Collection performance section	207
Figure 5.3c	Carbon footprint section	207
Figure 5.3d	Segmented views of location status table and operator performance indicator	208
Figure 5.4	Looker studio implementation of the i-MORSYS operational dashboard	210
Figure 5.4a	Weight tracking and location by Kg CO2e section	211
Figure 5.4b	Category analysis section	211
Figure 5.4c	Performance metrics and user activity tracking section	212
Figure 5.5	The filled IDDM canvas (DDB) for the i-MORSYS analytical dashboard – Tableau implementation	217
Figure 5.6	The filled IDDM canvas (DDB) for the i-MORSYS analytical dashboard – Looker Studio implementation	218
Figure 5.7	Tableau implementation of the i-MORSYS analytical mock-up dashboard	221
Figure 5.7a	Environmental impact metrics section	222
Figure 5.7b	User and location section	223
Figure 5.7c	Collection performance section	223
Figure 5.7d	Demographic information section	224
Figure 5.8	Looker Studio implementation of the i-MORSYS analytical mock-up dashboard	226
Figure 5.8a	Key performance metrics section	227
Figure 5.8b	Geographical flow analysis section	228
Figure 5.8c	Comparative performance section	229

Figure 5.9	Braun and Clarke’s (2006) six-phase thematic analysis Framework	236
Figure 6.1	Tree metaphor illustrating the layered research contributions within the DSRM	272
Figure 6.2	DSR contribution types based on solution and domain maturity	275
Figure 6.3	Positioning of artefacts in the DSR knowledge contribution matrix	277
Figure 6.4	Levels of design knowledge	279
Figure 6.5	Artefact positioning in levels of design knowledge	281
Figure 6.6	Positioning of this study’s artefact (IDDM Canvas, grounded in IDDO) within the design theory schools	285

LIST OF ABBREVIATIONS

ADR	Action Design Research
AgiSCont	Agile Ontology Engineering Methodology
AI	Attractiveness Index
ARMA	Association of Records Managers and Administrators
BMC	Business Model Canvas
BMO	Business Model Ontology
BS	Behavioral Science
CIT	Critical Incident Technique
CRISP-DM	Cross-Industry Standard Process for Data Mining
CTA	Cognitive Task Analysis
DD1	Dashboard Designer 1
DD2	Dashboard Designer 2
DDBs	Dashboard Design Blueprints
DOLCE	Descriptive Ontology for Linguistic and Cognitive Engineering
DS	Design Science
DSR	Design Science Research
DSRM	Design Science Research Methodology
et al.	*et alia*; and others
e.g.	*exempli gratia*; example
ETL	Extract, Transform, Load
GPM	Green Project Manager

HCI	Human-Computer Interaction
IDD	Information Dashboard Design
IDDM	Information Dashboard Design Method
IDDO	Information Dashboard Design Ontology
IG	Information Governance
IGIM	Information Governance Implementation Model
IGMM	Information Governance Maturity Model
IGRM	Information Governance Reference Model
i-MORSYS	Intelligent Monitoring Recycle System
IR 4.0	Fourth Industrial Revolution
IS	Information Systems
KPIs	Key Performance Indicators
LOT	Linked Open Terms
MSS	Metric Specification Structure
MSW	Municipal Solid Waste
NCA	National Clinical Audits
NICU	Neonatal Intensive Care Unit
OD101	Ontology Development 101
ODMs	Ontology Development Methods
OFR	Overdose Fatality Review
PLD	Prescriptive Learning Dashboard
POCs	Proofs of Concept

RO	Research Objectives
RQ	Research Questions
SBW	Santa Barbara Walk
SDGs	Sustainable Development Goals
SUMO	Suggested Upper Merged Ontology
TAM	Technology Acceptance Model
UFO	Unified Foundational Ontology
UML	Unified Modeling Language
UOA	Unified Ontological Approach
WI	Walkability Index
WME	Management Expert
WoS	Web of Science

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

Municipal Solid Waste (MSW) can be an intricate problem if not systematically managed. In 2021, Malaysia generated 38,427 metric tonnes of MSW per day, contributed by 32.8 million people who were estimated to produce 1.17 kg of MSW per person daily (MIDA 2021). In daily waste operations, thousands of bins must be emptied and the collected waste transported to gazetted landfills. According to recent studies (Alourani et al. 2025; Ginting & Damayanti Apnena 2024), relying solely on manual surveillance can be inefficient and prone to errors, as it is nearly impossible to confirm whether all waste has been collected according to schedule. As we enter the Fourth Industrial Revolution (IR 4.0), it is imperative to embrace technological assistance to improve the efficiency and effectiveness of MSW management (Manik et al. 2024).

From an applied research standpoint, leveraging smart technology addresses several persistent challenges in MSW management, such as bin collection monitoring, contractor performance surveillance, on-site inventory tracking, and real-time reporting (Henaien et al. 2024; Maturi et al. 2025). At the core of these issues lies the need to manage stakeholder expectations, ensuring that waste is collected as scheduled and that relevant operational data is accessible to support timely interventions. All these requirements highlight the importance of analyzing and presenting operational information through a more structured and visual approach.

As environmental sustainability is increasingly recognised as a global concern aligned with the Sustainable Development Goals (SDGs), there is also a growing need to monitor the progress of recycling initiatives, which form an important branch of waste management. Rather than dealing with scattered and complex datasets, tracking this effort through a consolidated visual overview is far more practical and actionable.

This is where the information dashboard becomes increasingly significant. Dashboards consolidate vast amounts of data into a unified visual display (Few 2006), offering decision-makers an immediate and comprehensive overview (Wexler et al. 2017) . Additionally, according to Sarikaya et al. (2019), they also enhance decision-making by centralizing data into a single interface, allowing users to detect trends and identify anomalies more quickly. Productivity is improved by enabling on-demand access to critical information, freeing up time for higher-value tasks like analysis and strategic planning. Moreover, dashboards support clearer communication across organizational layers - employees, stakeholders, or the public, promoting transparency and encouraging data-driven collaboration (Rossi et al. 2025; Stahlman et al. 2025). Increased visibility also helps raise awareness and facilitates proactive management.

Despite the increasing reliance on information dashboards as strategic enablers, the effectiveness of such dashboards is highly dependent on how well their underlying design knowledge is structured, shared, and consistently applied (Sarikaya et al. 2019). In practice, dashboard design often relies heavily on designers' experience and ad hoc decision-making resulting in inconsistencies in how concepts, metrics, and visual elements are interpreted across different systems and stakeholders (Bach et al. 2023).

To address this limitation, an ontology-based approach offers a systematic means of formally structuring dashboard design knowledge by defining key concepts, relationships, and constraints in an explicit and reusable manner (Noy and Mcguinness 2001). By providing a shared conceptual foundation, ontology enhances consistency, reduces ambiguity, and improves communication among stakeholders involved in dashboard design and usage. In addition, embedding Information Governance (IG) considerations within such a structured foundation ensures that dashboards are not only visually effective but also aligned with governance requirements such as data quality, accountability, transparency, and responsible use of information (Liu et al. 2022).

Consequently, integrating ontology and IG into the dashboard design process has the potential to enhance the efficiency, accuracy, and scalability of information dashboards, particularly in complex operational environments such as smart waste management.

In summary, information dashboards are not merely visual tools but strategic enablers that improve operational performance, facilitate informed decisions, and strengthen stakeholder engagement. In the context of waste management, dashboards provide a structured mechanism for visualizing key performance indicators (KPIs), making them indispensable for driving smarter, more accountable waste operations.

1.2 RESEARCH BACKGROUND

Malaysia's population is increasing rapidly, reaching 32.7 million in 2022. Based on the Department of Statistics Malaysia data, Malaysia's population is projected to grow at a rate of 2.4 percent or equivalent to an additional 600,000 people yearly (DOSM, 2021). The increasing population and rapid urbanization process have caused a hike in waste generation (Chen 2018). Based on a Compendium of Environment Statistics, Malaysia data, there has been a significant increase in waste generation in recent years. Daily waste generation rose progressively from 36,843 tonnes in 2018 to 37,462 tonnes in 2019, 38,081 tonnes in 2020, 38,699 tonnes in 2021, and reached 39,936 tonnes in 2022 (MIDA 2021). According to Faridah et al. (2018), managing waste has been a complex and crucial task not only in Malaysia but also around the world. Hence, the integration of smart technologies is crucial for revolutionizing waste management, enhancing efficiency, and maximizing effectiveness, ultimately leading to a more sustainable environment (EEA 2021; Muhammad Zar et al. 2020; Liehu et al. 2022). One key component of a smart waste management system is a well-designed dashboard. A dashboard is a centralized platform that gives real-time information, analytics, and control over various waste management aspects. It acts as a visual interface, allowing users to dynamically monitor, track, and manage data efficiently for decision support (Sarikaya et al. 2019). A smart waste management system dashboard can display a wide range of information, including waste collection schedules, routes, bin fill levels, the operational status of waste disposal facilities, and environmental indicators (Dillon

2023). Consolidating and visualizing the data in the dashboard will enable local councils, contractors, decision-makers, and those stakeholders involved in waste management to gain a comprehensive overview of the system's performance. A well-designed dashboard is a significant step towards improving urban management which includes waste management, fostering the development of smart, comfortable, and sustainable cities and environments (MHLG 2018).

While dashboards play a central role in supporting smart waste management, their design increasingly involves complex interdependencies between data sources, operational processes, performance indicators, and stakeholder requirements. Without a formally structured foundation, such complexity can lead to inconsistent interpretations of dashboard components and hinder systematic reuse across projects and domains.

Ontology provides a mechanism to formally capture and organize this complexity by explicitly defining dashboard-related concepts and their relationships, thereby supporting a more structured and reusable IDDM. When complemented with IG principles, the resulting framework further ensures that dashboard designs support reliable data interpretation, traceable decision-making, and consistent performance monitoring across organizational boundaries.

In this study, smart waste management is selected as the application context due to its inherently complex, data-intensive, and multi-stakeholder operational environment. The domain involves diverse data sources, performance indicators, operational processes, and accountability requirements, making it a suitable and representative context for validating a standardized, ontology-based and governance-aware Information Dashboard Design Method (IDDM). Using smart waste management as the case context enables the proposed method to be evaluated in a realistic setting, while demonstrating its applicability to other domains with similar complexity.

1.3 MOTIVATION

Utilizing advanced technology to address the escalating issue of waste generation and enhance waste collection services is crucial for systematic and efficient waste management (Furqan Durrani et al. 2019). Recognizing the importance of integrating technology to enhance the efficiency, effectiveness, and sustainability of waste management services, numerous studies have explored smart waste management systems (Abdullah et al. 2022a; Pardini et al. 2020a; Widaningsih & Suheri 2021; Xenya et al. 2020a; Zeb et al. 2019). Commonly, the information dashboard plays a pivotal role in providing a consolidated overview of waste management service performance in any smart waste management system. The effectiveness of an information dashboard in delivering insights to its users, however, critically depends on how well it is designed to meet the specific requirements of its users and various stakeholders. This underscores the pivotal role of dashboard design in delivering insights and highlights its critical significance.

Given this dependency on dashboard design quality, there is a strong motivation to move beyond ad hoc design practices towards a more systematic and reusable design approach. Incorporating ontology into the IDDM enables the formalization of dashboard design knowledge, supporting consistent application, improved design efficiency, and reduced reliance on individual expertise. At the same time, integrating IG considerations ensures that the resulting dashboards are aligned with organizational accountability, data integrity, and transparency requirements.

These motivations collectively underpin the need for an ontology-based and governance-integrated IDDM, which forms the foundation of this research.

1.3.1 Intersection of Key Areas

As depicted in Figure 1.1, this study involves three key intersection areas: the ICT domain (information dashboard), the application domain (smart waste management), and the solution domain (ontology + information governance). The fundamental outcome, representing the core PhD merit and body of knowledge, emerges from the synthesis of these three domains at their central intersection. This synthesis leads to the development of the primary artifact - the “IDDM Canvas”, which is developed using an ontological approach and demonstrated within the smart waste management domain. The “IDDM Canvas” represents the principal contribution of this study, serving as a methodological framework that bridges theoretical foundations with practical application.

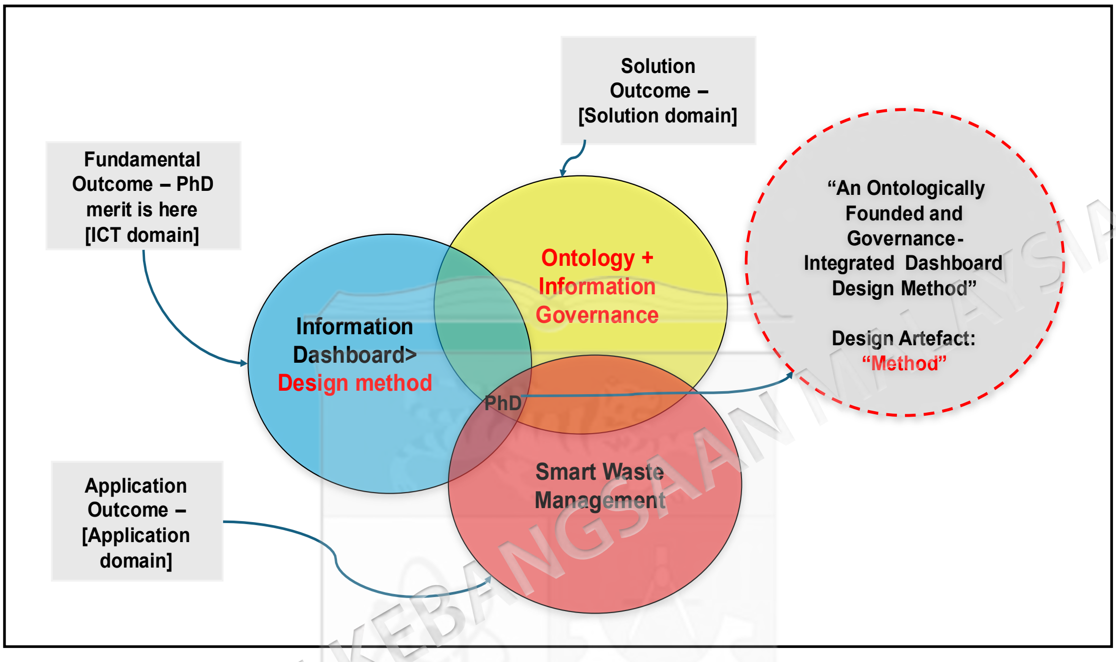

Figure 1.1 Intersection key areas

1.4 PROBLEM STATEMENT

The extensive use of information dashboards as tools for visualizing data and facilitating effective decision-making has widely studied across various domains (Lavalle et al. 2025; Pamuk & Schumann 2024; Poppe et al. 2024; Salvi et al. 2024; Conrow et al. 2023; Bach et al. 2023; Wu et al. 2021; Balletto et al. 2020; Elshehaly et al. 2020; Pestana et al. 2020; Young & Kitchin 2020; Syaiful et al. 2019; Kokoç & Altun 2019). However, a noticeable gap exists regarding the emphasis on a standardized and reusable IDDM within this body of research, particularly in the context of smart waste management.

While some studies touch upon IDDM elements, their primary focus often remains on domain-specific dashboard development (Pamuk & Schumann 2024; Poppe et al. 2024; Salvi et al. 2024; Balletto et al. 2020; Elshehaly et al. 2020; Pestana et al.

2020; Young & Kitchin 2020; Kokoç & Altun 2019; Syaiful et al. 2019), limiting their universal applicability. Notable exceptions include the studies by Lavalle et al. (2025), Conrow et al. (2023), Bach et al. (2023), and Wu et al. (2021), which develop a methodology for the systematic design of storytelling dashboard, conceptual framework for developing a dashboard that can handle big mobility data, provide structured guidance on dashboard patterns, and propose a deep learning-based analytical dashboard design approach.

The identified problem centers around the lack of a standardized approach for designing dashboards tailored specifically to the smart waste management domain, as well as the broader need for a unified version of IDDM. This lack of standardization potentially hampers the dashboard design process, diminishing its overall effectiveness.

More critically, existing IDDM-related studies have not adopted formal ontological approaches as a foundational mechanism for explicitly structuring and defining dashboard design knowledge. The absence of an ontology-driven foundation results in ambiguities in concept definitions, weak semantic consistency, and limited support for the systematic reuse and governance of design knowledge. This limitation becomes more pronounced in complex and data-intensive domains such as smart waste management, where dashboard design involves multiple interrelated concepts, processes, stakeholders, and governance expectations.

Therefore, the identified problem lies not only in the lack of a standardized and unified IDDM, but also in the absence of an ontology-based foundation that can formally organize and structure dashboard design knowledge while supporting governance-aware design practices across domains. Addressing this gap necessitates the development of a domain-independent, ontology-based IDDM that eliminates ad hoc design practices and enables the systematic design and demonstration of information dashboards, with smart waste management serving as the application domain for validation.

1.5 RESEARCH QUESTIONS

Based on the identified problem, this study seeks to address the following research questions (RQ):

RQ1: What are the existing information dashboard design methods and their limitations, particularly in terms of standardization, ontological structuring, and support for information governance considerations?

RQ2: How can a standardized, domain-independent, ontology-based and governance-aware IDDM be developed to effectively guide the design and implementation of information dashboards?

RQ3: How can the proposed ontology-based and governance-aware IDDM be systematically demonstrated and validated using smart waste management as the application domain?

1.6 RESEARCH OBJECTIVES

The primary objective of this research is derived from the above research questions. Accordingly, the research objectives (RO) are as follows:

RO1: To examine existing information dashboard design methods and identify their limitations with respect to standardization, ontological structuring, and support for information governance considerations.

RO2: To develop standardized, domain-independent, ontology-based and governance-aware IDDM that effectively guides the design and implementation of information dashboards.

RO3: To demonstrate and validate the proposed ontology-based and governance-aware IDDM using smart waste management as the application domain.

1.7 RESEARCH SCOPE

The scope of this study is divided into several elements:

1. This study involves designing and developing a unified IDDM framework based on ontological representation and IG principles.
2. The research methodology employed for this study is the Design Science Research Method (DSRM), a well-received and recognized methodology in the information systems discipline.
3. The IDDM will be demonstrated in the smart waste management system domain through the development of I-MORSYS – an Intelligent Monitoring Recycle System, designed as a mock-up dashboard to monitor and analyze recycling collection operations and performance.
4. The evaluation of the IDDM framework was conducted using a qualitative approach, specifically thematic analysis, to assess its usability, completeness, and effectiveness.

1.7.1 Research Strategy Diagram

The scope of this study is depicted in the research strategy diagram, which is grounded in the widely accepted Design Science Research (DSR) process model proposed by Peffers et al. (2007) . This diagram is depicted in Figure 1.2.

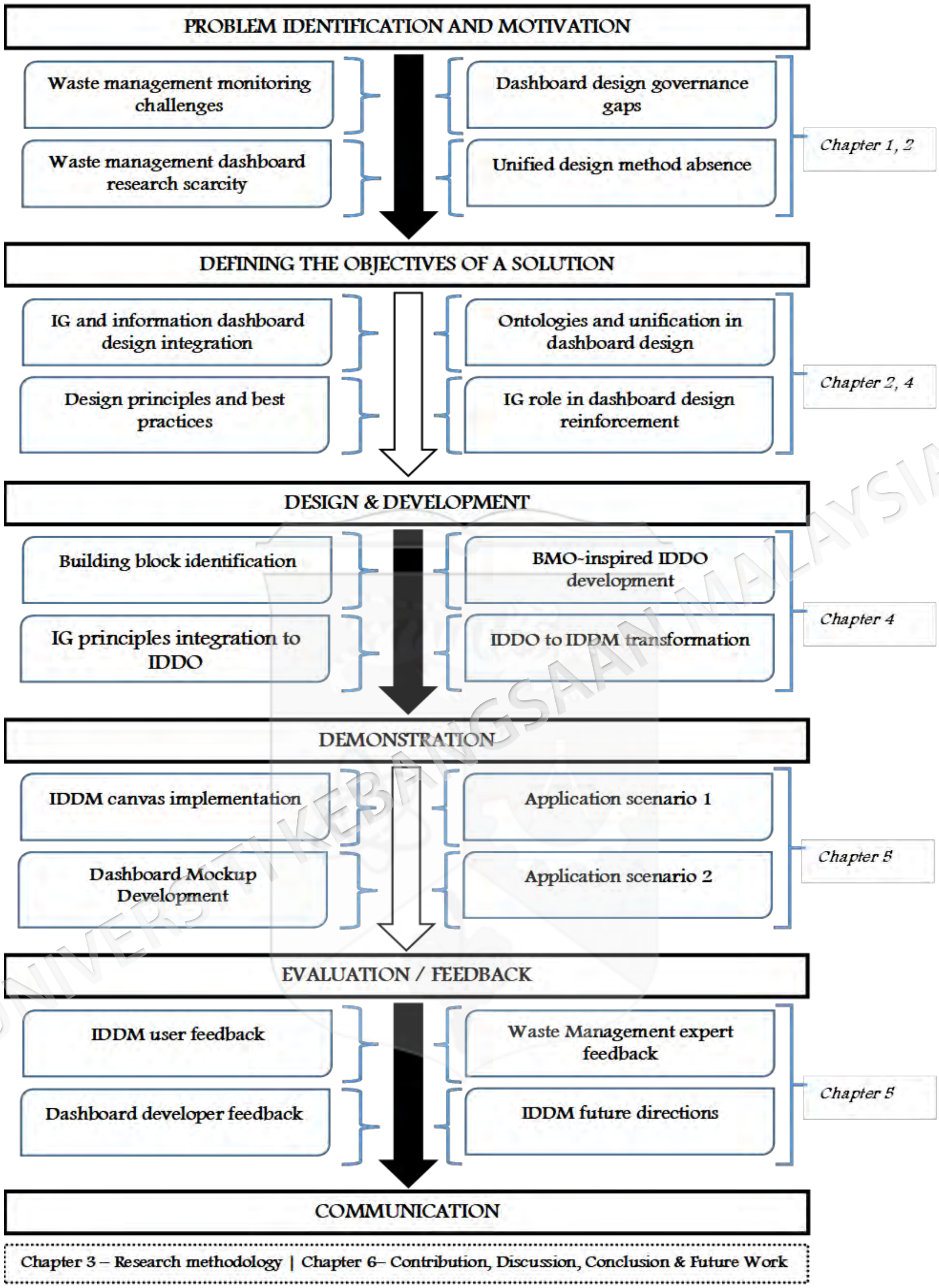

Figure 1.2 Research strategy diagram

1.8 THESIS OUTLINE

This thesis consists of six chapters, which are outlined in Table 1.1 below. Each chapter provides an in-depth study of a specific aspect of the research.

Table1.1 Thesis outline

Chapters	Description
Chapter 1	**Introduction** Provides an overview of the research background, outlines the problem statement, defines the research objectives and questions, and explains the scope, significance, and structure of the thesis.
Chapter 2	**Literature Review** Reviews the current state of information dashboard design (IDD), including common design issues, mistakes, principles, best practices, and the concept of unification. Explores IG as a foundational framework for IDD and reviews established IG models. Systematically reviews thirteen recent works, synthesizing key elements including methodologies, design principles, and features. Identifies critical gaps: absence of standardized IDDM, lack of IG integration in IDD, no ontological approaches, and limited research in smart waste management—establishing the rationale and novelty of this study.
Chapter 3	**Part I: Overview of Design Science Research Methodology** Provides an overview of the fundamental principles and core concepts of the DSRM, contextualised within the field of information systems. **Part II: Application of Design Science Research Methodology** Explains how the DSRM is applied in this study through a clear and comprehensive step-by-step description of the research process, covering the design, development, and evaluation of the proposed artefacts.
Chapter 4	**Transforming Ontology into Practical Application: Design and Development of the IDDM** Presents the design and development of the IDDM through an ontological approach, identifying 12 key building blocks derived from dashboard design literature commonalities. The building blocks are formalized into the IDDO using OntoUML and grounded in UFO as kernel theory, with IG principles embedded as foundational governance. The IDDO is transformed into the IDDM Canvas, providing a structured, visual framework for systematic dashboard design.
Chapter 5	**Putting IDDM to Work: Demonstration and Evaluation in Real-World Scenario** Demonstrates the practical application of the IDDM framework through mock-up dashboards developed for the Intelligent Monitoring Recycle System (i-MORSYS), a conceptual smart waste management system. Two dashboard types are implemented across different visualization platforms by independent designers using the IDDM Canvas as design blueprints. The framework is evaluated through semi-structured interviews with these designers and a waste management expert, with findings analyzed thematically.
Chapter 6	**Research Achievement, Contribution, and Future Work** Consolidates the research achievements by demonstrating systematic fulfillment of each research objective, from identifying the methodological gap through developing the ontologically grounded IDDM framework to its validation. Positions the study's contributions within DSR frameworks, adopting a Kernel Theory Fundamentalist perspective with Unified Foundational Ontology (UFO) and IG principles as foundational kernel theories. Concludes with future research directions informed by respondent feedback and emerging technological opportunities.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

Many studies are being conducted in the realm of smart waste management (Ali et al. 2020; Abdullah et al. 2022; Aliyu et al. 2023; Pardini et al. 2020; Szpilko et al. 2023). Smart waste management systems are designed to streamline the way waste is tracked, collected, and handled, using digital technologies as enablers. According to Xenya et al. (2020), a critical part of this system is the smart bin, essentially a garbage bin that's been upgraded with sensors, internet connectivity, and analytical features, allowing for better visibility and control over waste collection in real time. The smart bin contributes to the effective monitoring and efficiency of waste collection services (Fang et al. 2023). One of the key components in a smart waste management system is the information dashboard, which presents meaningful insights derived from waste data collected through sensors and AI technologies embedded in the smart bins (Widaningsih & Suheri 2021). This dashboard, as noted by Yun Arifatul Fatimah et al. (2020), helps stakeholders such as municipalities, waste collectors, and the public to evaluate the effectiveness of waste collection operations and services. However, despite its importance, there is no standardized method to guide the development of the dashboard, resulting in ad hoc and inconsistent dashboard designs, often developed without clear guidelines or a unified design framework.

In a fast-paced world where information is required instantly, information dashboards have emerged as a powerful tool to help decision-makers make informed decisions. Information dashboards, according to Few (2013) and Wexler et al. (2017) are data visualizations that can be used to measure progress toward goals, discover trends, and provide at-a-glance insights to make the most accurate decision. The universally accepted purpose of the dashboard is to improve information comprehension and facilitate the decision-making process while synthesizing large and various data types and sources (Few 2010). Similarly, Sarikaya et al. (2019) argue that with the rise of big data, dashboards have become more sophisticated and evolved from simple data visualization tools to powerful decision-making tools that integrate a variety of data analytics tools, such as charts, graphs, and tables.

2.2 INFORMATION DASHBOARD DESIGN (IDD): BACKGROUND AND ISSUES

Sarikaya et al. (2019) opine that the definition of an information dashboard is evolving, encompassing interactive interfaces with multiple views and objectives, including communication, learning, and motivation, in addition to monitoring and decision support. Bach et al. (2023) simplify the concept of the information dashboard as a combination of visual representations and graphical enhancements that provide layers of abstraction and simplification for related data points, offering viewers an overview of the most important or relevant information briefly.

Today, the information dashboard has been widely used in a variety of industries, including healthcare, finance, retail, and marketing, to provide organizations with a better understanding of their data and improve decision-making (Bach et al. 2023). Bach et al. (2023), Orlovskyi and Kopp, (2020) and Sarikaya et al., (2019) all concur that information dashboards commonly consist of several elements, including graphs, charts, tables, maps, and other visualizations that help users comprehend their data. They are typically designed to be interactive, allowing users to manipulate the data to gain deeper insights and to be highly customizable so that organizations can tailor their dashboards to meet their specific needs.

Although the information dashboard has emerged as a vital tool in facilitating decision-making, there are several issues surrounding the information dashboard, particularly in the design process. Among the issues in the dashboard designs are too much visual clutter (Bach et al. 2023), inflexible and non-customizable (Alhamadi et al. 2022), poor organization (Bach et al. 2023), and security and privacy (Sarikaya et al. 2019). According to Bugwandeen and Ungerer (2019) and Bach et al. (2023), these issues must be resolved to unlock the potential effectiveness of the information dashboard in aiding the decision-making processes.

2.2.1 Design Issues

The most common issue in the information dashboard design is too much clutter and the presence of too much information or visual elements on a dashboard. According to Bach et al. (2023), too much clutter is a common issue in dashboard design, which can lead to information overload and confuse the user. This notion is supported by Alhamadi et al. (2022), who argue that integrating too much information on a single display potentially leads to information overload and hinders effective decision-making.

Sedrakyan et al., (2019) argue that a good information dashboard should possess a high degree of flexibility and customization capability. However, some dashboards are rigid and cannot be customized, resulting in difficulties for users, especially novices. According to Alhamadi (2020), this issue often arises due to the lack of user involvement during the development process. When developers fail to consider the varying levels of visual literacy among users, the constraints of layouts, and the presented information, dashboards can become challenging to comprehend and utilize. To address this problem, Alhamadi (2020) emphasizes the importance of customizable dashboards that allow users to personalize them according to their specific needs.

Bach et al. (2023) highlight the issue of information organization within the layout as a key design issue. Poor organization can lead to user confusion, frustration, and decreased productivity. In determining the most appropriate option, designers must prudently evaluate various layout patterns, such as open, stratified, table, grouped, and schematic layouts. This notion aligns with the perspective of Young and Kitchin (2020), who emphasize the importance of achieving a balance between aesthetics and usability for a visually appealing, user-friendly, and efficient dashboard design.

Sarikaya et al. (2019) highlighted that security and privacy are the utmost dashboard design issues and concerns. Alhamadi et al. (2022), added that in today's digitalization era, data sharing, privacy, and security are common issues, particularly in healthcare and education-related dashboard. Therefore, it is imperative to implement appropriate measures, such as encryption and access controls while considering privacy concerns during the design process.

2.2.2 Common Mistakes

Ahn et al. (2019) pointed out that ignoring user needs is a common and significant mistake in information dashboard design. Alhamadi et al. (2022) and Latif et al. (2021) are also in agreement with Ahn et al. (2019) and state that if a dashboard doesn’t meet the users’ needs, it becomes pointless and unlikely to work well, no matter how excellent it is designed and developed. To avoid this issue, designers should conduct user information needs analysis to better understand the user’s needs and preferences before developing a functional dashboard (Cairo 2019; Correll et al. 2020; O’Brien & Lauer 2018).

One of the most common mistakes in information dashboard design is overloading the dashboard with data. Providing too much information in a dashboard can have negative outcomes that ultimately decrease the effectiveness of the dashboard. Specifically, overloading the dashboard with too much information can lead to information overload, causing confusion, misdirection, and even deception (Cairo 2019; Correll et al. 2020; O’Brien & Lauer 2018). Therefore, it is imperative for the designers to be meticulous in the selection of data and wisely choose the most relevant and useful information for users without overwhelming users with irrelevant or unnecessary data.

Lack of focus is another common issue noted by Bach et al. (2023). Without a clear focus, users may struggle to identify the key insights or trends within the data presented. To avoid this, designers should consider the user's goals and create a dashboard that supports those goals. This may involve creating multiple dashboards tailored to different user needs or designing a customizable dashboard that allows users to select the information they want to view (Latif et al. 2021).

2.2.3 Design: Principles and Practices

Bach et al. (2023) highlight the significance of design principles such as user-centricity, simplicity, usability, data integrity, actionable insights, and visual hierarchy in crafting effective dashboards. Martins et al. (2022) assert that adhering to these principles reduces errors and achieves a balance between usability and aesthetics.

Adherence to design principles reduces the likelihood of errors (Matheus et al. 2020) and promotes a convergence between usability and aesthetics (Martins et al. 2022). Emphasizing the importance of understanding user requirements, Ahn et al. (2019) argue that designs must always consider users' needs; otherwise, they lose their significance.

Ahn et al. (2019) contend that addressing user requirements is a basic principle in dashboard design, as designs neglecting users' needs are meaningless. This aligns with the critique of current dashboard systems presented by Young and Kitchin (2020), particularly in the context of city dashboards where the user's views are often neglected resulting in non-intuitive and frustrating user experiences. Therefore, as underscored by Alhamadi et al. (2022), emphasizing user requirements and adopting a user-centered design approach are essential principles that will significantly contribute to improving the effectiveness, efficiency, and user satisfaction when using the dashboards.

Sharp et al. (2019) provide insights into common and best practices for dashboard design, emphasizing the importance of incorporating established design principles and tailoring dashboards to meet the specific needs and objectives of the target users. They advocate for a user-centric and data-driven approach. Furthermore, they recommend flexibility in applying these common practices, allowing for adaptation to the unique requirements of individual users.

In line with this, Alhamadi et al. (2022) stress the significance of customizability in dashboards, enabling users to personalize the dashboard according to their specific requirements. This perspective aligns with other researchers who highlight the importance of flexibility and customization in dashboard designs to cater to the diverse needs of users (Bach et al. 2023; Martins et al. 2022; Alhamadi 2020; Sarikaya et al. 2019).

Similarly, Vázquez-Ingelmo (2019) underscores the value of understanding and addressing user needs in shaping dashboard design processes. The author proposes an approach for organizing user characteristics that facilitates the creation of more personalized dashboard designs. This approach reinforces well-established design principles such as user-centeredness and context awareness, emphasizing the significance of considering users' motivations, beliefs, and expertise. By following these common practices and incorporating user-centric design principles, dashboard designers can create more effective and tailored solutions. Understanding and addressing user needs, along with providing customization options, can lead to the development of dashboards that better meet the requirements and expectations of users (Alhamadi et al. 2022; Bach et al. 2023; Sarikaya et al. 2019; Sedrakyan et al. 2019).

2.2.4 Common Dashboard: Elements and Characteristics

Information dashboards commonly consist of several elements and characteristics, including graphs, charts, tables, maps, and other visualizations that help users to understand their data (Bach et al. 2023; Orlovskyi & Kopp 2020; Sarikaya et al. 2019). These elements and characteristics play a crucial role in presenting data in a visually appealing and comprehensible manner. Users can explore and analyze the data through interactive functionalities, such as filtering, sorting, and drilling down into specific details (Alhamadi et al. 2022). Additionally, the flexibility of dashboards allows organizations to customize the elements based on their specific needs and requirements.

The characteristics of dashboards have evolved beyond their traditional role as single-view reporting screens. Sarikaya et al. (2019) argue that dashboards now encompass interactive interfaces that facilitate real-time monitoring of dynamically updating data. They differentiate between the visual genre of dashboards, which typically features tiled layouts of charts and numbers, and the functional genre, which focuses on real-time data monitoring. This expansion of characteristics accommodates diverse purposes, including communication, learning, motivation, and decision support (Sarikaya et al. 2019).

Combining the insights from Bach et al. (2023), Sarikaya et al. (2019), and Orlovskyi and Kopp (2020), a cohesive understanding of the common elements and characteristics of dashboards emerges. It is evident that dashboards should consider the evolving nature of information presentation, encompassing both visual representation and functional interactivity (Bach et al. 2023; Sarikaya et al. 2019). The elements, such as graphs, charts, and tables, provide users with a comprehensive view of their data, while interactive features empower them to delve deeper into the information (Orlovskyi & Kopp 2020). The flexibility of dashboard design enables customization to meet specific organizational needs and target diverse user groups (Sarikaya et al. 2019).

To summarize, a common dashboard incorporates various elements and characteristics that enable users to comprehend complex datasets efficiently. By leveraging visualizations, interactivity, and customization, dashboards facilitate effective data analysis and decision-making. Future advancements in dashboard design should continue to consider the evolving nature of dashboards, accommodating the diverse needs of users and domains.

2.2.5 Towards Unification: Principles, Practices, and Others

The study of unification in dashboard design has been limited in previous research, highlighting the opportunity for further investigation into its principles and practices. Martínez-Ortiz et al. (2019) explain that unification, within the dashboard context, involves integrating multiple data sources into a cohesive and consistent visualization. This integration allows users to have a comprehensive and unified view of information. Building upon this idea, Stein (2022) underscores that unification improves design clarity and organization and contributes towards better comprehensibility.

The key objective of a unified design is to optimize the user experience, streamline information updates, and expedite troubleshooting when challenges arise (Hishamadie et al. 2020). Based on Hishamadie et al. (2020), Stein (2022) and Martínez-Ortiz et al. (2019) work, it can generally be concluded that the concept of unification can be represented via a common framework, serving as a guidance tool for dashboard designers to map out key elements, flow, activities, and required resources. This framework provides an overview that facilitates identifying the requirements for delivering a well-structured and user-centric dashboard.

Martínez-Ortiz et al. (2019) define a unified dashboard as a centralized platform or interface that integrates data and information from multiple sources or activities. This consolidated dashboard offers users a comprehensive view of relevant data, enabling analysis and interpretation of information encompassing various elements such as metrics, visualizations, and reports. By merging data from diverse sources into a single, integrated display, a unified dashboard can provide a holistic perspective and facilitate streamlined decision-making processes across different domains.

Hishamadie et al. (2020) argue for the necessity of a unified dashboard capable of managing and integrating multiple systems. The lack of a centralized application or dashboard, coupled with inadequate integration between various applications, poses challenges in operations and maintenance. The objective is to develop a single dashboard application that combines operational and maintenance data, presenting it in a unified and simplified manner. This unified dashboard would serve as a central hub for monitoring, operating, maintaining, and troubleshooting systems. Different user roles possess specific privileges and corresponding dashboard views. The inclusion of a hierarchical view enables aggregated information and facilitates action control on groups with similar attributes.

By embracing the principles of unification in dashboard design, organizations can effectively consolidate data, streamline operations, and enhance decision-making processes (Hishamadie et al. 2020; Martínez-Ortiz et al. 2019; Stein 2022). This approach not only improves clarity, organization, and comprehensibility but also facilitates efficient monitoring and management of diverse systems. Overall, the integration of unification principles in dashboard design holds significant potential for optimizing the usability and effectiveness of dashboards across various domains.

2.2.6 Conclusion

Information dashboards have noticeably emerged as essential tools for organizations and decision-makers, giving a clear and simplified visual depiction of crucial data at a glance view to enable informed decision-making. To maximize their usefulness, however, it is critical to solve frequent challenges and designs issues and mistake that can restrict their functionality. This narrative literature review explores the effectiveness of information dashboards, identifying prevalent issues, and common mistakes in the design process, and examining principles, best practices, elements, and features. Moreover, this study also investigates the concept of unification in the information dashboard design. The notion of unification, which emphasizes the integration of disparate data sources into a unified visualization, has great promise for the development of complete dashboards that promote simplified decision-making across multiple domains. It is essential for ongoing advancements in dashboard design to keep pace with the evolving nature of dashboards and cater to the diverse needs of users and domains. With further research in this area, a unified dashboard design methodology can be realized, enabling organizations to unlock the full potential of information dashboards in driving accurate and informed decisions.

2.3 ONTOLOGY

Ontology, adapted from philosophy into computer and information science, provides a formal framework for knowledge representation and semantic modeling (Gruber 1993; Guarino et al. 2009). In this context, ontology offers a structured mechanism for explicitly defining key concepts and relationships within a domain, thereby supporting a shared and consistent understanding of complex knowledge structures (Tudorache 2020). Such formalization is particularly valuable in information-intensive environments, where ambiguity and inconsistent interpretation can hinder systematic analysis and reuse of knowledge.

Despite the widespread use of information dashboards across domains, existing studies have primarily focused on visualization techniques, analytical capabilities, or domain-specific implementations. Comparatively little attention has been given to ontology as a foundational mechanism for structuring dashboard design knowledge in a systematic and reusable manner. This indicates a gap in the literature, particularly in relation to providing a formal conceptual foundation that supports consistency, standardization, and cross-domain applicability in dashboard design.

In this study, ontology is introduced to address this gap by serving as the structural foundation for organizing dashboard design knowledge. Rather than functioning as a computational reasoning engine, ontology is employed as a conceptual and representational mechanism to support clarity, consistency, and reuse in the design process. The application of ontology within the context of this study is comprehensively presented and discussed in Chapter 4.

2.3.1 What is Ontology?

In computer science and information systems, ontology is commonly defined as “an explicit specification of a conceptualization” (Gruber 1993). It provides a formal framework for representing knowledge about a specific domain through a shared vocabulary and an explicit semantic structure. Unlike philosophical ontology, which is concerned with the nature of existence, computational ontology focuses on representing domain knowledge in a form that can be consistently interpreted and reused across systems and stakeholders (Guizzardi et al. 2023).

The fundamental components of an ontology typically include: (1) classes or concepts that represent categories of entities; (2) attributes or properties that describe the characteristics of those entities; (3) relationships that define how entities are connected; and (4) constraints that express domain-specific rules (Noy & McGuinness 2001). For example, in a dashboard design ontology, classes may represent dashboard components, visualization techniques, or data elements; attributes may describe properties such as layout structure or refresh frequency; and relationships may specify how visualization elements are organized and linked to underlying data elements. Constraints can be used to express rules governing valid associations between analytical purposes and their supporting design elements.

Ontologies are distinguished from taxonomies and database schemas by their ability to capture richer semantic relationships (Guarino 1998). While taxonomies primarily provide hierarchical classifications and database schemas define data structures, ontologies explicitly represent how concepts relate to one another and under what conditions those relationships hold (Fernandez-Lopez et al. 2002). This semantic richness enables ontologies to support clearer interpretation and more consistent use of domain knowledge.

Several levels of ontology can be identified. Top-level or foundational ontologies describe highly general concepts independent of specific domains, such as the Unified Foundational Ontology (UFO) (Guizzardi 2005). Domain ontologies capture concepts specific to a particular application area, while application ontologies focus on knowledge required for specific use cases (Guarino 1998). Ontology development typically follows established methodologies involving specification, knowledge acquisition, conceptualization, formalization, implementation, and evaluation (Fernández-López et al. 1997; Noy & McGuinness 2001).

While ontology offers a formal mechanism for knowledge representation, it is not the only approach available within information systems. Several alternative approaches have been proposed to support design knowledge representation and reuse.

2.3.2 Alternative Knowledge Representation Approaches in Information Systems

Prior to adopting ontology as the foundational mechanism for structuring dashboard design knowledge, it is important to acknowledge that several alternative knowledge representation and design support approaches have been widely used within the information systems literature. These include conceptual frameworks, design guidelines and heuristics, reference models, taxonomies, and templates. Conceptual frameworks are commonly employed to organize key constructs and relationships at a high level, offering flexibility and ease of interpretation (Gregor 2006; Hevner et al. 2004). Design guidelines and heuristics, such as visualization principles and best practices, provide prescriptive advice derived from expert knowledge and empirical findings (Few 2006; Munzner 2014). Reference models and templates further support reuse by offering predefined structures that can be adapted across projects and domains (Becker et al. 2007).

Despite their usefulness, these approaches predominantly rely on informal or semi-formal representations expressed in natural language or graphical diagrams. As a result, they often lack explicit semantics, making consistent interpretation, systematic reuse, and extensibility across domains challenging (Guarino 1998; Uschold & Gruninger 1996). Taxonomies, while effective for classification purposes, primarily capture hierarchical relationships and provide limited support for representing complex interdependencies among concepts (Nickerson et al. 2013). Similarly, design guidelines and templates tend to encode procedural or experiential knowledge without formally capturing the underlying conceptual structures that govern design decisions (Sedrakyan et al. 2019).

In complex and data-intensive domains such as information dashboard design, these limitations become more pronounced. Dashboard design involves multiple interrelated concepts, including analytical objectives, performance indicators, visualization techniques, layout structures, and user contexts. Representing such complexity using informal approaches may lead to ambiguity, inconsistent application, and limited support for scalability and long-term reuse (Eckerson 2010; Sarikaya et al. 2019). These limitations motivate the need for a more formal and structured knowledge representation mechanism, which is addressed through the adoption of ontology in this study.

2.3.3 Why Ontology?

The adoption of ontology in dashboard design methodology is motivated by limitations commonly observed in ad hoc design practices, where design knowledge is often fragmented, informally expressed, and inconsistently applied across projects. Existing dashboard design knowledge is typically distributed across literature and practice in narrative or experiential forms, making it difficult to systematically interpret, share, and reuse (Few 2006; Sarikaya et al. 2019). Ontology provides a formal mechanism for structuring such knowledge in an explicit and unambiguous manner, supporting clearer representation of dashboard-related concepts, properties, and relationships (Gruber 1995; Noy & McGuinness 2001).

Inconsistent design practices have been shown to negatively affect dashboard usability and decision-making effectiveness (Sarikaya et al. 2019). By offering a shared conceptual structure, ontology supports consistency in design decisions by providing a common reference for interpreting dashboard elements and their roles. Rather than enforcing rigid rules, ontological structures function as design guidance that helps align analytical objectives, performance indicators, and visualization strategies, thereby contributing to improved clarity and interpretability.

Ontology also supports the reuse of design knowledge by enabling standardized representations that can be adapted across projects and domains. In the absence of such representations, organizations frequently reinvent similar dashboard design solutions, leading to inefficiencies and inconsistent outcomes (Sedrakyan et al. 2019). Ontological representations allow domain-specific design knowledge to be derived from more general structures while preserving established principles, supporting scalability and long-term sustainability of design practices (Noy & McGuinness 2001).

Collectively, these considerations position ontology as a suitable foundation for structuring complex dashboard design knowledge and motivate its adoption in this study. The application of ontological principles within the proposed framework is further elaborated in subsequent sections, where ontology is operationalised to support the development of the IDDM.

2.3.4 Conclusion

This section has established ontology as a formal knowledge representation mechanism that addresses critical gaps in information dashboard design. While alternative approaches such as conceptual frameworks, design guidelines, taxonomies, and templates have been widely used in information systems, they predominantly rely on informal or semi-formal representations that lack the explicit semantics required for consistent interpretation, systematic reuse, and scalability across domains (Guarino 1998; Uschold & Gruninger 1996).

Dashboard design involves multiple interrelated concepts: analytical objectives, performance indicators, visualization techniques, layout structures, and user contexts that require formal representation to avoid ambiguity and inconsistent application (Sarikaya et al. 2019). Ontology provides this formalization by offering an explicit specification of conceptualization (Gruber 1993) that enables clearer interpretation, enhanced consistency, and improved reusability of design knowledge.

In this study, ontology serves as the structural foundation for the IDDO, which is operationalized through the IDDM Canvas to support systematic and governance-aware dashboard design. Unlike computational reasoning applications, ontology is employed here as a conceptual and representational mechanism that guides design decisions while maintaining adaptability across diverse domains. The detailed development and application of IDDO is presented comprehensively in Chapter 4.

2.4 INFORMATION GOVERNANCE (IG)

In designing an effective information dashboard, it is crucial to have a guiding framework and principles in place. In the IDD context, IG can play a pivotal role by providing guidelines to control and manage the information to be displayed in the dashboard. In this section, the role of IG and its potential integration in supporting the IDD will be briefly discussed.

2.4.1 What is IG?

The Association of Records Managers and Administrators (ARMA) defines IG as the comprehensive strategy that coordinates and manages organizational information so that it transforms into an asset and minimizes liability based on the specific business needs and risk tolerance of the organization. Liu et al. (2022) and Kooper et al. (2011) define IG as “the set of activities aimed at establishing a normative foundation to facilitate and stimulate sense-making interactions”. On the other hand, according to Lomas and Makhlouf Shabou (2019), IG is a detailed framework that encompasses the policies, standards, processes, metrics, and defined roles that are necessary to manage an organization's information assets effectively.

According to Datta et al. (2019), the role of IG is imperative to ensure the information is well managed while at the same time adhering to all relevant legal and regulatory requirements and supporting the organization’s overall goals and objectives. Lomas (2019) concluded that by having clear IG policies, standards and processes, it will enable the optimization of the organization’s information asset value.

2.4.2 IG for Supporting IDD: Relationship

In the realm of IDD, IG holds strong potential to guide strategic decision-making and support the efficient, consistent development of dashboards. As a comprehensive framework comprising policies, standards, processes, metrics, and clearly defined roles, IG provides essential structure throughout the design process. More importantly, as noted by Mikalef et al. (2020), IG serves as a key coordination mechanism for managing data across the organisation. When thoughtfully integrated, it helps ensure that dashboard content aligns with organisational goals while strengthening overall information capabilities.

Data, as the core element of any information dashboard, gains greater value when governed by IG principles throughout the design and development process. Incorporating these principles streamlines data coordination, accessibility, and utilisation, enabling the delivery of relevant, timely, and actionable insights to users. Azman et al. (2019) underscore IG's role in strengthening data trustworthiness, which is crucial for ensuring that dashboards display accurate information in the right context. Likewise, Liu et al. (2022) highlight IG's contribution to maintaining high information quality, reinforcing the dashboard's reliability as a decision-support tool.

In line with this, integrating IG into the dashboard design process lays a solid foundation for ensuring data reliability and adherence to quality standards. Such integration not only enhances the value of insights provided to users but also ensures compliance with key IG principles, including data security and privacy regulations.

encompasses a diverse range of principles, including quality, transparency, accessibility, compliance, and accountability. The selection of which principles to apply is highly dependent on the implementation context and the specific objectives to be achieved. This view is supported by Liu et al. (2022), who note that different organisations may adopt distinct sets of IG principles, standards, and regulatory practices tailored to their respective application scenarios. Collectively, these perspectives indicate that the application of IG principles is inherently flexible and should be adapted to align with the goals and contextual needs of each environment.

2.4.3 Review of Established IG Models

This section will briefly review three established IG models; (1) Information Governance Reference Model (IGRM); (2) Information Governance Implementation

Model (IGIM); (3) Information Governance Maturity Model (IGMM). The selection of these IG models for review is due to their diverse applicability in many domains and demonstrated utility by many organizations, which may potentially be applied to IDD.

The Information Governance Reference Model (IGRM) presents a comprehensive framework that promotes cross-functional collaboration and executive discourse, rendering it efficacious in supporting corporate information governance initiatives of varying magnitudes (EDRM 2022). The IGRM's capacity to establish linkages between value, duty, and information assets underscores its adaptability and extensive applicability across diverse organizational contexts (EDRM 2022). Furthermore, the Information Governance Implementation Model (IGIM) proffers detailed directives for the development and execution of information governance strategies, which have been efficaciously implemented across multiple sectors to optimize information management processes and role delineations (ARMA International n.d.). The Information Governance Maturity Model (IGMM) is widely employed to evaluate and enhance information governance practices, enabling organizations from various domains to incrementally augment their information governance capabilities (Pulsipher 2022). The extensive applicability and demonstrated efficacy of these models substantiate their selection as foundational elements in the conceptualization and design of information dashboards.

a. Information Governance Reference Model (IGRM)

The Information Governance Reference Model (IGRM) as outlined by EDRM (n.d.) emphasizes the importance of collaboration among stakeholder groups namely business users, IT departments, legal, risk and regulatory teams. This model delineates the phases of the information lifecycle and the governance objectives for each stage. The main aim of IGRM is to establish a framework and common language for IG while also aligning the interests and goals of the stakeholders involved. The IG principles covered in the IGRM are compliance, protection, integrity, availability, retention, transparency, accountability, quality and effectiveness (EDRM 2011). These principles are particularly relevant to the IDD as they form a basis for integrating governance practices throughout the design and development phases. By embracing these IG principles, organizations can potentially enhance the accuracy, reliability, and security of data displayed in dashboards. This can ultimately support the decision-making processes and better alignment with organizational objectives. A visual depiction of IGRM is presented in Figure 2.1 which showcases the structure of the model and how its components interrelate.

Figure 2.1 Information Governance Reference Model (IGRM)

b. Information Governance Implementation Model (IGIM)

The IGIM, created by the Association of Records Managers and Administrators (ARMA), provides a framework for organizations to evaluate and enhance their IG program across eight essential areas: steering committee, authorities, supports, procedural framework, capabilities, information lifecycle, architecture, and infrastructure (Abdul Malak 2022). The focal point here is the “implementation” aspect, which offers direction and resources for assessing and comparing the performance of the IG and monitoring the progress of the organization's implementation efforts. The approach presented provides a practical method for implementing IG, by examining the essential components that must be established in each of the eight crucial areas required for a successful IG program (InfoGov Basics n.d.). The IGIM is able to establish a shared understanding and coordinated implementation strategy by focusing on eight distinct areas and elements. These areas encompass people, policy, technology, and other crucial aspects across these eight critical areas. The IG principles are highly likely to be relevant to the IDD as they provide a systematic framework for implementing governance practices. By incorporating these principles, one can achieve comprehensive coverage of all necessary aspects for effective information management. This, in turn, leads to the development of more reliable, secure, and user-friendly dashboards that are in line with the goals of the organization. Figure 2.2 illustrates the IGIM framework.

Figure 2.2 Information Governance Implementation Model (IGIM)

c. Information Governance Maturity Model (IGMM)

Another widely utilized IG model by numerous organizations is the IGMM. According to Proença et al. (2016), IGMM is a framework that assists organizations in evaluating their current IG practices and provides directives for ongoing enhancement in the management of their information as a valuable resource. The primary objective of IGMM is to assess the level of maturity of an organization's IG initiatives by gauging the organization's sophistication in its approach to IG, ranging from initial awareness to optimized processes. Multiple IGMM are accessible, such as the ones created by OvalEdge, IBM, and Gartner. While the presentation of the framework may vary, all IGMMs offer structured frameworks for evaluating the maturity of IG initiatives across different dimensions, including principles such as data quality, data security, data lineage, and data stewardship. The IBM IGMM is a highly comprehensive and adaptable framework for IGMM. It is comprised of five maturity levels, as illustrated in Figure 2.3. The IG principles in IGGM are relevant to the IDD as they provide a systematic method for assessing and enhancing the level of IG practices. By embracing these principles, dashboards are developed with a primary focus on continuously improving information management and enhancing data quality, security, and stewardship. This alignment will potentially facilitate the creation of dashboards that are more dependable and efficient, serving as strategic assets for the organization.

Figure 2.3 The IBM Information Governance Maturity Model (IGMM)

A short review of the three established IG models inferred that IG is an intricate and multifaceted field that requires the cooperation and coordination of different stakeholders, processes, and technologies. Every IG model fulfills a specific role in IG initiatives, offering distinct perspectives and strategies for governing the information. The IGRM prioritizes the significance of collaboration across different departments, including business, IT, and legal stakeholders. It underscores the necessity of a consolidated framework to efficiently oversee information governance. In contrast, the IGIM primarily emphasizes the pragmatic elements of IG implementation, providing comprehensive instructions and tools for assessing and comparing IG effectiveness. Finally, the IGMM evaluates and enhances the level of maturity of IG practices, offering a systematic method for ongoing enhancement in information governance.

Comprehending the advantages and constraints of each IG model is essential for their integration with the IDD. The IGRM prioritizes stakeholder collaboration to ensure that dashboards are created with input from all relevant parties, thereby enhancing their usefulness and significance. The IGIM's methodical approach to implementation ensures that governance practices are systematically integrated into the dashboard design process. The IGMM prioritizes the evaluation of maturity to enhance the ongoing enhancement of dashboard functionality and data accuracy.

2.4.4 Conclusion

In conclusion, IG can play a significant role in IDD. In Chapter 4, the diversity of the IG principles, which includes the insights from the three established IG models discussed earlier will be synthesized to derive the relevant IG principles in the context of IDD. Incorporating the relevant IG principles into IDD can help to improve the precision, dependability, and protection of the data displayed in dashboards, ultimately facilitating more informed decision-making and aligning with the objectives of the organization. IG will govern the information displayed on the dashboard and serve as a mechanism for governing the data and ensuring its quality, ultimately enhancing the capabilities of the information dashboard in providing insights to the users. By incorporating IG into the design process, organizations can optimize the use of data, deliver valuable insights to users, and improve their understanding and decision-making capabilities. Overall, IG is a vital component in supporting the IDD.

2.5 PROPOSING NEW CONCEPTS IN IDD

Sarikaya et al. (2019) found that information dashboards are diverse and can be used in many different contexts. However, it's important to note that research on the connection between IG and IDD is unavailable at this point of this study. This clear absence in academic studies emphasizes a significant gap that this study aims to fill. Little theoretical knowledge has been systematically documented concerning dashboard design principles, as highlighted by Sedrakyan et al. (2019). Therefore, as information dashboards continue to proliferate across diverse application domains, it becomes imperative to establish a novel concept of IDDM that incorporates principles of IG. The IDDM, in its development, aims to establish itself as a definitive standard guideline for steering the IDD process, not only within the context of Smart Waste management but also as a universal framework applicable to various application domains.

2.5.1 IG as a Theoretical Framework for IDD

To strengthen the development of IDDM, IG is proposed as its foundation. This incorporation is vital as IG facilitates data organization, thereby enhancing organizational capabilities (Mikalef et al. 2020) through the information dashboard. Additionally, applying IG ensures the quality of displayed information, empowering users with meaningful insights (Liu et al. 2022). By applying IG, the information dashboard becomes a valuable tool for improving decision-making and maximizing the value of displayed data. The integration of IG in the IDDM also aligns with Kernel Theory. Kernel theory, a descriptive theory that guides the creation of artifacts, is an essential element of design theory. It is characterized as a descriptive theory that guides design research, specifically DSR, and ideally should be integrated into an established body of design knowledge (Knutas et al. 2019).

In the context of this study which employs DSR methodology, the incorporation of IG can be regarded as an application of Kernel Theory. Kernel Theory, within the DSR framework, pertains to the fundamental theories that support the creation of artifacts. Originally characterized as the principles that guide design specifications, it has progressed to encompass "any information that enlightens design science research, including encompassing informal knowledge acquired from practical experience" (Möller et al. 2022). A more comprehensive discussion on DSR and Kernel Theory will be explained later in Chapter 3.

In a nutshell, incorporating IG in the IDD will ensure that the quality, and relevance of the displayed information on the dashboard can be controlled and ensured, thus aligning with the goal of enhancing user understanding and decision-making capabilities.

2.5.2 The Notion of the Ontology of Information Dashboard

As established in Section 2.3, ontology provides a structured framework for representing domain knowledge. However, at the time of this study, no available research directly addresses the application of the ontological approach in information dashboard design. This apparent absence in the literature highlights a significant gap that the present study endeavors to address. Within the scope of this study, the utilization of the IDDO serves as a formal representation of knowledge pertinent to information dashboards. By employing IDDO, the study aims to establish a foundation for the consistency, structure, and standardization of data presented on the dashboard, thereby contributing to the enhancement of data quality, increased consistency, improved usability, refined data analysis, and, ultimately, facilitating more informed decision-making. Furthermore, the integration of ontological representation within the IDDM allows for the development of a unified and adaptable version that can be implemented across diverse domains. This approach aligns with previous research emphasizing the reusability of ontologies (France-Mensah & O'Brien 2019; Tudorache 2020) ensuring the long-term sustainability of the IDDM. By leveraging ontological principles, the IDDM will evolve into a sustainable and versatile framework, effectively filling the aforementioned gap in the literature.

2.5.3 The Framework: Information Dashboard Design Method Based on IDDO

According to Tudorache (2020), ontologies provide a structured framework for understanding and describing fundamental concepts and relationships within a specific domain. There are two dimensions of ontologies namely the level of detail and degree of reliance on a specific task or perspective. The level of detail refers to how closely an ontology represents the intended meaning of the vocabulary, but it usually comes at the cost of a more complex and representative language. Meanwhile, a simpler ontology can be developed with consideration for certain inference services, to be shared among users who already share common ground on basic concepts. Consequently, Guarino (1998) asserts that a differentiation can be made between reference ontologies and shareable ontologies, or alternatively, offline and online ontologies. In the second dimension, As briefly discussed in subsection 2.3.1, Guarino (1998) suggests the possibility of developing various types of ontologies based on their level of generality:

top-level ontology, domain ontology, task ontology, and application ontology, as illustrated in Figure 2.4 below.

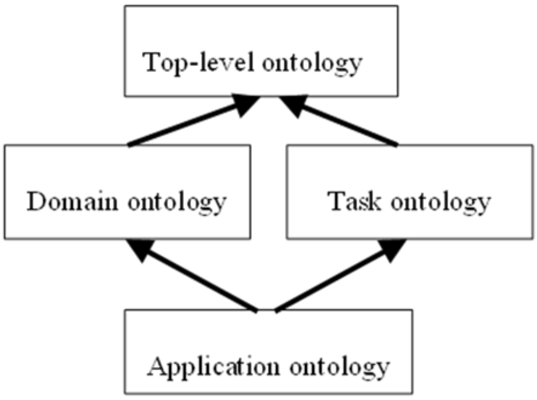

Figure 2.4 Kinds of ontologies, according to their level of dependence on a particular task or point of view

Source: Guarino 1997

1. **Top-level ontologies** explain highly general concepts such as space, time, matter, object, event, action, etc., which are independent of specific problems or domains. In theory, it appears logical to have unified top-level ontologies that can cater to large communities of users.
2. **Domain ontologies** and **task ontologies** describe, respectively, the vocabulary associated with a generic or specific domain like medicine or automobiles or a generic task or activity such as diagnosing or selling by specializing the terms introduced in the top-level ontology.
3. **Application ontologies** entail concepts that depend on both a particular domain and task, often serving as specializations of the related ontologies. These concepts frequently correspond to the roles performed by entities within the domain while engaging in a specific activity, such as replaceable units or spare components.

Building upon the insights provided by Tudorache (2020) regarding the structured framework of ontologies for understanding and describing fundamental concepts within a specific domain, this study aims to develop the IDDM. The IDDM will be developed based on the IDDO, which serves as a formal representation of knowledge in IDD. The IDDO will be developed intensively based on the suitable

Ontology Development Method (ODM) which will be discussed in the advanced stage of this study in Chapter 4**.** By incorporating the dimensions of ontologies, namely the level of detail and reliance on specific tasks, as proposed by Guarino (1998), the ontological-based IDDM will offer a simplified and user-friendly approach to designing effective and usable information dashboards. This integrated approach ensures a unified and efficient IDD process.

2.6 RELATED WORKS AND GAP ANALYSIS

Although there are many recent studies on information dashboards, the central focus is commonly on the information dashboard design within a specific domain in general and without elaborating on the method to design it comprehensively (Abduldaem & Gravell 2019; Vazquez-Ingelmo et al. 2019). This section will analyze and discuss thirteen recent related works on IDD based on eight (8) elements as follows:

1. Application domain
2. Standard methodology
3. Key phases
4. Design principles
5. Best practices
6. Key features
7. Modeling tools
8. Key outcomes

These eight elements above represent common themes and components discussed in most of the dashboard design articles (Bach et al. 2023; Kuznetsova et al. 2021; Abduldaem & Gravell 2019; Vazquez-Ingelmo et al. 2019; Staron 2015). The identification of all eight elements mentioned above is crucial to identify commonalities and shared components that are essential requirements for the development of the IDDM to answer the research questions that have been raised in Chapter 1 (Section 1.4). This section is vital as it will provide a comprehensive understanding of the current state of IDD by addressing the following questions:

1. What is the application domain covered by the recent IDD study?

2. Are there any established standard methodologies utilized in the recent IDD study?
3. What are the key phases or stages involved in the recent IDD study?
4. Are there any specific design principles employed in the recent IDD study?
5. What are the best practices commonly adopted in the recent IDD study?
6. What are the key features or components identified in the recent IDD study?
7. Which modeling tools are commonly utilized in the development of the IDD?
8. What are the design outcomes in the recent IDD study?

By answering these questions, a comprehensive understanding of the current scenario of IDDM will be obtained, providing valuable insights for the development of an effective and comprehensive IDDM. The subsequent section presents a discussion of thirteen recent related works (RW) to IDD as indexed in Table 2.1 below:

Table 2.1 Index of related works

Related Work	Reference	Title
RW 1	Lavalle et al. (2025)	A Methodology for the Systematic Design of Storytelling Dashboards Applied to Industry 4.0
RW2	Poppe et al. (2024)	Development of a Web-Based Oxygenation Dashboard for Preterm Neonates: A Quality Improvement Initiative
RW3	Pamuk & Schumann (2024)	Towards AI Dashboards in Financial Services: Design and Implementation of an AI Development Dashboard for Credit Assessment
RW 4	Salvi et al. (2024)	Development of a Real-Time Dashboard for Overdose Touchpoints: User Centered Design Approach
RW 5	Conrow et al. (2023)	A Conceptual Framework for Developing Dashboards for Big Mobility Data
RW 6	Bach et al. (2023)	Dashboard Design Patterns
RW 7	Wu et al. (2021)	MultiVision: Designing Analytical Dashboards with Deep Learning Based Recommendation
RW 8	Pestana et al. (2020)	Improving Health Care Management in Hospitals Through a Productivity Dashboard
RW 9	Balletto et al. (2020)	A Dashboard for Supporting Slow Tourism in Green Infrastructures: A Methodological Proposal in Sardinia (Italy)
RW 10	Young & Kitchin (2020)	Creating Design Guidelines for Building City Dashboards from A User's Perspective

to be continued…

…continuation

RW 11	Elshehaly et al. (2020)	QualDash: Adaptable Generation of Visualisation Dashboard for Healthcare Quality Improvement
RW 12	Syaiful et al. (2019)	Proposed Design and Modeling of Smart Energy Dashboard System by Implementing IoT (Internet of Things) Based on Mobile Devices
RW 13	Kokoç & Altun (2019)	Effects of Learner Interaction with Learning Dashboards on Academic Performance in An E-Learning Environment

In RW1, Lavalle et al. (2025) introduced a structured methodology for designing storytelling dashboards specifically tailored for Industry 4.0 environments, particularly within the context of smart manufacturing. Their approach unfolded through six key phases: beginning with requirement elicitation using the i* framework, followed by concept refinement through a hierarchical tree model, preparation and selection of relevant datasets, conceptual design, dashboard implementation using Power BI, and finally, a usability-focused evaluation through a controlled experiment. The dashboard design centers around storytelling, not merely in narrative aesthetics, but in the way users engage with information. Layouts were hierarchically structured to reflect how users process data and make decisions. These structures were complemented by knowledge graphs, which added semantic clarity and supported more coherent navigation across dashboard elements. Instead of building from scratch, the team leveraged Power BI to develop a fully functional prototype, integrating both real-time and historical data into an interactive interface. Key features included guided navigation, context-aware visual cues, and a multi-level storytelling flow that adapts to the user's data exploration path. This work stands out by bridging technical modeling techniques with narrative visualization. The outcome is not just a functional dashboard, but a reusable framework that can inform future designs across similar industrial contexts. It fills a methodological gap by offering a replicable, semantically structured approach to dashboard design that aligns well with the complex needs of Industry 4.0 settings.

Poppe et al. (2024) in RW2 developed a web-based oxygenation dashboard for real-time monitoring and visualization of oxygen saturation data in preterm neonates in the Neonatal Intensive Care Unit (NICU). The study employed a user-centered design approach with iterative development and evaluation. Key phases in the research included interviews with clinicians, dashboard prototype development, and evaluation during clinical rounds. The design principles emphasized combining detailed and summarized data displays, enabling real-time monitoring, and supporting decision-making. Best practices included synchronizing data from multiple devices, implementing histogram visualization for data distribution, and allowing flexible time interval selection for data viewing. Key features of the dashboard include real-time monitoring of oxygen saturation, time-based data exploration capabilities, estimation of hypoxia levels, and assessment of respiratory instability. The modeling tools employed in this study are not explicitly mentioned. The primary outcome was a web-based oxygenation dashboard that enhances real-time monitoring and visualization of oxygen saturation data in preterm neonates, facilitating timely interventions in the NICU.

In the meanwhile, Pamuk and Schumann (2024) in RW3 constructed a comprehensive AI dashboard named "AIDash" to support the iterative process of creating, managing, comparing, and validating AI models for credit assessment in financial services. The study combined a problem-oriented DSR approach with the Cross-Industry Standard Process for Data Mining (CRISP-DM). Key phases included data understanding, data preprocessing, model development, and model evaluation. The design principles focused on simplicity, customization, interactivity, clear visualizations, transparency, and compliance with regulatory standards. Best practices included displaying only essential information, using clear charts and graphs, showing data origins and usage, implementing strong access controls, and adhering to explainability and interpretability standards. Key features of AIDash include the ability to create, manage, compare, and validate AI models, visualization of model performance, downloadable models and training/test sets, and a comprehensive report generation capability. The study used Python-based Django Framework for modeling. The outcome was a comprehensive AI dashboard designed to support the iterative process of AI model development and validation in financial services, with a focus on credit risk assessment.

In RW4, Salvi et al. (2024) in their study developed “The Indiana Touchpoints Dashboard,” a real-time dashboard to enhance overdose prevention efforts by visualizing critical interactions with health and justice systems. The study employed a user-centered design approach combined with participatory methods and iterative feedback from Overdose Fatality Review (OFR) experts. Key phases included user needs assessment, data integration, visualization design, dashboard development, and user evaluation. Design principles emphasized user-centered design, data privacy and security, actionable insights, intuitive visualizations, and timeliness. Best practices included iterative feedback, comprehensive data integration, ensuring accessibility, transparency in data sources and methods, and providing training and support. Key features of the dashboard include prevalence and rates of touchpoints before overdoses, county-level insights, interactive visualizations using bar charts, line graphs, and maps, and comprehensive data integration from various sources. The modeling tools used were not explicitly mentioned. The outcome was a real-time dashboard providing county-level insights for public health officials, visualizing critical interactions with health and justice systems to enhance overdose prevention efforts.

In their study in RW5, Conrow et al. (2023) developed a conceptual framework for designing dashboards tailored to big mobility data. This framework follows an iterative, user-centered, and interactive design approach. It comprises five key phases - identifying the intended purposes and end-users of the dashboard, specifying and implementing aspects related to data selection, transformation, visualization, and assembly, conceptualizing a generalized trajectory model, building the dashboard using a user-centered and interactive approach and involving end-users at different stages of development to ensure higher usability of the resulting dashboards. The study emphasizes three design principles: user-centered design, interactive design, and visual design, aimed at meeting end-users needs, enabling dynamic data visualization, and effectively communicating data patterns and trends. As for best practices, Conrow et al. (2023) underscore the importance of a user-centered, interactive design, guiding data selection with a conceptual model, choosing suitable chart formats, using web technologies like D3.js for dynamic visuals, applying visual communication principles, and consistently evaluating and refining dashboards. The key features of the dashboard discussed in the study include indicators, charts, maps, filters, and interactive features for user exploration, such as zooming, panning, selecting, hovering, and linking. The study does not explicitly mention the modeling tools used in developing the conceptual framework. The key outcome of this study is a conceptual framework for designing dashboards tailored to big mobility data.

Bach et al. (2023) in RW6 conducted a systematic analysis of the real-world example of the dashboard design to identify common design patterns. This approach involved a structured analysis of existing dashboards, allowing for a thorough understanding of the current state of the field. The key phases involved in the research are defining data selection, establishing dashboard structure, designing individual pages, incorporating interactivity, and selecting a suitable colour scheme. The design principles mentioned in this study are reducing the number of pages and optimizing screen space, using color sparingly and with purpose, providing context for data, considering the needs of different users, incorporating accessibility factors, and simplifying design iterations and prototype creation with the help of dashboard design tools. The best practices mentioned are reducing information load, considering visual perception, using interactivity to ensure visualization literacy, formalizing common solutions with design patterns, grouping patterns into content and composition categories, considering the intended audience and purpose of the dashboard, utilizing a framework to streamline design, balancing the amount of information shown, and contextualizing the information displayed. The key features identified include the visual display of important information, the display of dynamic information, drill-down capabilities for data exploration, and the presentation of analytical data insights. Bach et al. (2023) do not explicitly mention the modeling tools used in their study. Overall, the contribution of this study is a comprehensive list and description of 64 dashboard design patterns intended to guide designers and practitioners in creating effective and usable dashboards.

In their work on data visualization and dashboard design in RW7, Wu et al. (2021) employed a deep-learning-based method to develop two models for the assessment of individual charts and the evaluation of multiple charts simultaneously. The key phases involved are defining the dashboard's purpose and key questions to address, selecting relevant data sources and identifying critical data columns for visual analysis, choosing suitable chart types and ensuring consistency across multiple charts, designing an intuitive layout for the dashboard, and conducting user testing to verify effective communication and alignment with user needs. The design principles aimed to foster collaboration between humans and computer automation through mixed-initiative systems. Best practices included reducing the overhead of data selection, automating the selection process for multiple charts, providing recommendations for charts based on optional manual selections, and leveraging provenance data, such as authoring logs, to improve the selection process. The key elements of the dashboard include the visual display of important information, the display of dynamic information, and the presentation of analytical data insights. The study utilizes a deep-learning model to assist in designing analytical dashboards for analyzing a data table. The design outcome is a deep learning algorithm integrated into Multivision to create an analytical dashboard for assisting in dashboard designs.

Pestana et al. (2020) study in RW8 is on the development of a healthcare dashboard using the DSRM. The aim is to improve health care management in hospitals by providing valuable insights through the dashboard. The development process consists of several key phases: conducting research and analysis, and ETL (extract, transform, load) processes to create a solid baseline for the dashboard; developing an initial proposal based on the baseline created in the first step; demonstrating and evaluating the proposed dashboard through a series of iterative interviews with stakeholders; and using the feedback gathered from the previous iteration to improve and fine-tune the dashboard. The principles used in designing the dashboard include incorporating principles of Gestalt's visual perception, specifically proximity, similarity, and enclosure, for effective design. These principles were used to guide the development of the graphic components of the dashboard, particularly the KPIs. The best practices mentioned include minimizing visual effects in graphs, using color purposefully to achieve communication goals, grouping physically close objects for perceptual association, and creating a sense of grouping through interconnections between objects. The key features of the dashboard include the visual display of important information, the display of dynamic information, drill-down capabilities for data exploration, the presentation of analytical data insights, KPIs with annual values and compared with the homologous year, and graphs that show the monthly distribution of KPIs and other analyses. The authors do not explicitly mention the modeling tool used in the study. By utilizing public health data, the dashboard aims to provide easily understandable insights that can support effective healthcare management. In this study, the design outcome is a web-based hospital management dashboard, focused on productivity to monitor key performance indicators (KPIs) and serves as a decision support tool for hospital managers and stakeholders.

In RW9, Balletto et al. (2020) work is on the tourism application domain, specifically focusing on the walkability of a location. The standard methodology used in developing the dashboard is a convergent parallel design where both quantitative and qualitative data are collected at the same time and analyzed separately. The key phases of the project include defining the conceptual framework to organize the contents of the dashboard, defining the layout to organize the contents of the Santa Barbara Walk (SBW) circular dashboard, collecting, analyzing, and classifying the intrinsic and extrinsic characteristics of the Walk, collecting and analyzing user-generated content from the smart community, elaborating and compiling a comprehensive data set, generating internal reports for SBW managers, developing the dashboard as a collector capable of organizing a comprehensive data set, establishing connections with social networks for data collection, monitoring, and sharing, and observing, maintaining, and keeping SBW data updated. The design principles incorporate extrinsic features, such as highlighting points of interest within a 1 km buffer from the location walkways, and intrinsic features, such as providing information on distance, difficulty, and travel time required to reach the locations. The best practice highlighted in the study is that locational or geographical data should be displayed with a complete indicator. The key features of the dashboard include a homepage providing general information about the location and separate web pages dedicated to each route. These pages feature the Walkability Index (WI), Attractiveness Index (AI), rating, navigation features, and charts maps. The modeling tools used are not explicitly mentioned. The design outcome of this study is a dashboard supporting slow tourism in green infrastructures, displaying the walkability of a tourism location, and relying on maps sourced from available online portals and open-source Google Sites. The dashboard design relies on various maps from available online portals and utilizes open-source Google Sites to present the walkability of the tourism location.

In their fascinating work on Community informatics in RW10, Young and Kitchin (2020) employed a range of innovative methodologies, including Cognitive Task Analysis (CTA), Critical Incident Technique (CIT), and analysis of design principles, to develop a city dashboard that provides valuable insights into Dublin's community, economy, environment, mobility, and population demographics. The key phases of the project include establishing the dashboard's purpose and objectives, identifying the target audience and their specific needs, and conducting user research to gain insights into user preferences and requirements. This is followed by creating user personas to represent different user types, developing a content strategy to define the data and information to be included in the dashboard, and creating wireframes or prototypes to evaluate layout and functionality. The next steps involve designing visual elements, including colour palette, typography, and imagery, conducting user testing to gather feedback and make necessary improvements, and finally launching the dashboard and continuously collecting feedback for further refinement. All these steps are taken with a focus on usability and effectiveness. The key features of the dashboard are navigation features that allow users to easily explore the data, various types of visualizations that present data in an understandable format, interactive visual displays that enable users to manipulate the data and view it from different perspectives, time-based visualizations that show changes in data over time, and real-time data displays that provide the most current information. The design principles integrated cutting-edge research from the fields of human-computer interaction (HCI) and digital civic-oriented research with social computing perspectives. Best practices included providing explicit and actionable data meaning for diverse users, ensuring data accuracy, precision, and clear lineage, and using effective language and appropriate visualizations for multi-platform communication. The study does not explicitly mention the modeling tools used. The design outcome is a set of design guidelines for building city dashboards that provide valuable insights into urban life.

In the healthcare domain in RW11, Elshehaly et al. (2020) employed the Metric Specification Structure (MSS) as their standard methodology for designing dashboards. The key phases of the project include investigating challenges and opportunities in National Clinical Audits (NCA) data usage, conducting interviews with healthcare professionals to identify user task sequences, collaboratively designing a metric card metaphor for visual analysis in healthcare quality improvement, creating a Metric Specification Structure (MSS), and deploying and iteratively enhancing the design of QualDash. The design principles of QualDash are based on the dimensions of the dashboard design space and address specific challenges in healthcare quality improvement, focusing on user task sequences, metric definition, visual features, and dashboard updatability. Best practices include using minimal GUI elements for effective interaction. The key features of QualDash include Metric Specification Structures (MSSs) for configuration, a visual display of important information, the display of dynamic information, the use of Visual Grammar (Vega-lite), and Run Charts. The modeling tool used is QualDash itself. The design outcome is QualDash, a concise and adaptable dashboard for healthcare quality improvement that visualizes key metrics and benchmarks using metric cards and the Metric Specification Structure (MSS). The tool's effectiveness and adaptability were validated through deployment in five NHS hospitals, leading to refinements for a second version of QualDash.

Syaiful et al. (2019) in their study in RW12 on the energy monitoring domain follow a multi-step process involving IoT implementation on mobile devices. The key phases involved in the development of a Smart Energy Dashboard System include assembling the tools in accordance with the system design, building a prototype in the form of miniature houses and connecting it to the application, building an application program using the Arduino IDE and extracting it into the APK form, and testing the applications installed on the smartphone for success and rebuilding the prototype if needed. The design principles of the system dashboard include flexibility in controlling electrical energy through the system, efficient use of electric energy, and user-friendly interfaces for managing and controlling electronic equipment. The best practices identified in the study include the use of IoT and mobile devices to provide flexibility and convenience in controlling electrical equipment and monitoring energy usage, and testing and validation of the system to ensure quality and minimize errors and discrepancies. The key features of the system dashboard include real-time data visualization for energy consumption, device status, and environmental conditions, an intuitive navigation interface for mobile devices like smartphones or tablets, drill-down capabilities to access detailed energy usage data, and device control enabling remote or automated control of electronic devices, including on/off, settings adjustment, and scheduling for energy optimization. The modeling tool utilized in the study is Arduino IDE, and the design outcome is a mobile-friendly dashboard with IoT technology to monitor energy usage in a premise. The dashboard enables the monitoring of energy usage in a premise using a mobile application to provide users with real-time information and control over electrical devices, allowing building owners to manage and optimize energy consumption remotely.

Finally, in the e-learning domain in RW13, Kokoç and Altun (2019) designed the Prescriptive Learning Dashboard (PLD), an innovative open-source tool that visualizes and predicts learners' online behaviors and provides personalized recommendations for improving their learning performances. This project employs an iterative design methodology. There are nine key phases involved in this work: reviewing and reorganizing the course database, making decisions on student visualizations, designing the dashboard, creating paper-based prototypes, gathering expert input, developing code structures for interaction data, implementing database adjustments, utilizing AJAX for data extraction, and computing personalized recommendations through predictive model algorithms. These phases ensure a comprehensive approach to dashboard design and implementation. The PLD was designed based on information dashboard design principles and information visualization principles, developed using a rapid prototyping approach and refined through feedback from instructional technology experts. Algorithms in the predictive model were used to calculate personalized recommendations and display results in text format. The design principles of the PLD include a simple and comprehensible interface, visualization of interaction data to support awareness of learning progress, not overloading the server network bandwidth, and providing personalized advice to learners to support self-reflection. Best practices include using diverse chart types for effective data visualization, employing rapid prototyping and gathering expert feedback, visualizing eight predictor variables for learning analysis, predicting and suggesting improvements in learner performance, and having an easily accessible screen location within Moodle. The key features of the PLD include visualizations of students' online behaviors, a predictive model for personalized recommendations, data sources and indicators, and visualization techniques to aid student understanding. These elements are integrated into a simple interface that promotes learning progress awareness and self-reflection. The RapidMiner Studio 6.2 was used as the modeling tool in this study.

The thirteen related works discussed above represent diverse approaches to information dashboard design across various application domains and methodological frameworks. To facilitate systematic comparison and analysis, Table 2.2 below summarizes these studies across the eight analytical elements identified earlier: application domain, standard methodology, key phases, design principles, best practices, key features, modeling tools, and key outcomes. This comprehensive comparison forms the basis for the detailed discussion in Section 2.6.1 and the identification of research gaps in Section 2.6.2.

Table 2.2 Recent related studies in information dashboard design (IDD)

Reference	Application Domain	Standard Methodology	Key Phases	Design Principles	Best Practices	Key Features	Modelling Tools	Key Outcomes
Lavalle et al. (2025)	Industry 4.0 (Smart Manufacturing)	i* Framework (i-Star) for Analytical Requirements, Tree Model Structuring and Knowledge Graph Integration	1. Requirement gathering 2. Structuring & refinement 3. Data Selection & preparation. 4. Conceptual model design. 5. Dashboard implementation. 6. Evaluation & comparison.	• Storytelling-based visualization to improve data interpretation. • Hierarchical structuring of dashboard elements to align with user decision-making processes. • User-centered design to enhance usability and effectiveness. • Interactivity and guided narratives for better comprehension.	• Incorporate storytelling in dashboards to facilitate understanding and reduce cognitive load. • Use hierarchical structuring to align with mental models of users. • Ensure a logical flow in data visualization to guide users through decision-making processes. • Leverage knowledge graphs to enhance contextual relationships between dashboard components.	• Hierarchical dashboard layout based on analytical requirements. • Integrated storytelling flow with guided data exploration. • Interactive visualization components for decision support. • Real-time and historical data representation for trend analysis.	Power BI	A structured storytelling dashboard framework that improves data comprehension and decision-making efficiency by integrating hierarchical structuring, storytelling elements, and interactive visualization techniques.
Poppe et al. (2024)	Neonatal Intensive Care	User-centered design approach with iterative development and evaluation	1. Interviews with clinicians. 2. Dashboard prototype development. 3. Evaluation during clinical rounds	• Combine detailed and summarized data • Enable real-time monitoring • Visualize physiological trends • Estimate key clinical indicators • Support decision-making • Ensure ease of understanding • Facilitate timely interventions	• Synchronize data from multiple devices (pulse oximeters and ventilators). • Enable both real-time and retrospective data visualization. • Allow flexible time interval selection for data viewing. • Implement histogram visualization for data distribution.	• Display of physiological data trends • Real-time monitoring of oxygen saturation • Time-based data exploration capabilities. • Estimation of hypoxia levels. • Assessment of respiratory instability.	Not explicitly mentioned.	A web-based oxygenation dashboard for real-time monitoring and visualization of oxygen saturation data in preterm neonates in the NICU.

to be continued…

… continuation

Pamuk & Schumann (2024)	Financial services	A combination of problem-oriented Design Science Research (DSR) approach and Cross-Industry Standard Process for Data Mining (CRISP-DM).	1. Data Understanding 2. Data Preprocessing 3. Model Development 4. Model Evaluation	• Simplicity: Show only the most important information. • Customization: Allow changes to layout, data, and visuals. • Interactive: Enable easy data and model exploration. • Clear visualizations: Include easy-to-understand charts and graphs. • Transparency: Clearly show data sources and usage. • Security: Protect user data with proper access controls. • Compliance: Meet regulatory standards for explainability and interpretability.	• Display only essential information. • Interactive Features: Enable data and model exploration. • Use clear charts and graphs. • Show data origins and usage. • Implement strong access controls. • Adhere to explainability and interpretability standards.	• Create, manage, compare, and validate AI models for credit assessment of private customers in financial services. • Range of model-building algorithms available for financial credit risk assessment. • Visualization of model performance and comparative analysis of model results. • Downloadable models and training/test sets. • Creation of a full report containing model performance metrics, metadata about the model, classifications made, training/test datasets, graphs, hyperparameters.	Python-based Django Framework	A comprehensive AI dashboard, named "AIDash", designed to support the iterative process of creating, managing, comparing, and validating AI models for credit assessment in financial services.
Salvi et al. (2024)	Public Health	A user-centered design approach combined with participatory methods and iterative feedback from Overdose Fatality Review (OFR) experts.	1. User Needs Assessment: Identified stakeholder needs through interviews, surveys, and focus groups. 2. Data Integration: Pre-processed and integrated relevant data sources into a unified repository. 3. Visualization	• User-Centered Design: Engaging end-users (OFR experts) throughout the design process to ensure the dashboard meets their needs. • Data Privacy and Security: Ensuring the anonymity of decedents and protecting	• Iterative Feedback: Continuously refining the dashboard based on feedback from focus groups and surveys. • Comprehensive Data Integration: Linking multiple administrative data sets to provide a holistic view of overdose touchpoints.	• Prevalence and Rates: Shows the percentage and rates of touchpoint use before overdoses. • Frequency and Recency: Visualizes touchpoint frequency and timing before overdoses. • County-Level Insights: Provides data at both county and state levels	Not explicitly mentioned.	"The Indiana touchpoints dashboard", a real time dashboard developed to enhance overdose prevention efforts by visualizing critical interactions with health and justice systems, providing county-level insights for public health officials.

to be continued…

… continuation

			Design: Created various visualizations to address different research questions. 4. Dashboard Development: Developed an interactive dashboard for data exploration. 5. User Evaluation: Evaluated the dashboard with Overdose Fatality Review (OFR) teams and public health officials using surveys, interviews, and usability tests.	sensitive data. • Actionable Insights: Providing visualizations that highlight key touchpoints, and opportunities for intervention. • Intuitive Visualizations: Using easy-to-understand visual formats like bar charts, line graphs, and maps. Timeliness: Offering real-time updates	• Accessibility: Ensuring the dashboard is accessible to all users, including those with varying levels of data literacy. • Transparency: Clearly explaining the data sources, methods, and limitations within the dashboard. Training and Support: Providing training and resources to help users interpret and utilize the data.	• Interactive Visualizations: Uses bar charts, line graphs, and maps. • Data Privacy: Ensures anonymity and protects sensitive data. Comprehensive Data Integration: Combines data from various sources for a holistic view.		
Conrow et al. (2023)	Big mobility data	Iterative design approach	1. Identify the intended purposes and end-users of the dashboard. 2. Specify and implement aspects related to data selection, transformation, visualization, and assembly. 3. Conceptualize a generalized trajectory model. 4. Build the dashboard using a user-centered and interactive approach. 5. Involve end-users at different stages	Emphasizes user-centered design, interactive design, and visual design principles to create dashboards that meet the needs and preferences of end-users, enable dynamic and interactive visualization of mobility data, and effectively communicate patterns and trends in the data.	• Prioritize a user-centered, interactive design. • Guide data selection with a conceptual model. • Choose appropriate chart formats. • Use web technologies like D3.js for dynamic visuals. • Apply visual communication principles. • Continuously evaluate and refine dashboards.	• Indicators: Quantitative or qualitative data representing mobility insights from sources like GPS, Bluetooth, Wi-Fi, and cellular networks. • Charts: Graphical representations of indicators showing patterns and trends • Maps: Spatial representations of indicators displaying geographic distribution • Filters: Interactive controls to modify indicators and	Not explicitly mentioned.	A conceptual framework for developing dashboards for big mobility data.

to be continued…

… continuation

			of development to ensure higher usability of the resulting dashboards.			parameters (e.g., sliders, checkboxes, drop-down menus). • Interactions: Dynamic features for user exploration (e.g., zooming, panning, selecting, hovering, linking).		
Bach et al. (2023)	General	A systematic review of real-world examples of dashboard design pattern	1. Defining data selection. 2. Establishing dashboard structure. 3. Designing individual pages. 4. Incorporating Interactivity.	• Reduce the number of pages and optimize screen space. • Colour should be used sparingly and with a specific purpose in mind. • Provide context for data to aid in comparison. • Consider the differences in needs between novice and expert audiences. • Consider accessibility factors such as titles, colors, and chart sizes. • Design iterations and prototype creation should be simple and assisted by dashboard design tools.	• Reduce information load. • Consider visual perception. • Use interactivity to ensure visualization literacy. • Use design patterns to formalize common solutions to design decisions. • Group patterns into content and composition categories. • Consider the dashboard's intended audience and purpose. • Utilize a useful framework to streamline dashboard design.	• Visual display of important information • Display of dynamic information • Drill-down capabilities for • Data Exploration • Presentation of Analytical Data Insights	Not explicitly mentioned.	A comprehensive list and description of 64 dashboard design patterns.
Wu et al. (2021)	Data visualization and dashboard design	Deep- learning-based method	1. Define the dashboard's purpose and key questions to address.	Foster collaboration between humans and computer automation through mixed-initiative	• Reduce the overhead of data selection. • Automate the selection process for multiple charts.	• Visual display of important information. • Display of dynamic information.	Deep-learning model	A deep learning algorithm integrated into Multivision to create an analytical dashboard for

to be continued…

… continuation

			2. Select relevant data sources and identify critical data columns for visual analysis. 3. Choose suitable chart types and ensure consistency across multiple charts. 4. Design an intuitive layout for the dashboard. 5. Conduct user testing to verify effective communication and alignment with user needs.	systems.	• Provide recommendations for charts based on optional manual selections • Leverage provenance data, such as authoring logs, to improve the selection process.	• Presentation of analytical data insights.		assisting in dashboard designs.
Pestana et al. (2020)	Healthcare	Design Science Research Methodology (DSRM)	1. Research and analysis, and ETL (extract, transform, load) processes to create a solid baseline for the dashboard. 2. Develop an initial proposal based on the baseline created in the first step. 3. Demonstrate and evaluate the proposed dashboard through a series of iterative interviews with stakeholders. 4. Use the feedback gathered from the previous iteration to improve and fine-tune the dashboard.	Incorporates principles of Gestalt's visual perception for effective design specifically proximity, similarity, and enclosure. These principles were used to guide the development of the graphic components of the dashboard, particularly the KPIs.	• Minimize visual effects in graphs. • Utilize colour purposefully to achieve communication goals. • Group physically close objects for perceptual association. • Create a sense of grouping through interconnections between objects.	• Visual display of important information. • Display of dynamic information. • Drill-down capabilities for data exploration. • Presentation of analytical data insights. • KPIs with annual values and compared with the homologous year. • Graphs are shown with the monthly distribution of KPIs and other analyses.	Not explicitly mentioned.	A web-based hospital management dashboard, focused on productivity to monitor key performance indicators (KPIs) and serves as a decision support tool for hospital managers and stakeholders.
Balletto et al. (2020)	Tourism	Convergent Parallel design -	1. Define the conceptual	• Extrinsic features: Highlight points of	Locational/ geographical data	• Walkability Index (WI)	Not explicitly mentioned	A dashboard design supporting slow

to be continued…

… continuation

		Quantitative and qualitative data are collected at the same time and analyzed separately.	framework to organize the contents of the dashboard. 2. Define the layout to organize the contents of the Santa Barbara Walk (SBW) circular dashboard. 3. Collect, analyze, and classify the intrinsic and extrinsic characteristics of the Walk. 4. Collect and analyze user-generated content from the smart community. 5. Elaborate and compile a comprehensive data set. 6. Generate internal reports for SBW managers. 7. Develop the dashboard as a collector capable of organizing a comprehensive data set. 8. Establish connections with social networks for data collection, monitoring, and sharing. 9. Observe, maintain, and keep SBW data updated	interest within a 1 km buffer from the location walkways. • Intrinsic features: Provide information on distance, difficulty, and travel time required to reach the locations.	should be displayed with a complete indicator.	• Attractiveness Index (AI) • Rating • Navigation features • Charts Maps		tourism in green infrastructures, which displays the walkability of a tourism location, relies on various maps sourced from available online portals and open-source Google Sites.
Young & Kitchin (2020)	Community informatics	• Cognitive Task Analysis (CTA) • Critical incident	1. Establish the dashboard's purpose and objectives.	Integrate usability-focused human-computer	• Explicit and actionable data meaning for diverse users.	• Navigation features. • Various types of visualizations.	Not explicitly mentioned	A set of design guidelines for

to be continued…

… continuation

		technique (CIT • Analysis of design principles	2. Identify the target audience and their specific needs. 3. Conduct user research to gain insights into user preferences and requirements. 4. Create user personas to represent different user types. 5. Develop a content strategy to define the data and information to be included in the dashboard. 6. Create wireframes or prototypes to evaluate layout and functionality. 7. Design visual elements, including colour palette, typography, and imagery. 8. Conduct user testing to gather feedback and make necessary improvements. 9. Launch the dashboard and continuously collect feedback.	interaction (HCI) research and digital civic-oriented research with social computing perspectives.	• Accurate, precise, and well-documented data with clear lineage Effective language and appropriate visualizations for multi-platform communication.	• Interactive visual displays. • Time-based visualizations • Real-time data displays.		building city dashboards.
Elshehaly et al. (2020)	Healthcare	Metric Specification Structure (MSS)	1. Investigate challenges and opportunities in National Clinical Audits (NCA) data usage.	The design principles of QualDash are based on the dimensions of the dashboard design space and	Use minimal GUI elements for effective interaction.	• Metric Specification Structures (MSSs). • Visual display of important information. • Display of Dynamic Information.	QualDash	QualDash - a concise and adaptable dashboard for healthcare quality improvement. It visualizes key

to be continued…

… continuation

			4. Conduct interviews with healthcare professionals to identify user task sequences. 5. Collaboratively design a metric card metaphor for visual analysis in healthcare quality improvement 6. Create a Metric Specification Structure (MSS). 7. Deploy and iteratively enhance the design of QualDash.	address specific challenges in healthcare quality improvement, focusing on user task sequences, metric definition, visual features, and dashboard updatability.		• Visual Grammar (Vega-lite) • Run Charts		metrics and benchmarks using metric cards and the Metric Specification Structure (MSS).
Syaiful et al. (2019)	Energy monitoring	Multi-step process involving IoT implementation on mobile devices	1. Assembling the tools in accordance with the system design. 2. Building a prototype in the form of miniature houses and connecting it to the application. 3. Building an application program using the Arduino IDE and extracting it into the Android Application Package (APK) form. 4. Testing the applications installed on the smartphone for success and rebuilding the prototype if needed.	• Flexibility in controlling electrical energy through the system. • Efficient use of electric energy. • User-friendly interfaces for managing and controlling electronic equipment	• Use of IoT and mobile devices: The proposed system is based on IoT and mobile devices, which can provide flexibility and convenience in controlling electrical equipment and monitoring energy usage. • Testing and validation: The system is tested and validated to ensure quality and minimize errors and discrepancies in the use of the system.	• Real-time data visualization (energy consumption, device status, environmental conditions). • Intuitive navigation interface (for mobile devices like smartphones or tablets). • Drill-down capabilities (to access detailed energy usage data). • Device Control (enabling remote or automated control of electronic devices, including on/off, settings adjustment, and scheduling for energy optimization).	Arduino IDE	A dashboard that is mobile-friendly with the aid of IoT technology for monitoring energy usage of a premise.
Kokoç & Altun (2019)	E-Learning	Iterative design approach	1. Review and reorganize the course database for	• The interface of the PLD should be	• Use diverse chart types for effective data visualization.	• Visualizations of students' online behaviors.	RapidMiner Studio 6.2	The prescriptive learning dashboard

to be continued…

… continuation

	proper storage of interaction data. 2. Make decisions on visualizing students and selecting suitable visualizations and techniques. 3. Design the dashboard by applying information dashboard design and information visualization principles. 4. Create paper-based prototypes and translate them into the system using rapid prototyping methods. 5. Gather input from instructional technology experts and implement dashboard revisions as needed. 6. Develop necessary code structures to handle log data relating to interaction variables. 7. Implement necessary database adjustments to record student interactions with the dashboard. 8. Utilize AJAX for efficient data extraction and communication	simple and comprehensible. • The PLD should visualize interaction data reflecting. learner traces to support awareness of learning progress • The working flow of the PLD should not overload the server network bandwidth. • The PLD should provide personalized advice to learners, supporting self-reflection.	• Employ rapid prototyping and gather expert feedback.	• Predictive model for personalized recommendations • Data sources and indicators. • Visualization techniques to aid student understanding.		(PLD) - an open-source tool designed to visualize and predict learners' online behaviors and provide personalized recommendations for improving their learning performances.

to be continued…

… continuation

9. Compute personalized recommendations through algorithms in the predictive model and present results in text format

2.6.1 Discussion of Related Works

This section presents a detailed analysis of the thirteen related works based on the eight analytical elements. The narrative literature review conducted highlights several clear gaps in existing research. Notably, there is an absence of studies that explicitly propose a standardized methodology for IDDM. Research focusing on dashboard design within the domain of smart waste management is also notably lacking. Moreover, there is a complete absence of studies that explicitly integrate IG as a foundational framework for IDDM. Similarly, no research has been found that applies ontological approaches in constructing an IDDM framework. These omissions underscore a significant gap that this study aims to address.

In addition, most of the recent related studies primarily focus on developing information dashboards within specific application domains, with elements relevant to IDDM often present but not positioned as the central theme. Notable exceptions include the works of Lavalle et al. (2025), Conrow et al. (2023), Bach et al. (2023), and Wu et al. (2021). Lavalle et al. (2025) propose a structured six-phase methodology for storytelling dashboard design within Industry 4.0 settings, integrating i* modeling, hierarchical structuring, and knowledge graphs to enhance narrative flow and usability. Conrow et al. (2023) develop a conceptual framework for dashboards targeting big mobility data, emphasizing user-centeredness, interactivity, and iterative refinement. Bach et al. (2023), through a comprehensive analysis of real-world dashboard design patterns, provide practical guidance on visualization structures, layout genres, and usability trade-offs. Meanwhile, Wu et al. (2021) introduce a deep learning-based system for automating analytical dashboard generation, tailored specifically to tabular data interpretation. Collectively, these studies contribute valuable insights to the development of IDDM, particularly in advancing methodological rigor, structural clarity, and domain adaptability.

The remaining studies (Pamuk & Schumann 2024; Poppe et al. 2024; Salvi et al. 2024; Elshehaly et al. 2020; Balletto et al. 2020; Pestana et al. 2020; Young & Kitchin 2020; Syaiful et al. 2019; Kokoç & Altun 2019) are primarily focused with the development of informative dashboards, yet their focus remains largely domain-specific. Nevertheless, each of these studies implicitly includes elements of IDDM that provide foundational references and practical considerations for this research. The synthesis of the thirteen recent works on information dashboard design is discussed below:

a. Application domain

The recent works revolve in various application domains, including energy monitoring (Syaiful et al. 2019), healthcare (Elshehaly et al. 2020; Pestana et al. 2020), tourism (Balletto et al. 2020), e-learning (Kokoç & Altun 2019), community informatic Young & Kitchin 2020). Notably, three most recent studies have expanded this range of domains: Poppe et al. (2024) focused on neonatal intensive care, Pamuk & Schumann (2024) addressed financial services, and Salvi et al. (2024) targeted public health for overdose prevention. Lavalle et al. (2025), on the other hand, contributed to the domain of smart manufacturing under the broader Industry 4.0 umbrella, applying a storytelling dashboard framework to enhance operational decision-making. Only three studies (Conrow et al. 2023; Bach et al. 2023; Wu et al. 2021) were not specific to any domain and could be generally applied in the design of the information dashboard. However, none of the recent studies are on the smart waste management domain, revealing a significant gap that this research aims to address. The wide range of application domains however demonstrates the universal relevance of information dashboard design and its potential to benefit any application areas.

b. Standard methodology

Based on Table 2.2, all studies employ different methodologies in developing information dashboards (Conrow et al. 2023; Bach et al. 2023; Wu et al. 2021; Balletto et al. 2020; Young & Kitchin 2020; Elshehaly et al. 2020; Pestana et al. 2020; Syaiful et al. 2019; Kokoç & Altun 2019). However, common methodologies such as the comprehensive analysis of real-world dashboard examples by Bach et al. (2023), the iterative design approach applied by Conrow et al. (2023) and Kokoç and Altun (2019), and the DSR methodology employed by Pestana et al. (2020), are generally applicable across diverse domains. The newly added recent studies further enrich this methodological diversity. Poppe et al. (2024) adopted a user-centered design approach with iterative development and evaluation. Pamuk and Schumann (2024) combined a problem-oriented DSR approach with the Cross-Industry Standard Process for Data Mining (CRISP-DM). Salvi et al. (2024) utilized a user-centered design framework supported by participatory methods and iterative feedback loops. Meanwhile, Lavalle et al. (2025) introduced a structured six-phase methodology that integrates i* modeling, hierarchical tree structuring, and knowledge graphs, validated through a controlled experiment within a smart manufacturing context. This structured approach stands out by bridging conceptual modeling with empirical usability testing. On the other hand, the remaining studies (Wu et al. 2021; Elshehaly et al. 2020; Balletto et al. 2020; Young & Kitchin 2020; Syaiful et al. 2019) have adopted methodologies tailored to their respective study contexts. Consequently, it can be concluded that there is no one-size-fits-all methodology for information dashboard design, as the choice of method often depends on the specific application domain and research objectives.

c. Key phases

In the development of information dashboards, key phases vary from one study to another due to differences in the methodologies employed, each having its own distinct process. Nevertheless, a shared component across these phases is the initial analysis to identify user needs, which typically serves as the common starting point. This preliminary analysis, as highlighted by Lavalle et al. (2025), Conrow et al. (2023), Elshehaly et al. (2020), Pestana et al. (2020), and Young and Kitchin (2020), plays a crucial role in understanding the current issues related to the subject of interest. The most recent studies further reinforce this trend. Poppe et al. (2024) began with interviews with clinicians, followed by dashboard prototype development and evaluation during clinical rounds. Pamuk and Schumann (2024) included phases for data understanding, preprocessing, model development, and evaluation. Salvi et al. (2024) started with user needs assessment, followed by data integration, visualization design, dashboard development, and user evaluation. Lavalle et al. (2025), on the other hand, implemented a comprehensive six-phase methodology that begins with requirement elicitation using i* modeling and progresses through structured refinement, data preparation, conceptual design, dashboard implementation, and final usability evaluation, demonstrating a highly structured and replicable approach to dashboard development. This structured process ensures that the resulting information dashboard effectively addresses user needs and tackles the core problems it intends to solve. In summary, while the specific phases involved in dashboard development may vary, the initial analysis consistently emerges as a critical step. This step is pivotal as it deepens the developers' understanding of user needs and context, ultimately paving the way for more effective and usable solutions.

d. Design principles

The common principle in information dashboard design is user-friendliness and ease of use. Lavalle et al. (2025) proposed storytelling-based design principles grounded in hierarchical layouts, guided narratives, and semantic structuring using knowledge graphs, aimed at reducing cognitive load and enhancing interpretability in Industry 4.0 dashboards. Bach et al. (2023) observe several general principles applicable across diverse application domains, such as optimizing screen space, minimizing page numbers, and providing contextual data. Similarly, Young and Kitchin (2020) and Conrow et al. (2023) advocate the incorporation of usability-centric reviews of human-computer interaction (HCI) literature as a foundation for effective dashboard design.

Other studies have emphasized domain-specific design considerations that reflect their unique application contexts. Poppe et al. (2024) focused on combining detailed and summarized data displays to support real-time decision-making in clinical settings. Pamuk and Schumann (2024) prioritized simplicity, interactivity, transparency, and regulatory compliance within financial services. Salvi et al. (2024) stressed user-centered design, data privacy, actionable insights, and timely feedback in public health contexts. While these general principles are widely acknowledged, the specific design considerations often vary depending on the user context and application domain. Researchers such as Syaiful et al. (2019), Balletto et al. (2020), Elshehaly et al. (2020), Kokoç and Altun (2019), Pestana et al. (2020), and Wu et al. (2021) have each proposed tailored design guidelines that reflect the needs and expectations of their respective users. In conclusion, although design principles may differ across studies, the overarching goal remains consistent: to create dashboards that are effective, user-friendly, and supportive of informed decision-making.

e. Best practices

Recent studies in information dashboard design highlight common best practices that encompass key principles. These practices stress the importance of striking a balance in information load while considering visual perception, addressing user needs, and ensuring effective data communication. Lavalle et al. (2025) emphasized a storytelling-based structure that guides users through information hierarchically, supported by semantic linkages and knowledge graphs. This approach not only reduces cognitive load but also enhances user comprehension and interpretability, and was validated through empirical usability testing within an Industry 4.0 setting. Bach et al. (2023) stress the necessity of reducing information load while also incorporating considerations related to visual perception. Pestana et al. (2020) advocate minimizing visual effects in graphs and the deliberate use of color to enhance data communication. Elshehaly et al. (2020) recommend employing minimal GUI elements to enhance user interaction, while Young and Kitchin (2020) emphasize the imperative of providing explicit and actionable data insights for a diverse user audience. Wu et al. (2021) direct their focus toward automating the chart selection process and providing recommendations based on optional manual selections. In contrast, Syaiful et al. (2019) center their efforts on leveraging IoT and mobile devices. Kokoç and Altun (2019) champion the use of diverse chart types for effective data visualization, and Wu et al. (2021) propose utilizing provenance data, such as authoring logs, to enhance the chart selection process. Conrow et al. (2023) distinguish themselves by prioritizing a user-centered, interactive design approach, guiding data selection with a conceptual model, selecting appropriate chart formats, leveraging web technologies like D3.js for dynamic visuals, applying visual communication principles, and persistently evaluating and refining their dashboards. Poppe et al. (2024) emphasized synchronizing data from multiple devices, implementing histogram visualization for data distribution, and allowing flexible time interval selection for data viewing. Pamuk and Schumann (2024) highlighted displaying only essential information, using clear charts and graphs, showing data origins and usage, implementing strong access controls, and adhering to explainability and interpretability standards. Salvi et al. (2024) stressed iterative feedback, comprehensive data integration, ensuring accessibility, transparency in data sources and methods, and providing training and support. In summary, these best practices underscore the importance of achieving a balance in information load, considering visual perception and user requirements, utilizing appropriate technology and design techniques, and ensuring the effective communication of data insights

f. Key features

Diverse studies revealed various essential elements in information dashboard design. Lavalle et al. (2025) structured their dashboard around a guided storytelling flow, integrating hierarchical layouts, semantic links through knowledge graphs, and multi-view data presentations that combine real-time and historical information. These features were designed to enhance interpretability, guide user attention, and reduce cognitive load through structured narratives. Conrow et al. (2023) incorporate essential elements into their dashboards, including indicators, charts, maps, filters, and interactive features. Similarly, Balletto et al. (2020) included a map and chart as the key features of their dashboard. The common key features in dashboards mentioned across most studies are visual displays of important information (Bach et al. 2023; Elshehaly et al. 2020; Pestana et al. 2020; Wu et al. 2021), and the display of dynamic or time-based information (Bach et al. 2023; Elshehaly et al. 2020; Pestana et al. 2020; Wu et al. 2021). Poppe et al. (2024) included real-time monitoring of oxygen saturation, time-based data exploration capabilities, estimation of hypoxia levels, and assessment of respiratory instability. Pamuk and Schumann (2024) featured tools to create, manage, compare, and validate AI models, visualize model performance, download models and datasets, and generate comprehensive reports. Salvi et al. (2024) incorporated prevalence and rates of touchpoints before overdoses, county-level insights, interactive visualizations using bar charts, line graphs, and maps, and comprehensive data integration from various sources. Beyond these common key features, several other components are also mentioned across studies. For instance, interactive and navigational elements are often regarded as standard components, depending on the specific purpose of the dashboard and its intended users. These elements enhance the user experience, allowing for more personalized interaction with the data.

g. Modelling tools

Based on the review of the related works literature, it is observed that a significant number of studies (Poppe et al. 2024; Salvi et al. 2024; Conrow et al. 2023; Bach et al. 2023; Balletto et al. 2020; Pestana et al. 2020; Young & Kitchin 2020) have not explicitly stated the modeling tools used in their research. This lack of specificity is possibly due to the utilization of multiple tools without specifying the main modeling tools used in their study. However, there are studies that have explicitly mentioned the modeling tools used in their work. Lavalle et al. (2025), for instance, employed a combination of i* modeling for requirements elicitation, a hierarchical tree model for conceptual structuring, knowledge graphs for semantic representation, and Power BI for dashboard implementation, forming a comprehensive and structured modeling workflow. Wu et al. (2021) employed a deep-learning model, Elshehaly et al. (2020) utilized QualDash, Syaiful et al. (2019) applied Arduino IDE, and Kokoç & Altun (2019) made use of RapidMiner Studio 6.2. Pamuk and Schumann (2024), on the other hand, used a Python-based Django framework for modeling. These studies typically concentrate on a single primary modeling tool, offering in-depth insights into its application and effectiveness. In conclusion, while the explicit mention of modeling tools can contribute valuable context, the absence of such information does not necessarily detract from the value or applicability of the study's findings. Furthermore, this absence underscores the novelty of this study, which leverages ontology principles as its core modeling foundation.

h. Key outcomes

Based on the literature reviews, it can be concluded that there are many forms of key outcomes and most of them produce a domain-specific dashboard. Only a few studies differ in their key outcomes, such as Bach et al. (2023) who have come up with a comprehensive list and description of 64 dashboard design patterns. Lavalle et al. (2025), meanwhile, developed a structured six-phase methodology resulting in a storytelling-based dashboard framework tailored for Industry 4.0. Their outcome integrates modeling, semantic structuring, and narrative design, and was empirically validated through a controlled usability experiment, offering a replicable approach to dashboard development across complex industrial settings. In contrast, several other works have concentrated on crafting domain-specific outcomes like Syaiful et al. (2019), who created a mobile-friendly IoT-powered dashboard, Pestana et al. (2020), who developed a web-based hospital management dashboard, and Balletto et al. (2020), who introduced a dashboard to facilitate leisurely tourism in green infrastructures. Furthermore, Kokoç and Altun (2019) introduced the prescriptive learning dashboard (PLD), Young and Kitchin (2020) laid out design principles for urban dashboards, Wu et al. (2021) incorporated deep learning algorithms into Multivision, and Elshehaly et al. (2020) crafted QualDash for enhancing healthcare quality. Additionally, Poppe et al. (2024) developed a web-based oxygenation dashboard for real-time monitoring and visualization of oxygen saturation data in preterm neonates. Pamuk and Schumann (2024) created a comprehensive AI dashboard named "AIDash" to support the iterative process of creating, managing, comparing, and validating AI models for credit assessment in financial services. Salvi et al. (2024) developed "The Indiana Touchpoints Dashboard," a real-time dashboard to enhance overdose prevention efforts by visualizing critical interactions with health and justice systems. Notably, Conrow et al. (2023) have proposed a conceptual framework dedicated to the development of dashboards specifically designed for the management of extensive mobility data as the key outcomes of their study.

The comprehensive analysis of thirteen related works across the eight analytical elements reveals several important insights into the current state of information dashboard design research. The studies collectively demonstrate the universal relevance of dashboard design across diverse application domains, from healthcare and financial services to tourism and e-learning. Various methodological approaches have been employed, ranging from DSR and user-centered design to iterative development and deep learning-based automation. The key phases identified across studies consistently emphasize the importance of initial user needs analysis, followed by iterative design, development, and evaluation cycles. Design principles and best practices highlight the significance of user-centeredness, visual clarity, data quality, and interactive features in creating effective dashboards.

Despite these valuable contributions, the analysis also reveals several critical gaps in the existing body of research that warrant further investigation. These identified research gaps are discussed in detail in the following subsection.

2.6.2 Identified Research Gaps

The comprehensive review and discussion of thirteen related works across eight analytical elements in subsection 2.6.1 reveal four critical research gaps that this study addresses. These gaps emerged from systematic analysis of application domains, standard methodologies, key phases, design principles, best practices, key features, modeling tools, and key outcomes across all reviewed studies. The identification of these gaps is essential in establishing the theoretical and practical justification for developing a comprehensive IDDM that addresses the underexplored aspects of dashboard design research. Table 2.3 below summarizes these identified gaps with supporting evidence from the literature.

Table 2.3 Research gaps identified from related works analysis

Gap No.	Research Gaps	Key Evidence from Related Works	Section Reference
1	**Absence of existing studies focusing specifically on standardized IDDM** • No comprehensive, standardized methodology for information dashboard design that is applicable across different domains. • Existing studies focus on domain-specific development or partial frameworks without unified, systematic guidance.	• RW1 (Lavalle et al. 2025): Six-phase methodology for Industry 4.0 storytelling dashboards only • RW5 (Conrow et al. 2023): Conceptual framework for mobility data, not complete methodology • RW6 (Bach et al. 2023): 64 design patterns, not comprehensive methodology • Remaining studies: Varied or context-specific methodologies without standardization	2.6.1(b)
2	**Unavailability of an information dashboard study in the smart waste management domain** • None of the thirteen reviewed studies address dashboard design within the smart waste management domain, • despite its growing importance in sustainable urban development.	Application domains covered: Industry 4.0 (RW1), Healthcare (RW2, RW8, RW11), Financial Services (RW3), Public Health (RW4), Urban/Mobility (RW5, RW10), Tourism (RW9), Energy (RW12), E-Learning (RW13) • **Smart waste management: Not covered by any study**	2.6.1(a)

to be continued…

…continuation

3	**No studies employ ontology as a formal knowledge representation** • Complete absence of research that applies ontological approaches in constructing IDDM framework. No use of ontology principles as core modeling foundation.	Modeling tools used: • RW1: i* modeling, hierarchical tree, knowledge graphs, Power BI • RW7: Deep-learning models • RW11: QualDash framework 7 out of 13 studies: Did not explicitly state modeling tools	2.6.1(g)
4	**Lack of study on the integration of IG principles as the foundation of IDDM** • Complete absence of studies that explicitly integrate IG as foundational governance framework.	Current focus areas: • Technical implementation and visualization design • User-centered design and usability • Domain-specific functional requirements	2.6.1(b), 2.6.1(d), 2.6.1(e)

Overall, the analysis presented in Sections 2.6 and 2.6.1 critically examines the related works on information dashboard design within various application domains, extracting detailed information across the eight analytical elements. The review of thirteen related studies confirms that none of them directly addresses the creation of a unified method for designing information dashboards, the use of IG as the IDDM governance foundation, or the application of ontology as a modeling tool, and none focus specifically on the smart waste management domain. These four identified research gaps, as summarized in Table 2.3 above, indicate certain aspects of prior studies that remain underexplored, which this study attempts to examine further. The findings from this literature review, including the identified research gaps and the intended contributions of this study, are illustrated in Figure 2.5.

2.7 SUMMARY

In summary, Chapter 2 provides a comprehensive overview of IDD, beginning with a discussion of general challenges, common design mistakes, guiding principles, and prevailing practices. It also highlights the growing need for a unified, structured methodology to support consistent dashboard development across domains.

The chapter then explores the foundational role of IG and ontology in strengthening the IDD process. Three established IG models (IGRM, IGIM, and

IGMM) are reviewed and synthesised into a set of core governance principles relevant to dashboard design. The concept of an ontology-driven approach is also introduced, forming the basis for the IDDO and the proposed IDDM both of which are further developed in Chapter 4.

A detailed analysis of thirteen recent related works is also presented, covering various application domains and assessed using eight analytical elements: application domain, standard methodologies, critical phases, design principles, best practices, key components, modelling tools, and key outcomes. The findings from the literature review, including identified research gaps and the intended contributions of this study are summarised in Figure 2.5.

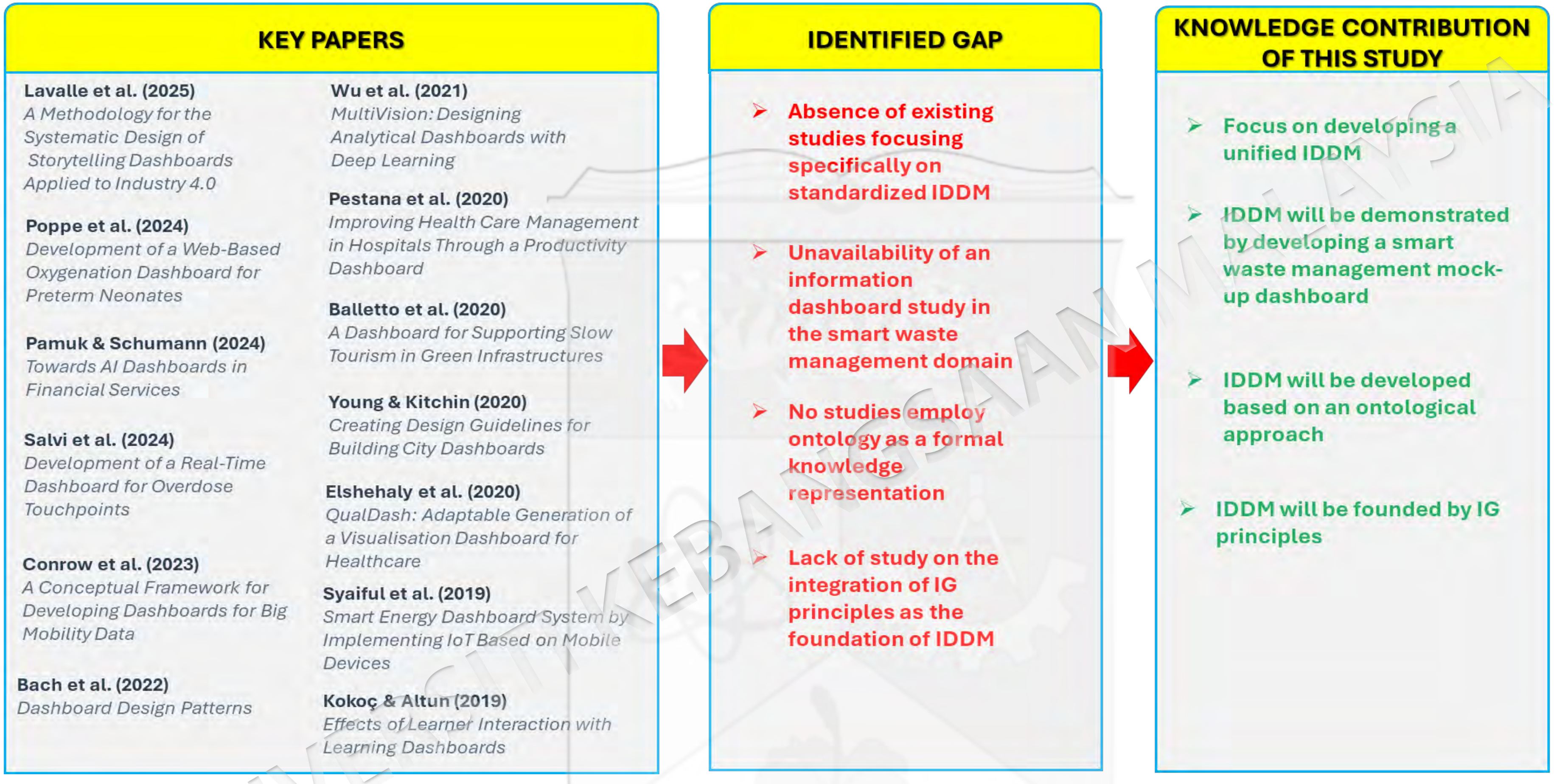

Figure 2.5 Summary of key papers, identified gaps, and knowledge contribution of this study

CHAPTER III

METHODOLOGY

3.1 INTRODUCTION

According to Phrabat. Pandey and Pandey (2015), research methodology plays a pivotal role in academic endeavours. As suggested by Phrabat. Pandey and Pandey (2015), it involves applying the scientific method to solve problems. This process is systematic, formal, and intensive, aligning with the methodical and structured approach of scientific analysis. Common research methodologies include qualitative, quantitative, mixed methods, and experimental research.

DSR is relatively new to Information Systems (IS) research, as noted by Alturki et al. (2013). However, in recent years, several researchers have successfully introduced design research into the field of IS research, establishing the credibility and importance of design science (DS) as a valid research paradigm (Hevner et al. 2004; March & Smith 1995; Walls et al. 1992) and integrating design as a significant component of research.

According to Wiegmann et al. (2023), DSR is rapidly emerging and has successfully gained attention and recognition across various disciplines. The DSR has evolved over several decades, particularly in information systems, and has recently expanded its application to numerous other domains, including the environmental field, as showcased by Wiegmann et al. (2023) in their research.

The fundamental aim of DSR is to generate knowledge that professionals in the field can utilize to design solutions for problems they encounter (Hevner et al. 2004; Peffers et al. 2007; vom Brocke et al. 2020) . DSR prioritizes the decision-making process regarding what is feasible and beneficial for the development of potential future outcomes, rather than focusing on the present state of affairs. This aim complements the objectives of behavioral science, which is characterized as “explanatory sciences,” such as the natural sciences and sociology. These sciences cultivate knowledge for the purpose of describing, explaining, and predicting (vom Brocke et al. 2020). As stated by Hevner et al. (2004), another key objective of DSR is to gain knowledge and comprehension of a problem area through the creation and implementation of a specifically designed artifact.

This study adopts the DSRM. It involves the development of the IDDM as the primary artifact of this study. The selection of DSRM as the methodology of this study aligns with the definition of DSRM provided by Hevner et al. (2004) and vom Brocke et al. (2020), where DSRM seeks to enhance knowledge bases in technology and science by developing innovative artifacts that address problems and enhance the surroundings in which they are instantiated.

3.2 RESEARCH PARADIGMS IN INFORMATION SYSTEMS

According to Kivunja and Kuyini (2017), a research paradigm is a philosophical framework that reflects a researcher's beliefs about the world and shapes how they perceive and make sense of it. It encompasses the underlying beliefs and principles that guide the understanding and interpretation of research data. Understanding the research paradigm is imperative, as it influences the entire research process, from the formulation of research questions to the interpretation of results (Abdul Rehman & Alharthi 2016).

In the field of information systems, a paradigm serves as the lens through which the world and its behaviours are viewed, as described by Noran (2016). The design-science paradigm in the realm of information systems has evolved to focus on creating new and innovative artifacts that extend the boundaries of human and organizational capabilities. Hevner et al. (2004) emphasize that this paradigm seeks to develop and apply knowledge and understanding of a problem domain through the construction and application of designed artifacts. Its goal is to generate innovations that define the ideas, practices, technical capabilities, and products for the effective and efficient analysis, design, implementation, management, and use of information systems.

Hevner et al. (2004), suggest that information system research is a combination of both the behavioral science paradigm, which aims to develop and verify theories explaining or predicting human and organizational behavior, and the design science paradigm, which seeks to extend the boundaries of human and organizational capabilities through the creation of new and innovative artifacts. Both paradigms are foundational to the information system discipline, situated at the intersection of people, organizations, and technology (Silver et al. 1995). It is argued that both the design science and behavioral science paradigms are necessary to ensure the relevance and effectiveness of IS research, considering the artificial nature of organizations and the information systems that support them. To enhance the comprehension of the integration of the behavioral science and design science paradigms, Hevner et al. (2004) introduce a conceptual framework for information research, depicted in Figure 3.1.

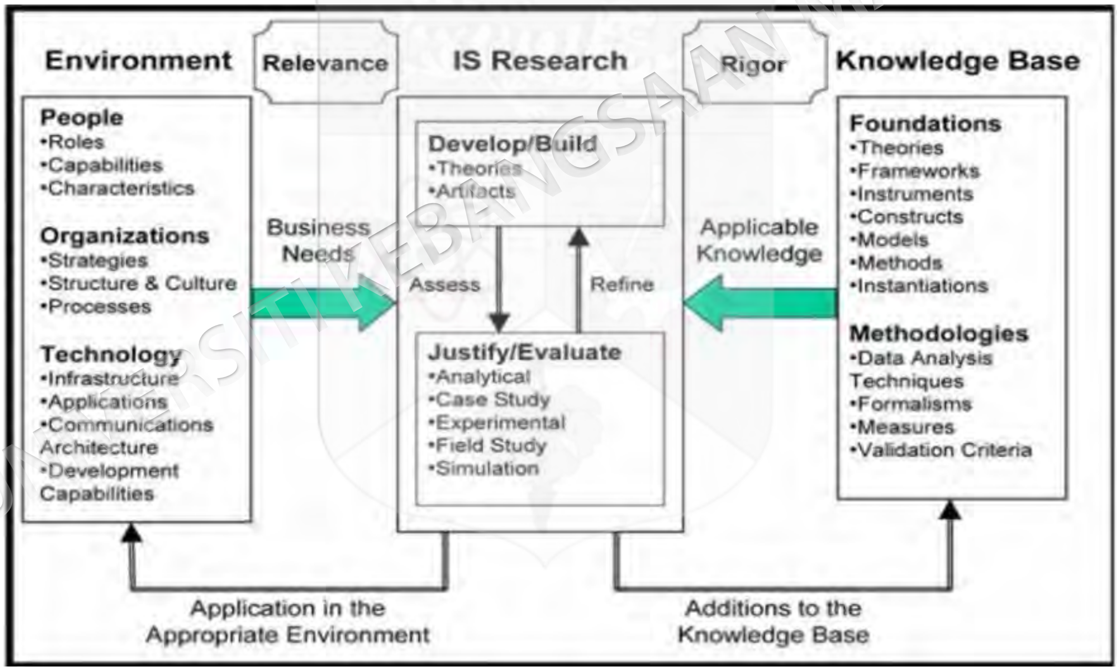

Figure 3.1 Information systems research framework

Source: Hevner et al. 2004

3.3 DESIGN SCIENCE RESEARCH METHODOLOGY: AN OVERVIEW

The concept of design science originated in 1957 with R. Buckminster Fuller (Ananthasuresh 2015). The term “Design Science Research” gained prominence in the 1990s, particularly within information systems, engineering, and computer science, as researchers adopted this approach to address complex issues in their respective fields (Weber 2010; Peffers et al. 2007; Hevner et al. 2004). According to vom Brocke et al. (2020), Peffers et al. (2007) and Hevner et al. (2004), DSR focuses on developing and validating prescriptive knowledge in information science. It's a process-driven approach that emphasizes problem-solving through the creation of purposeful and innovative artifacts (Hevner et al. 2004). Hevner et al. (2004) highlight the creation of purposeful IT artifacts specifically to address organizational issues, outlining seven guidelines for DSR, as summarized in Figure 3.2 below:

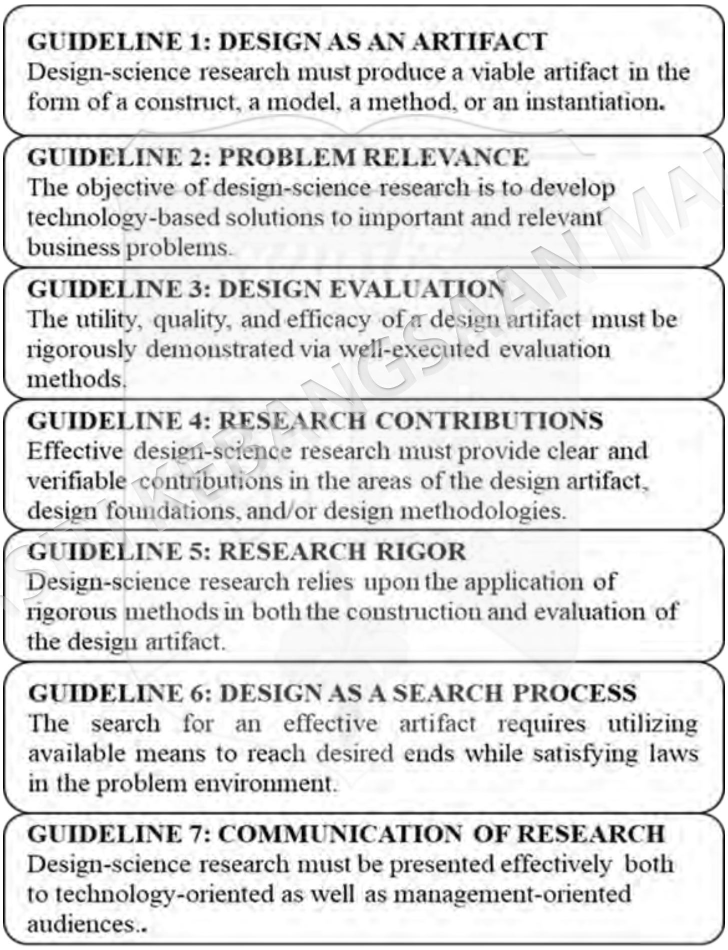

Figure 3.2 Seven guidelines for design science

Source: Hevner et al. 2004

Peffers et al. (2007) assert the vital role of DSR in information systems, primarily emphasizing the development and validation of artifacts intended to solve identified problems. However, they note a lack of a commonly accepted methodology for presenting DSR, which might have hindered its widespread adoption. Consequently, Peffers et al. (2007), proposed the DSRM to encompass the necessary principles, practices, and procedures for conducting such research. The DSRM aims to achieve three objectives: align with existing literature, provide a process model for conducting DSR, and offer a framework for presenting and evaluating DSR in information systems. They believe that the DSRM would promote rigor and relevance in DSR, facilitating its adoption within the information systems discipline. The overview of DSRM proposed by Peffers et al. (2007) which comprises six processes is depicted in Figure 3.3 below:

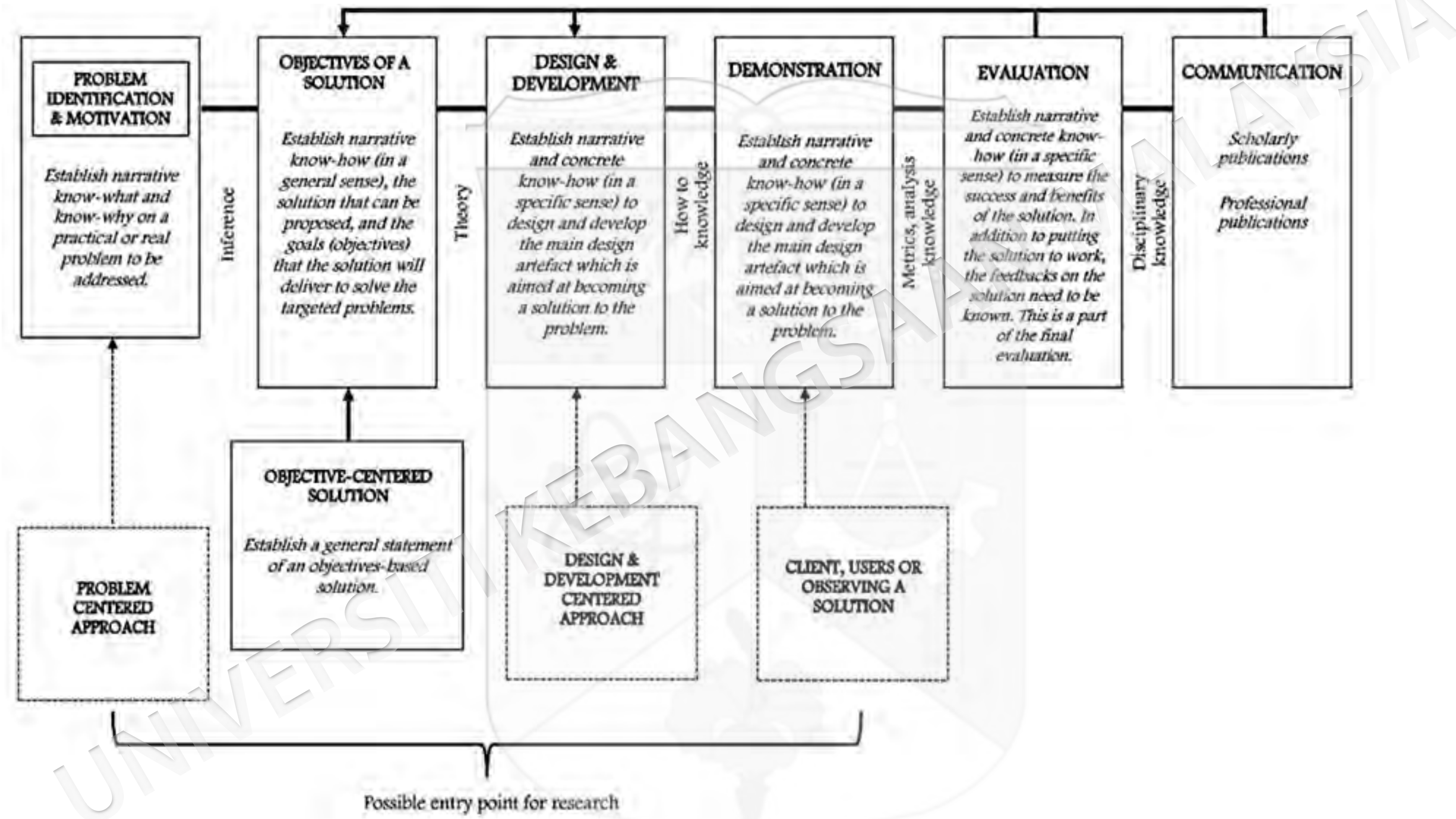

Figure 3.3 DSRM process model

Source: Peffers et al. 2007

To maximize the impact of DSR, it is crucial to identify the type and depth of the knowledge contribution that the artifact brings to the field. This identification can help position the artifact within the broader context of DSR and articulate its value. The knowledge contribution of DSR is categorized into different levels, as proposed by Gregor and Hevner (2013) and further elaborated by Gregor and Zwikael (2024). As depicted in Figure 3.4, Gregor and Hevner (2013) presented a table outlining the types of knowledge contributions at three distinct levels. In brief, Level 3 contributes to a more abstract, complete, and mature body of knowledge, while Level 1 yields more specific, limited, and less mature knowledge.

	Contribution Types	Example Artifacts
More abstract, complete, and mature knowledge	Level 3. Well-developed design theory about embedded phenomena	Design theories (mid-range and grand theories)
↕ ↕ ↕ ↕	Level 2. Nascent design theory—knowledge as operational principles/architecture	Constructs, methods, models, design principles, technological rules.
More specific, limited, and less mature knowledge	Level 1. Situated implementation of artifact	Instantiations (software products or implemented processes)

Figure 3.4 Design science research contribution types

Source: Gregor & Hevner 2013

Building upon the foundation of DSR and the DSRM, Gregor and Zwikael (2024) argue that the knowledge developed from DSR forms a continuum. They posit that this continuum spans from the knowledge represented in a physical occurrence or instantiation of a new or modified artifact, through nascent design theory in the forms of design principles, schemas, and methods, to full-fledged design theory. Echoing the views of Gregor and Hevner (2013), Gregor and Zwikael (2024) classify the knowledge contribution of DSR into three different levels, as illustrated in Figure 3.5.

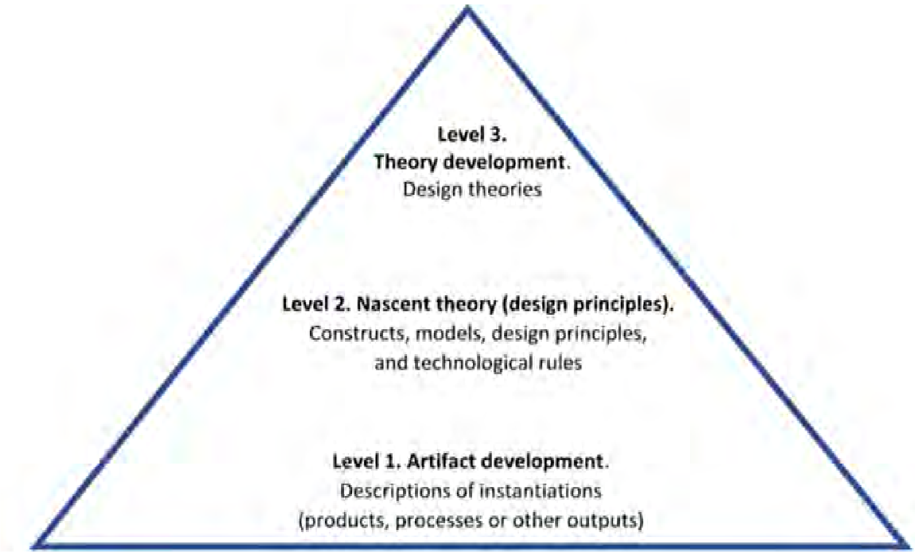

Figure 3.5 Level of design knowledge

Source: Gregor & Zwikael 2024

To ensure both rigor and relevance in DSR, Gregor and Zwikael (2024) advocate for contributions to all three levels of design knowledge. By contributing to all three levels of design knowledge, researchers can ensure the rigor and relevance of their work, thereby facilitating the adoption and impact of DSR within their respective disciplines.

Another crucial aspect to consider when discussing DSR and the DSRM is the role of Kernel Theories in the development of the design artifact. Kernel Theories are foundational theories originating from natural or social sciences and are used to guide the artifact's design and development (Kuechler et al. 2008).

In the context of DSR, three distinct perspectives exist concerning the necessity of applying Kernel Theories during the design and development of the artifact. Figure 3.6 illustrates these three unique viewpoints on the requirements of Kernel Theories as the foundational basis for the artifacts (Fischer et al. 2010).

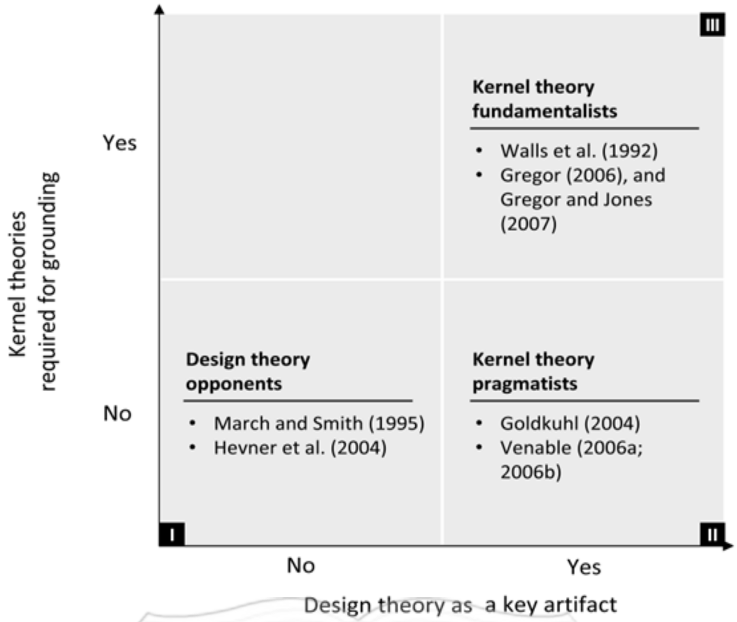

Figure 3.6 DSR schools of thoughts on Kernel Theory

Source: Fischer et al. 2010

The first view is by Hevner et al. (2004) and March and Smith (1995) known as "Design Theory Opponents" who argue that Kernel Theories are not necessary for DSR artifact development. Both Hevner et al. (2004) and March and Smith (1995) opine that DSR complements Behavioral Science (BS) rather than replicating it, and while Kernel theory is prevalent in BS research, they are not considered a priority or necessity in DSR. Hevner et al. (2004) suggest that knowledge from both BS and DSR may be used in constructing design science artifacts, but these artifacts do not necessarily need to be grounded in Kernel Theories. This perspective emphasizes that DSR complements BS rather than replicating it (Hevner et al. 2004; Möller et al. 2022).

The second perspective is referred to as "Kernel Theory Pragmatist" (Goldkuhl 2004; Venable 2006a, 2006b). This perspective adopts a moderate stance and proposes that although Kernel Theories are not essential in the process of constructing artifacts, the theory generated as an outcome of DSRM is acceptable as a significant influence and outcome of the research. This practical approach permits adaptability in employing theories within DSR projects.

The third perspective, often referred to as the 'Kernel Theory Fundamentalist,' represents the most stringent stance on the necessity of incorporating Kernel Theories into DSR artifacts. Drawing on the works of Gregor (2006), Gregor and Jones (2007), and Walls et al. (1992), this perspective highlights the incorporation of Kernel Theories in the creation of artifacts. It also recognizes the emergence of theory as an outcome of the DSRM. According to Walls et al. (1992), Kernel Theories, whether derived from natural or social sciences, play a crucial role in the construction of artifacts.

In summary, the stratification of knowledge contribution in DSR is a key aspect of the methodology that enhances its rigor, relevance, and impact. The notion of Kernel theory application in DSR artifact creation and their variety of perspectives enriches the discourse and practice of DSR, allowing for a range of approaches to artifact design and development. In a nutshell, DSR is a structured approach to knowledge creation that guides researchers and facilitates the evaluation of their work.

3.3.1 Problem Identification and Motivation

In the DSR, as emphasized by Hevner et al. (2004) and Peffers et al. (2007), the initial step involves problem identification, a pivotal aspect within the DSR process. This phase establishes the foundation for developing a solution to the identified problem. The main goal of this phase is to pinpoint specific issues and validate the value of the proposed solution. Hevner et al. (2004) note that problems can be identified through various means, including observation, interviews, surveys, and primarily, the analysis of existing literature. This ensures that the research audience comprehends the problem, thereby encouraging their engagement with the eventual solution (vom Brocke et al. 2020). Peffers et al. (2007) further illustrate that defining the problem is crucial in constructing an artifact that effectively addresses the issue. Justifying the solution's value achieves two key objectives: it motivates researchers to pursue the research and provides a basis for evaluating the artifact's effectiveness. As a result, the phase of problem identification and motivation stands as a key success factor in the DSR project (Hevner et al. 2004; Peffers et al. 2007; vom Brocke et al. 2020).

3.3.2 Objectives of a Solution

The objective of a solution is the second step in DSRM proposed by Peffers et al. (2007). Peffers et al. (2007) emphasize that, in the creation of a purposeful and effective artifact, establishing the objectives for a solution should be based on the understanding of the problem definition and what is feasible. Hevner et al. (2004) further stress the significance of setting clear objectives for a solution, which not only informs the creation of an innovative artifact but also underscores the need for rigorous evaluation to ensure its efficacy, efficiency, and utility. Peffers et al. (2007) argue that this stage serves a dual purpose: determining what the artifact should achieve and outlining the evaluation criteria. Without clearly defined objectives, assessing the artifact's effectiveness in solving the identified problem becomes a challenging task. Hence, the stage of defining objectives for the solution stands as a pivotal factor in the success of a DSR project (vom Brocke et al. 2020; Peffers et al. 2007; Hevner et al. 2004).

3.3.3 Design and Development

The essence of DSR lies in the design and development stage, the third activity proposed by Peffers et al. (2007) in the DSRM. This phase involves the creation of an innovative artifact as the solution to the identified problem. According to vom Brocke et al. (2020), researchers construct an innovative solution, often drawing from existing elements of a solution and combining, revising, and expanding on existing design knowledge. The design activities encompass "build" and "evaluate" tasks, typically undergoing multiple iterations. Similarly, Hevner et al. (2004) argue that while existing knowledge is utilized when applicable, the nature of Design Science often requires reliance on creativity and trial-and-error due to the absence of necessary knowledge. Therefore, conducting the design and development process diligently is crucial as the success of the entire DSR project heavily relies on the rigor and quality of this stage (vom Brocke et al. 2020; Peffers et al. 2007; Hevner et al. 2004).

3.3.4 Demonstration and Evaluation

Demonstration and evaluation are two of the six processes in the DSRM as proposed by Peffers et al. (2007). The demonstration stage involves demonstrating the effectiveness of the artifact that was developed in the design and development stage. The demonstration stage aims to exhibit the effectiveness of the artifact developed during the design and development phase. Its primary objective is to showcase the artifact's capacity to effectively resolve the identified problem and meet the defined objectives. This demonstration can take various forms, such as mock ups, prototypes, simulations, or case studies, typically conducted in real-world settings to validate the artifact's problem-solving efficacy (Peffers et al. 2007) . Peffers et al. (2007) highlight the critical nature of the demonstration stage, underlining its role in providing evidence of the artifact's effectiveness in addressing the identified problem and achieving the specified objectives, hence significantly contributing to the success of the DSR project.

The next crucial step is evaluation. The results of the demonstration will be rigorously evaluated to ensure that the artifact meets the defined objectives. The evaluation stage is important because it measures how well the artifact supports a solution to the problem. According to Peffers et al. (2007) the evaluation criteria include effectiveness, efficiency, and external consistency. The evaluation stage is crucial in determining whether the artifact is successful in solving the problem and meeting the objectives (vom Brocke et al. 2020; Peffers et al. 2007; Hevner et al. 2004).

3.3.5 Communication

The final activity in the DSRM is communication. According to vom Brocke et al. (2020), Peffers et al. (2007) and Hevner et al. (2004), the aim of this activity is to effectively communicate all aspects of the identified problem and the designed artifact to relevant stakeholders. The forms of communication, depending on research goals and the intended audience, are employed to cater various stakeholders, including practicing professionals. The implication of this phase lies in its role in enabling researchers to disseminate their findings, contributing to the collective knowledge within their respective fields (vom Brocke et al. 2020; Peffers et al. 2007; Hevner et al. 2004). Collectively, vom Brocke et al. (2020), Peffers et al. (2007) and Hevner et al. (2004) highlight that effective communication plays a significance role in ensuring the adoption and utilization of the artifact by the intended audience. Ultimately, this will enhance the artifact's impact and value within the field.

3.4 DESIGN SCIENCE RESEARCH METHODOLOGY: AN APPLICATION

Drawing upon the DSRM process model by Ken Peffers et al. (2007) as depicted in Figure 3.3, this study applies the six DSRM steps in an iterative manner to guide the design, development, and evaluation of the research artefacts. The relevance of using the Peffers DSRM model is further supported by its continued adoption in recent studies, including the development of digital transformation models (Mohammad Omar Sabri 2025), the design of a mobile learning application for cerebral palsy education (Muriyatmoko et al. 2024), and the integration of qualitative design methods within design science research (Muhammad Afif Fathullah et al. 2025). The application of DSRM in this study is summarised in Figure 3.7.

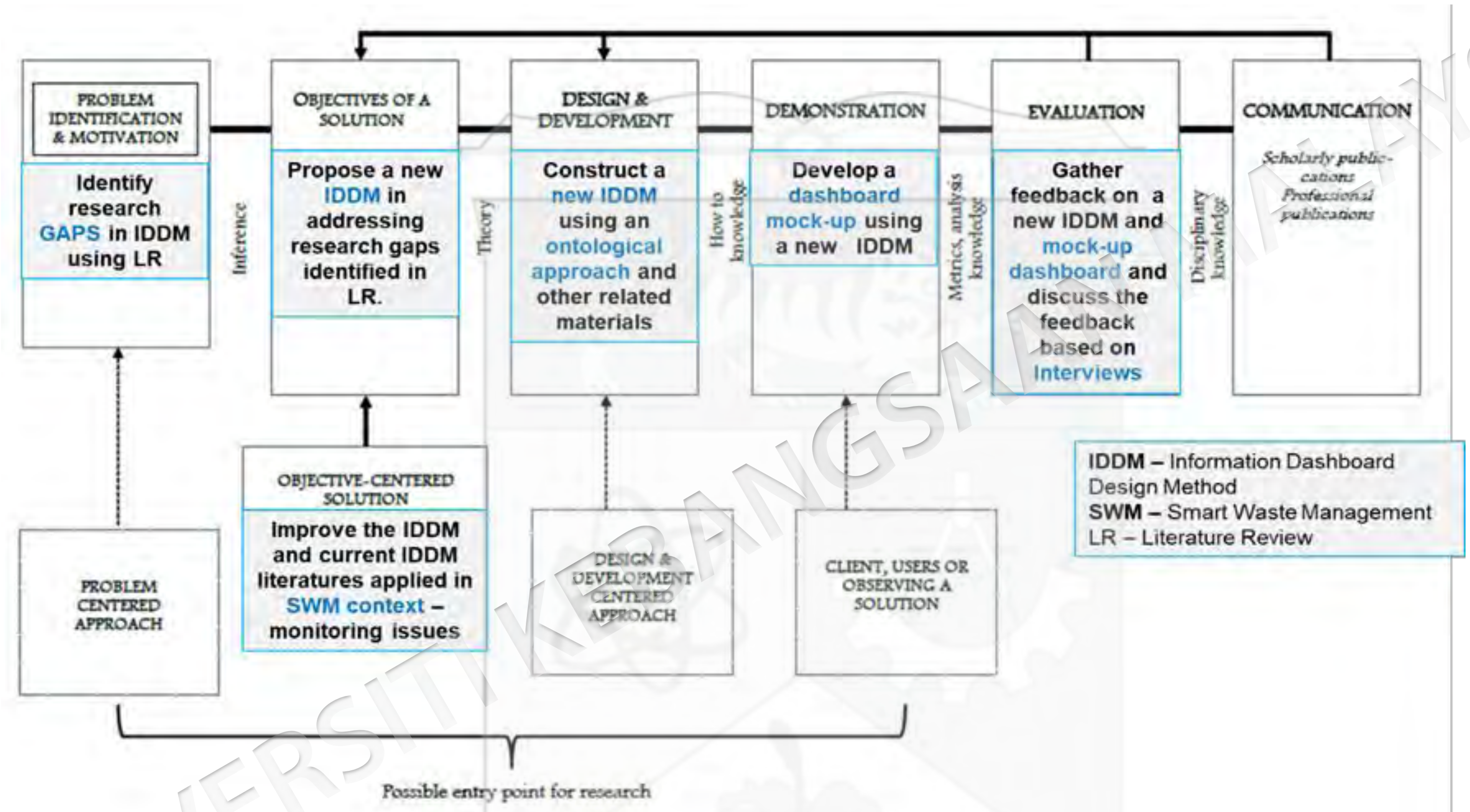

Figure 3.7 The entire DSRM processes applied to the study context

3.4.1 Problem Identification and Motivation

The problem identification process involves pinpointing the current shortcomings in the design methods for the dashboard. The narrative literature review delves into various application domains and use cases of dashboard design methods, aiming to gain a comprehensive understanding of the field. Through this analysis, existing design methods are scrutinized, revealing their strengths and weaknesses and pinpointing research gaps, ensuring that the research remains focused in the right direction. The extensive literature review highlights several significant gaps despite numerous studies in dashboard design. Specifically, four key areas lack substantial research: the absence of studies unifying design methods, a scarcity of research on dashboard design within smart waste management, unavailability of recent studies on integrating IG as the foundation of the IDDM, and the lack of studies focusing on applying ontology in developing the IDDM. These identified gaps lay the foundation for potential solutions and serve as motivation to pursue this study.

3.4.2 Objective of a Solution

Drawing from an extensive exploration of the literature, this study establishes its research objectives based on the research questions derived from the existing literature and the problem statement. The literature review encompasses diverse studies on dashboard design methods across various application domains. Employing a narrative literature review approach, this study not only identifies research gaps but also provides an overarching view of dashboard design practices. In this research context, the objective of the solution is to address the identified gaps by formulating a unified and domain-independent IDDM. These gaps notably include the absence of studies unifying dashboard design methods, the lack of research integrating IG as a foundational governance of IDDM, and the scarcity of studies applying ontological approaches in the development of IDDM. To demonstrate and validate the proposed IDDM, smart waste management is selected as the application domain due to its data-intensive and multi-stakeholder operational environment. This objective is derived directly from the research gaps identified during the problem identification phase, paving the way for a solution-driven approach.

3.4.3 Design and Development

The design and development stages are of paramount importance as they lead to the derivation of the key artifact of this study, the IDDO. From the synthesis of related works on information dashboard design, the common elements will be identified. These common elements in the information dashboard design will form the key building blocks of the IDDO.

Consequently, this study will proceed with the synthesis of established IG models and related works on IG to identify the relevant IG principles aligned with common design principles to be integrated as the foundational governance of the IDDM. The integration of the IG in the IDDM is in line with the view of Kernel Theory Fundamentalists (Gregor 2006; Gregor & Jones 2007; Walls et al. 1992), which emphasizes the development of an artifact that is founded on established concepts, such as IG.

The key building blocks of the IDDM and the relevant IG principles as its foundational governance are connected and systematically organized using ontology as a formal knowledge representation to form the IDDO. The development of the IDDO adheres to the Unified Ontological Approach (UOA), an alternative Ontology Development Method (ODM) developed by Ahadi et al. (2024b), derived from the synthesis of the strengths of existing ODMs and insights from the Business Model Ontology (BMO), where the BMO is the inspiration for this study, as previously mentioned.

Establishing the IDDO ensures a structured representation of essential concepts and knowledge within the IDDM, fostering a standardized and systematic approach. Furthermore, identifying these building blocks as core elements and IG as its foundational element strengthens the entire IDDO framework, resulting in a comprehensive and coherent structure. These elements collectively contribute to the creation of the IDDM, addressing research gaps and providing a reliable methodology to guide and facilitate the design of an information dashboard. The development of the IDDO using the UOA and it formalization utilizing Unified Foundational Ontology (UFO) will be elaborated comprehensively in Chapter 4.

3.4.4 Demonstration and Evaluation

Expanding on the demonstration and evaluation phase, the focus is on assessing the effectiveness of the IDDM through feedback from dashboard designers and domain experts. At this stage, mock-up dashboards for the Intelligent Monitoring Recycle System (i-MORSYS), a conceptual smart waste management system, will be showcased as instantiations of the IDDM framework. These mock-ups demonstrate the IDDM's practical application.

The evaluation process involves obtaining feedback via semi-structured interviews with the dashboard designers who used the IDDM to develop the mock-up dashboard and waste management experts to measure the effectiveness of the IDDM in addressing the identified problems. These feedback collections will be analyzed using thematic analysis to enable a comprehensive analysis of the IDDM's practical viability. Moreover, this stage aims to identify areas for refinement and optimization, ensuring the IDDM's adaptability and efficiency across various waste management scenarios. The integration of dashboard designer and domain expert feedback into the evaluation process aligns directly with the earlier phases, particularly the problem identification and the subsequent design and development stages. This approach ensures that the IDDM is developed not only to address the identified gaps but also undergoes rigorous assessment and refinement based on real-world feedback, strengthening its capacity to effectively resolve challenges in smart waste management and broader applications.

3.4.5 Communication

The development of the IDDM in this study is targeted to yield substantial benefits for dashboard designers, researchers, and industry practitioners. The findings from this study are disseminated through academic publications, professional magazines, and mainstream media to reach both academic and industry audiences. This deliberate sharing aims to enrich a broader audience and significantly enhance the knowledge base within the field. By providing comprehensive insights into the IDDM's development and implementation, these efforts seek to foster a deeper understanding and practical application among professionals and researchers operating within the dashboard design domain. This active dissemination not only contributes to collective knowledge but also plays a pivotal role in fostering the adoption and utilization of the IDDM by its intended audience. Through this communication strategy, the IDDM's impact and value within the domain are amplified, ensuring its relevance and practicality in addressing the challenges inherent in dashboard design for smart waste management and in universal context.

3.5 RESEARCH DESIGN DIAGRAM

Based on the discussion in Section 3.4, the entire process of this study is encapsulated in a research design diagram. This diagram is structured around the six processes delineated in the DSRM by Peffers et al. (2007), providing a streamlined overview of the study's trajectory.

The diagram comprises three interconnected components: the research process, key activities, and outputs. Each of these components plays a pivotal role and contributes significantly to the comprehensive understanding of the study.

The research process component is intrinsically anchored in the six processes of the DSRM. Each of these processes is meticulously designed to address a specific research question, thereby driving this study forward. Collectively, these six processes provide a systematic and comprehensive approach to conducting this study, ensuring that every aspect of the study is thoroughly examined and addressed. This systematic approach not only enhances the rigor of the study but also ensures its relevance and applicability.

The key activities component provides a succinct explanation of the activities involved in each DSRM process. This component outlines the steps taken to implement the research process, including tasks such as literature review, artifact design, and evaluation, among others. This provides insight into the practical aspects of conducting the research.

In the output component, the outcomes of each DSRM process and the associated activities are specified. These outputs represent the tangible results of this study, which includes the main artifact of this study - the IDDM.

Figure 3.8 presents the Research Design Diagram, offering a concise yet comprehensive view of the research flow, key activities involved, and the outputs produced throughout the study. This kind of visual representation has been used in other DSR-oriented research as well, serving as an effective way to convey methodological structure and logic (Bozkurt et al. 2025). Subsequently, each element within the diagram will be discussed in detail to provide a clearer understanding of the research process in its full complexity.

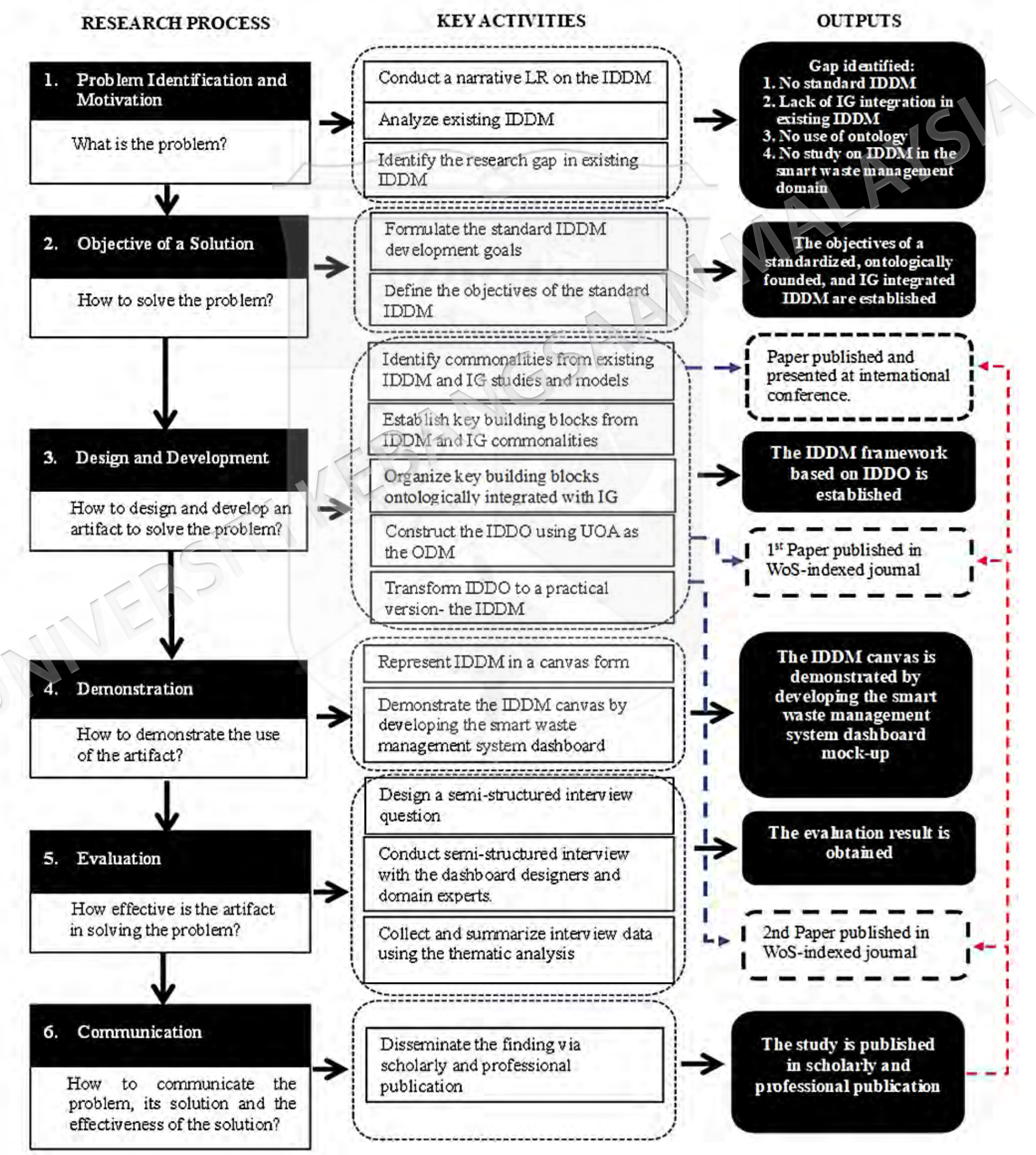

Figure 3.8 Research design diagram based on DSRM

The processes begin with Problem Identification and Motivation, the fundamental step of the DSRM process. This stage involves conducting a narrative literature review on the IDDM, analyzing existing IDDMs, and identifying research gaps in existing IDDMs. The key gaps identified are the absence of a standardized IDDM, lack of IG integration, no use of ontology, and no study applying IDDM in the smart waste management domain. The output of this stage is a clear definition of these critical research gaps.

Once this gap is identified, the subsequent step focuses on establishing the Objective of a Solution. This involves formulating the standard IDDM development goals and defining the objectives of the standard IDDM. This phase also introduces the integration of IG principles to ensure the framework is built on a strong governance foundation. The output is the establishment of objectives for a standardized, ontologically founded, and IG-integrated IDDM.

The third process is the Design and Development stage, the pivotal focus of this study. In this phase, the study's artifact, the IDDM framework, will be established. It begins by identifying commonalities from existing IDDM and IG studies and models, followed by establishing key building blocks from IDDM and IG commonalities. These building blocks are then organized ontologically and integrated with IG principles. The IDDO is constructed using UOA as the Ontology Development Method (ODM) and is subsequently transformed into a practical version- the IDDM canvas. The output of this stage is the establishment of the IDDM canvas based on IDDO.

Moving to the Demonstration stage, the IDDM is represented in a canvas form and demonstrated by establishing the smart waste management system dashboard mock-up. Semi-structured interview questions are also designed at this stage. The output is the IDDM canvas demonstrated by establishing the smart waste management system mock-up dashboard.

The subsequent phase is Evaluation, which involves conducting semi-structured interviews with dashboard designers and domain expert. The interview data is collected and summarized using thematic analysis. The output of this process will be the evaluation results obtained from the interviews.

Finally, the study's findings will be disseminated through scholarly and professional publications to ensure effective communication, a crucial final step within the DSRM framework, enabling a wider audience to be reached. The output is the publication of the study in scholarly and professional publications. A conference paper was published during the early Design and Development phase, while two comprehensive articles are targeted for publication in a Web of Science (WoS)-indexed journals at the advanced stages of this study.

3.6 SUMMARY

In summary, Chapter 3 extensively explores the research methodology employed in this study, the DSRM. The chapter is divided into two parts. The first part provides an overview of the DSRM, extensively discussing its six processes - problem identification and motivation, objective of a solution, design and development, demonstration, evaluation, and communication, as suggested by Peffers et al. (2007). The chapter then transitions to part two, delving into the application of the DSRM in the context of this study. The entire journey of applying the DSRM in this study is presented in a research design diagram depicted in Figure 3.8, offering a simplified view that maps out the entirety of the research process.

CHAPTER IV

TRANSFORMING ONTOLOGY INTO PRACTICAL APPLICATION: DESIGN AND DEVELOPMENT OF THE IDDM

4.1 INTRODUCTION

This chapter presents the core phase of the DSRM process, namely the Design and Development stage, where the primary artifact of this study, the ontologically founded IDDM Canvas is produced. According to the DSR process model proposed by Peffers et al. (2007), this third activity focuses on developing an innovative artifact to address the identified problem. In this study, the IDDM serves as that artifact, derived from the IDDO, and represents its practical implementation. The complete version of the IDDM will be presented at the advanced stage of this study.

The design and development process for the IDDO begins with selecting relevant elements from the commonalities identified in related works. These works have been thoroughly discussed in Chapter 2, specifically in Sub-section 2.6. The selected elements serve as the foundational building blocks of IDDO.

This approach aligns with arguments made by vom Brocke et al. (2020), Peffers et al. (2007), and Hevner (2004), who emphasize that the creation of an artifact in DSR often draws from existing solution elements. These elements are then combined, revised, and expanded upon to generate new design knowledge. The content of this chapter has also been published in Ahadi, Nik Habibullah, et al. (2025), explaining the development of the IDDO and IDDM Canvas as part of a governance-integrated, ontology-driven dashboard design method.

In this study context, the IDDO originates from the synthesis of related works by Lavalle et al. (2025);Pamuk and Schumann (2024); Poppe et al. (2024); Salvi et al. (2024); Conrow et al. (2023), Bach et al. (2023), Wu et al. (2021), Balletto et al. (2020), Pestana et al. (2020), Elshehaly et al. (2020), Young and Kitchin (2020), Syaiful et al. (2019), and Kokoç and Altun (2019). The commonalities found in these related works lead to the derivation of the essential building blocks of the IDDO. The following section provides a comprehensive discussion on deriving these key building blocks of the IDDO.

4.2 ESTABLISHING THE KEY BUILDING BLOCKS FOR IDDO

In determining the key building blocks of the IDDO, it is essential to refer to the second research objective outlined in Sub-section 1.6: *"To develop and standardize the IDDM to effectively guide the design and implementation of information dashboards."* This objective underscores the role of IDDM in supporting the development and implementation of such dashboards. Accordingly, the IDDO's key building blocks, later manifested as the IDDM are derived from common elements identified across various information dashboard design studies.

In subsection 2.6, the discussion on related works focuses on eight elements: 1. Application Domain; 2. Standard methodology; 3. Key phases; 4. Design principles; 5. Best practices; 6. Key features; 7. Modeling tools; and 8. Key outcomes. This is to gain an overview of what the related works on information dashboard design from various application domains entail. For the selection of the key building blocks of the IDDO, the commonalities among these elements are explored. However, in the pursuit of establishing the key building blocks, some elements, such as application domain, standard methodology, modeling tools, and key outcomes, are uncommon as they are exclusively relevant to the study context of each related work. Hence, this study delves into the commonalities in key phases, design principles, best practices, and key features to find the relevant building blocks for the IDDO.

The justification for selecting commonalities in key phases, design principles, best practices, and key features as the basis for forming the building blocks in the IDDO is rooted in the critical assessment of the literature and the focus on a common goal of the information dashboards design such as enhancing the functionality, user experience, and efficacy of information dashboards. The same approach of using commonalities to establish the building blocks and later organizing them using an ontology, which this study will employ, is solicited by Ashburner et al. (2000), Osterwalder (2004), Gallina and Szatmári (2016) , as well as recent works by Lei et al. (2022) and Schneider & Šimkus (2020). Although the studies from Ashburner et al. (2000) are in biology domain, Osterwalder (2004) in business domain, and Gallina and Szatmári (2016) in safety process domain, and the recent works are in the road asset management (Lei et al. 2022) and data management (Schneider & Šimkus 2020) domains respectively, the general principle of using commonalities in forming the building blocks and formally representing them using ontology is a proven approach. Table 4.1 below summarizes the basis of focusing on key phases, design principles, best practices, and key features from the related works to find the building blocks of the IDDO. Subsequently, the detailed discussion follows.

Table 4.1 The basis for establishing the building blocks involves focusing on key phases, design principles, best practices, and key features

Focus area	Basis
Key phases	• Procedural stages identified through research. • Essential for progression from conceptualization to deployment of a dashboard. • Represent a comprehensive and sequential guide to the design process.
Design principles	• Inform the aesthetic and functional aspects of dashboards. • Guide the visual representation of data and interface layout decisions. • Promote intuitiveness and accessibility.
Best practices	• Tried and tested methods for successful dashboard design and implementation. • Selected for their effectiveness across various domains and ability to address common design challenges. • Incorporated into the IDDO to enhance usability, functionality, and quality of dashboards.
Key features	• Constitute the core features and functionalities of a dashboard. • Selected for their critical role in tailoring the dashboard to organizational needs. • Include aspects such as information gist, interactivity, and real-time data representation.

4.2.1 Key Phases

All related works reviewed in subsection 2.6 elucidated that in developing the information dashboard, there are key phases involved. The key phases are procedural stages or the process flow where the design process commences until the information dashboard development is completed.

Although the key phases vary depending on the application domain of the information dashboard, some phases are common. These phases generally include problem identification as the initiation of the design process, followed by design and modeling, development and implementation, testing and evaluation, and iterative refinement through feedback. This pattern is consistently observed across the dashboard design literature (e.g., Lavelle et al. 2025; Salvi et al. 2024; Poppe et al. 2024; Pamuk & Schumann 2024; Bach et al. 2023; Balletto et al. 2020; Pestana et al. 2020; Young & Kitchin 2020; Elshehaly et al. 2020; Syaiful et al. 2019; Kokoç & Altun 2019).

The key phases in common identified from the related works are essential as they depicted the progression of the conceptualization until the deployment of the information dashboard. Based on many commonalities found in key phases elements, a comprehensive and sequential guide to the design process, this element is selected as one of the focus areas to look into in establishing the building blocks for the IDDO.

4.2.2 Design Principles

In the development of the IDDO, design principles are also one of the elements to be zoomed in. The related works reviewed in subsection 2.6 have highlighted that effective information dashboard design is also influenced by design principles.

Although there are varieties of the way the design principles are described in subsection 2.6, there are some design principles which are commonly applied in the information dashboard design works. Bach et al. (2023), Syaiful et al. (2019), and Kokoç and Altun (2019) emphasize the importance of simplicity and user-friendliness in the interface, which includes reducing the number of pages, optimizing screen space, and ensuring the system is easy to manage and control. Bach et al. (2023), Pestana et al. (2020), and Balletto et al. (2020) highlight the effective use of visual elements, where color should be used sparingly and with a specific purpose in mind, and visual elements should aid in data comparison and highlight points of interest. Lavelle et al. (2025) further reinforce these principles by introducing storytelling-based visualization, hierarchical structuring aligned with user decision-making processes, and interactive, user-centered design features to improve data interpretation and usability.

These commonalities in design principles are essential as they inform the aesthetic and functional aspects of dashboards, guide the visual representation of data and interface layout decisions, and promote intuitiveness and accessibility. They provide a comprehensive guide to the design process, ensuring that the information dashboard is not only functional but also user-friendly and effective. Therefore, based on the many commonalities found in design principles across the related works, this element is also selected as one of the focus areas to look into in establishing the building blocks for the IDDO. This approach ensures that the IDDO is grounded in proven design principles, enhancing its effectiveness and applicability across various application domains.

4.2.3 Best Practices

In subsection 2.6 the best practices in information dashboard design are also discussed and synthesized. Identifying the best practices is paramount as it is a tried and tested method in developing an effective information dashboard.

Similar to key phases and design principles, the best practices generally vary depending on the respective author’s perspectives. Nevertheless, some practices are commonly employed in the information dashboard design works. For instance, Bach et al. (2023), Pestana et al. (2020), and Kokoç and Altun (2019) emphasize the importance of the effective use of visual elements, consideration of user interaction (Bach et al. 2023; Elshehaly et al. 2020; Syaiful et al. 2019) and efficient information management (Bach et al. 2023; Wu et al. 2021). Lavelle et al. (2025) further contribute by demonstrating best practices such as guided storytelling to enhance user comprehension, hierarchical layout structuring to support user decision-making, and the integration of knowledge graphs to establish contextual clarity between dashboard elements.

These commonalities in best practices are essential to be considered in establishing the building blocks so that IDDO is in line with the good ways in the information dashboard design process and ultimately, it will enhance the overall usability, functionality, and quality of dashboards.

4.2.4 Key Features

The key features in the information dashboard design context constitute the core features and functionalities that a dashboard must possess to meet its intended objectives. Based on the discussion in subsection 2.6, there are a variety of key features found in the literature depending on the application domain of the information dashboard.

However, despite the variety, some key features are commonly available in the information dashboard across different domains. For instance, Bach et al. (2023), Pestana et al. (2020), and Kokoç and Altun (2019) emphasize the importance of effective use of visual elements, which includes using standalone components with clear axis labeling, legends, and high-resolution for effective data presentation, and helping users quickly and easily understand the data being presented. Bach et al. (2023), Pestana et al. (2020), and Kokoç and Altun (2019) also highlight the consideration of user interaction, which involves using interactivity to ensure visualization literacy, and ensuring that users can quickly and easily find the information they need on the dashboard without getting lost or confused. Lavelle et al. (2025) further emphasize key features such as hierarchical drill-down navigation, guided storytelling flow, and semantic structuring using knowledge graphs to support contextual understanding and decision-making. Their work also highlights the importance of interactive layouts and modular visual components to accommodate various user needs and analysis types.

The key features are essential elements in the information dashboard as they inform the aesthetic and functional aspects of dashboards, guide the visual representation of data and interface layout decisions, and promote intuitiveness and accessibility (Matheus et al. 2020; Sarikaya et al. 2019; Few 2006). Considering key features in establishing the building blocks of the IDDO is important for their critical role in tailoring the dashboard to organizational needs, such as information gist, interactivity, and real-time data representation.

Therefore, based on commonalities found in key features across the related works, this element is also selected as one of the focus areas to look into in establishing the building blocks for the IDDO. This approach ensures that the IDDO is grounded in proven key elements, enhancing its effectiveness and applicability across various application domains. This will ultimately lead to the creation of information dashboards that are not only functional but also user-friendly and effective.

In summary, subsections 4.2.1 to 4.2.4 briefly explain and justify the selection of key phases, design principles, best practices, and key features as the focus areas in finding the suitable building blocks of the IDDO. These four focus elements are the most relevant areas from Table 2.2 in subsection 2.6, as they consist of the commonalities of the information dashboard design works in the previous studies. The following chapter will comprehensively discuss the derivation of the building blocks and the key components of the IDDO.

4.3 THE COMMONALITIES

As discussed in the previous section, the key building blocks will be derived from the synthesis of commonalities among the key phases, design principles, best practices, and key features of related works on information dashboard design studies, which have been comprehensively discussed in subsection 2.6.

Inspired by the renowned BMO (Osterwalder 2004) framework, where the derivation of building blocks is from commonalities among a variety of business model elements, the IDDO mirrors a similar approach. The BMO has been globally recognized as an effective tool for designing a business enterprise model due to its simplicity, practicality, and effectiveness in guiding the formation of a complete business model (Holdford et al. 2022). This aligns with the noble objective of the IDDM, where it will serve as a tool to help those designing information dashboards to produce an effective and usable product.

The researcher in Ahadi et al. (2023) explored commonalities among design principles and best practices in information dashboard design studies. Their work represents the initial stage of this study, and the commonalities are gathered from the analysis and synthesis of related works, summarized in Table 2.2. The derivation of commonalities in their studies is crucial because it paves the way to unify information dashboard design, an important component in the development of the IDDO. The commonalities derived are summarized in Table 4.2 below:

Table 4.2 The summary of commonalities in design principles and best practices

Commonalities	
Design Principles	**Best Practices**
• Reduce pages • Optimize screen space • Use color purposefully • User-friendly interfaces • Effective data visualization • Tailored design approaches • Ensure accessibility • Simplify the design • Incorporate Gestalt's visual perception principles	• Reduce information overload • Balance information display • Provide context • Test and validate dashboards for quality assurance • Minimize visual effects • Purposeful use of color • Use diverse chart types to effectively present information • Use effective language and visualization techniques for improved comprehension • Reduce data selection overhead and automate selection for multiple charts • Use minimal graphical user interface (GUI) elements for effective interaction • Tailor best practices to the specific requirements of each domain • Create intuitive and visually appealing information dashboards • Deliver meaningful insights to users

The commonalities summarized in Table 4.2 above signify that, although many related works are being conducted in various application domains, there are shared design principles and best practices applied across the field of studies. However, in the context of this study, these two elements (design principles and best practices) are insufficient for developing an effective IDDO. Hence, as this study progressively evolves, two additional elements, namely key phases and key features in Table 2.2, are also examined to identify commonalities.

Taking the Business Model Canvas (BMC), an applicable version of the BMO by Osterwalder (2004), which is founded on common key phases and business elements, as a reference, the commonalities in key phases and key features are crucial. They will further strengthen the IDDO with the inclusion of a systematic development approach derived from key phases and features commonly available in any information dashboard. The summary of commonalities in key phases and key features analyzed and synthesized from Table 2.2 is presented in Table 4.3 below:

Table 4.3 The summary of commonalities in key phases and key features

Commonalities	
Key Phases	**Key Features**
• Problem identification • Design and modelling • Development and implementation • Testing and evaluation • Iterative process and feedback	• Visual display of important information • Interactive visual displays • Drill-down capabilities and data exploration • Presentation of analytical data insight

An overview of the commonalities in design principles, best practices (Table 4.2) and key phases, key features (Table 4.3) are depicted in Figure 4.1 below:

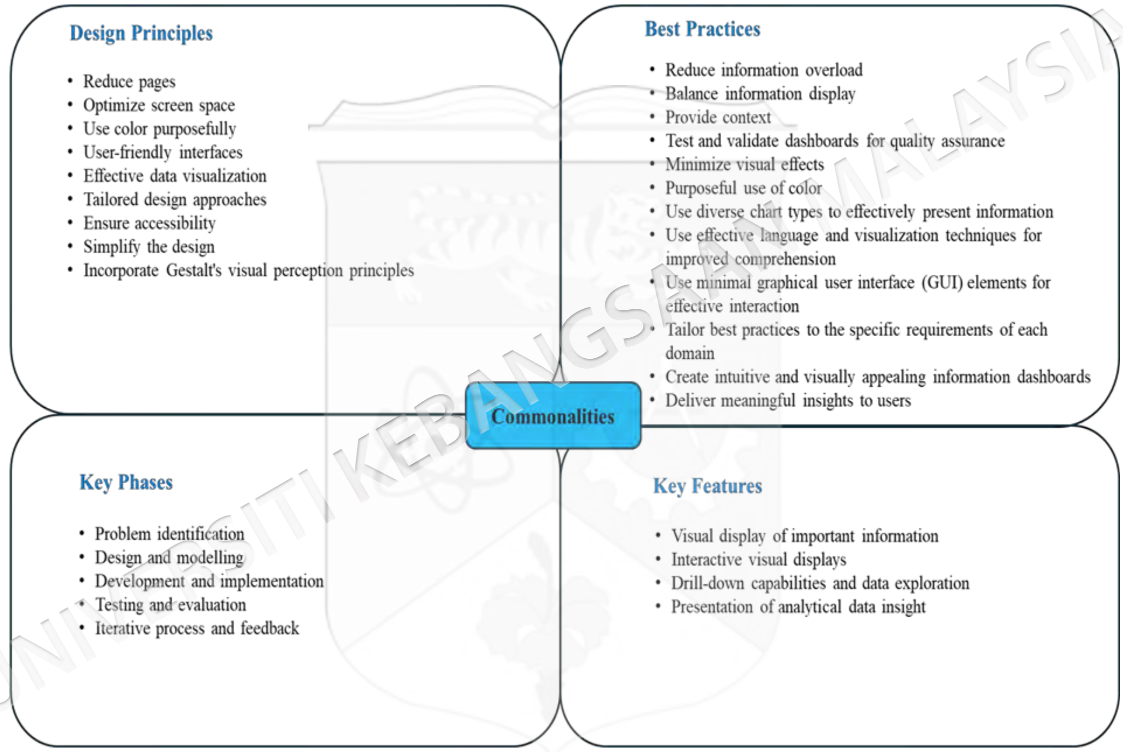

Figure 4.1 Combine view of commonalities of design principles, best practices, key phases and key features in the information dashboard

4.4 THE BUILDING BLOCKS

This subsection presents the "essence" of the IDDO – the building blocks. As previously explained, the derivation of these building blocks is based on four focus areas discussed in Section 2.6: design principles, best practices, key phases, and key features. In these four focus areas, numerous commonalities were identified across the application domain of information dashboard design studies (Lavelle et al. (2025); Pamuk & Schumann 2024; Poppe et al. 2024; Salvi et al. 2024; Conrow et al. 2023; Bach et al.

2023; Wu et al. 2021; Elshehaly et al. 2020; Pestana et al. 2020; Balletto et al. 2020; Young & Kitchin 2020; Syaiful et al. 2019; Kokoç & Altun 2019). These commonalities are summarized and depicted in Figure 4.1.

A crucial part of the development of IDDO is identifying the relevant commonalities as the building blocks. Drawing insight from Osterwalder's BMO, the building blocks are interrelated, allowing for the conception of a comprehensive business model (Osterwalder 2004). The BMO was later expanded into an "end user" version known as BMC (Osterwalder et al. 2010). It has now become a widely recognized tool to help startups and existing business owners develop and strategically formalize their business models. The masterpiece works by Osterwalder (2004) demonstrate the evolution of the BMO from a theoretical ontology framework into a practical version, the BMC.

Similarly, the IDDM, as an applicable version of the IDDO, serves as a design blueprint that enables dashboard developers to systematically plan, organize, and document all essential elements required for creating an effective and usable dashboard. Therefore, from this valuable insight into the BMO, the building blocks of the IDDO should be interrelated to drive the creation of the actual information dashboard.

The aspiration of making the IDDM function as a design and implementation planning template needs to be realized by choosing the most relevant commonalities as its building blocks. This will help the designers organize and visualize the dashboard's information, features, and flow before commencing the development of the fully functional information dashboard. Based on Figure 4.1, the 12 selected commonalities as key building blocks of the IDDO are depicted in Figure 4.2 below:

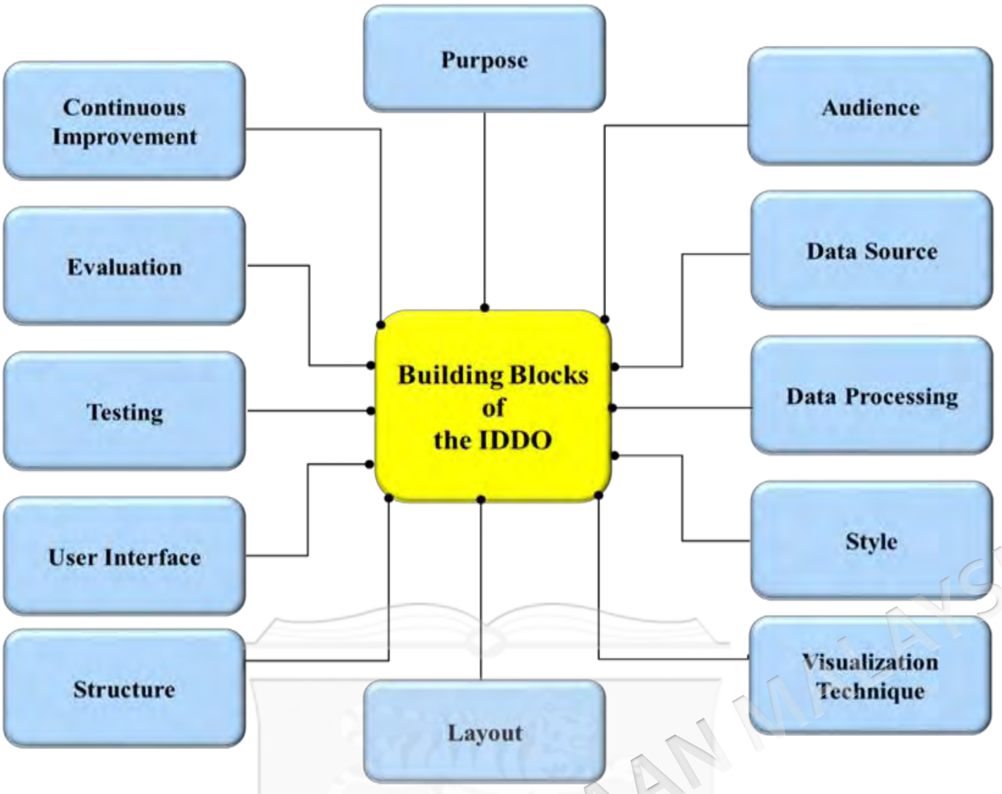

Figure 4.2 The key building blocks of the IDDO

The process of deriving the 12 building blocks is a complex task that requires meticulous consideration and numerous iteration cycles. The iterative processes, which are recurrent in nature, align with the behaviour of DSRM. This iteration ensures that the artifacts, which will be produced in the subsequent design phase, undergo a rigorous and relevant cycle.

Initially, eight building blocks were identified. During the early stages, some of these building blocks, such as ‘Purpose and Audience’ and ‘Layout and Structure’, were combined due to their perceived relevancies and similarities.

However, upon further reflection and drawing insights from the works of Guizzardi et al. (2022) and Noy and Mcguinness (2001), it became evident that each building block should be treated as a distinct entity. This is because each building block possesses a unique and distinct profile that sets it apart from the others.

Therefore, the initial approach of combining certain building blocks was reconsidered. The distinctness of each building block is crucial in maintaining the integrity of the ontology, as it ensures that each entity accurately represents a specific aspect of the domain of interest. This realization led to the final selection of 12 distinct building blocks, each contributing uniquely to the ontology. This approach aligns with the principles of ontology development, emphasizing the importance of clearly defined, distinct entities.

The 12 key building blocks of the IDDO as depicted in Figure 4.2 is summarized in Table 4.4 below. The relevant commonalities are used as the basis of the derivation to the building blocks. As the insight from the commonalities is not explicit and straightforward for the derivation, the terminology used as the building blocks is refined for easy comprehension and suited to the IDDO context without losing its original meaning.

Table 4.4 Derivation of key building blocks for the IDDO

The key building block	**Commonalities from where the building block is derived**	**Basis**
Purpose	• Problem identification. • Deliver meaningful insights to users. • Development and implementation.	• Purpose defines the problem the dashboard solves, setting the direction for its design. • Guides the delivery of meaningful insights to the user, ensuring the dashboard is valuable and effective. • Guides the entire development and implementation process, influencing decisions about features, layout, and user interface.
Audience	• Tailor best practices to the specific requirements of each domain. • User-friendly interfaces. • Tailor design approaches.	• Defines the specific users and stakeholders the dashboard serves. • Influences dashboard design and functionality to match user needs. • Ensures development of user-friendly interfaces tailored to end-users. • Guides customization of design approaches for different user groups. • Enhances dashboard relevance and usability through user-centric design
Data Source	• Drill-down capabilities and data exploration. • Presentation of analytical data insight.	• Determines the range and depth of information available for display. • Enables drill-down capabilities and data exploration features. • Provides the foundation for presenting analytical data insights.

to be continued…

…continuation

		• Influences the scope and accuracy of the dashboard's content.
Data Processing	• Reduce data selection overhead and automate selection for multiple charts. • Presentation of analytical data insight.	• Facilitates efficient handling and transformation of raw data. • Enables automation of data selection for multiple charts, reducing overhead. • Supports the generation of analytical insights from complex data sets. • Ensures data is prepared appropriately for visualization and analysis. • Ensures data quality and integrity throughout the processing pipeline, enhancing dashboard reliability.
Style	• Use color purposefully. • Minimize visual effects. • Create intuitive and visually appealing information dashboards.	• Guides the purposeful use of color to enhance data comprehension. • Ensures visual effects are minimized to focus on data presentation. • Contributes to creating intuitive and visually appealing dashboards. • Maintains consistency in visual design across the dashboard.
Visualization Technique	• Effective data visualization. • Use diverse chart types to effectively present information. • Visual display of important information.	• Determines how data is visually represented for effective communication. • Enables the use of diverse chart types to present information effectively. • Supports the visual display of important information in an engaging manner. • Enhances data interpretation and understanding through appropriate visual representations.
Layout	• Optimize screen space. • Balance information display.	• Guides the optimal use of screen space for information display. • Ensures a balanced arrangement of dashboard elements. • Facilitates logical grouping and positioning of related information. • Enhances overall dashboard readability and user navigation.
Structure	• Simplify the design. • Provide context.	• Defines the overall organization and hierarchy of dashboard elements. • Simplifies complex information by providing a clear, logical structure. • Provides context for data interpretation through thoughtful organization. • Supports intuitive navigation and understanding of dashboard components.
User Interface	• User-friendly interfaces.	• Facilitates easy access to dashboard features and functionalities.

to be continued…

…continuation

	• Use minimal graphical user interface (GUI) elements for effective interaction.	• Enhances overall user experience and dashboard usability. • Serves as the primary point of interaction between users and dashboard data, crucial for effective information access and interpretation.
Testing	• Test and validate dashboards for quality assurance. • Testing and evaluation.	• Validates data accuracy and visualization correctness. • Identifies and resolves usability issues before deployment. • Supports overall quality assurance of the dashboard. • Ensures dashboard functionality meets intended requirements.
Evaluation	• Testing and evaluation. • Deliver meaningful insights to users.	• Assesses the dashboard's effectiveness in delivering meaningful insights • Measures user satisfaction and dashboard performance. • Identifies areas for improvement. • Ensures the dashboard continues to meet evolving user needs and business objectives.
Continuous Improvement	• Iterative process and feedback. • Tailor best practices to the specific requirements of each domain.	• Facilitates ongoing refinement of the dashboard based on feedback and evaluation. • Allows for adaptation to changing user needs and business requirements. • Ensures the dashboard remains relevant and effective over time. • Incorporates lessons learned and best practices into future iterations. • Refines understanding of dashboard purpose and audience needs over time, creating a feedback loop for ongoing optimization.

4.4.1 Purpose

Establishing a clear purpose is of paramount importance in any information dashboard development work. "Purpose" is the first selected building block for the IDDO. It refers to the primary goal or objective that the dashboard is designed to achieve. purpose stems from problem identification, forming the foundation for the entire dashboard design process.

This building block is derived from key commonalities in dashboard design practices, including problem identification, the need to deliver meaningful insights to users, and the overarching process of development and implementation. The significance of setting a clear purpose is consistently mentioned across various works (Rasmussen et al. 2009; Sarikaya et al. 2019; Staron 2015; Toreini et al. 2022) . This emphasis is further underscored by Abduldaem and Gravell (2019), Roberts et al. (2017) and Few 2010), highlighting its critical role in dashboard design.

A clearly identified purpose guides the entire dashboard design and development process. It defines the problem the dashboard aims to solve, setting the direction for its design. Purpose also guides the delivery of meaningful insights to users, ensuring the dashboard is valuable and effective. Moreover, it influences decisions about features, layout, and user interface throughout the development and implementation process. As pointed out by Ahn et al. (2019), without a clear purpose, the dashboard may fail to provide meaningful insights to its audience, regardless of how excellently it is designed and developed.

Considering these points, it is justified to recognize purpose as a key building block of the IDDO. It serves as the foundational element that shapes all other aspects of dashboard design and development, ensuring that the final product aligns with its intended objectives and delivers value to its users.

4.4.2 Audience

The “Audience” in the context of the information dashboard refers to the intended users of the dashboard. Understanding the audience is crucial as it influences the design, complexity, and functionality of the dashboard. Understanding the audience is intrinsically linked to the purpose of an information dashboard and is equally crucial in the development process. This building block is derived from commonalities in best practices, including the need to tailor best practices to the specific requirements of each domain, create user-friendly interfaces, and tailor design approaches to specific user needs. The importance of understanding audience needs when designing the dashboard is consistently emphasized by many scholars (Abduldaem & Gravell 2019; Few 2010; Roberts et al. 2017; Sarikaya et al. 2019).

Knowing the audience is a critical initial stage that guides the entire dashboard design and development process. It defines the specific users and stakeholders the dashboard serves, influencing its design and functionality to match user needs. This understanding ensures the development of user-friendly interfaces tailored to end-users and guides the customization of design approaches for different user groups. By facilitating the adaptation of best practices to specific domain requirements, audience consideration enhances the dashboard's relevance and usability through user-centric design.

As Ahn et al. (2019) point out, overlooking user needs can undermine the objective of the information dashboard to provide insights, regardless of its design excellence. This user-centric approach is essential for creating dashboards that are not only well-designed but also effective and valuable to their intended users. Furthermore, understanding the audience informs decision-making on feature prioritization and information display, ensuring that the dashboard effectively meets the needs and expectations of its users.

Therefore, recognizing audience as a key building block of the IDDO is well-justified, given its fundamental role in shaping an effective and user-oriented dashboard design. It ensures that the resulting dashboard is not only technically sound but also highly relevant and useful to its intended users, maximizing its impact and value in real-world applications.

4.4.3 Data Source

Data serves as the cornerstone of an information dashboard (Sarikaya et al. 2019; Few 2010; Rasmussen et al. 2009). Data sources are a crucial building block of IDDO. They refer to the origins or repositories from which the dashboard obtains its information. These sources provide the raw data that is processed, analyzed, and ultimately visualized on the dashboard. This building block is derived from the “drill-down capabilities and data exploration” commonality. Data sources directly enable these features by providing the underlying information at various levels of detail. Without proper data sources, drill-down and exploration would be impossible. For example, hierarchical data sources allow users to navigate from summary to detailed views.

Another commonality that leads to the derivation of data sources as a key building block is the “presentation of analytical data insight”. Data Sources are fundamental to generating meaningful analytical insights. They provide raw materials that, when properly processed and analyzed, yield valuable information. For instance, comprehensive data sources allow for more robust and accurate trend analysis, whereas real-time data sources enable up-to-date insights and predictive analytics.

Clarifying the sources of data is a necessary step before proceeding to the next design and development stage. It is crucial to identify the source of data that will feed into the dashboard, in alignment with its purpose, and meet the audience's information needs. Therefore, data sources are selected as one of the key building blocks of IDDO.

4.4.4 Data Processing

“Data Processing” is the subsequent essential building block chosen for IDDO. It is a refined term within the IDDO context, derived from the commonalities of “reducing data selection overhead and automating selection for multiple charts” and “presenting analytical data insight”.

In the context of an information dashboard, “Data Processing” refers to the series of operations that are performed on raw data to prepare it for visualization (Rasmussen et al. 2009; Wexler et al. 2017). According to Rasmussen et al. (2009) and Wexler et al. (2017) this includes steps such as data collection, data cleaning, data transformation, and data aggregation.

Data processing typically commences following the establishment of a data source, guiding the methods used to process the data (Latif et al. 2021; Matheus et al. 2020; Few 2012). It comprises sequential steps that delineate how the data will be processed, including data collection and acquisition, data cleaning and processing, data visualization and reporting, as well as ensuring data security and privacy (Kelly et al. 2023; Matheus et al. 2020; Samrose & McDuf 2021).

The rationale for selecting “Data Processing” as a building block encompasses its role in facilitating efficient handling and transformation of raw data, enabling automation of data selection for multiple charts, supporting the generation of analytical insights from complex data sets, ensuring data is prepared appropriately for visualization and analysis, and maintaining data quality and integrity throughout the processing pipeline.

By elucidating the process through which data in the dashboard is processed, “Data Processing” enhances the effectiveness and utility of the dashboard, thereby justifying its inclusion as a building block of IDDO.

4.4.5 Style

The next chosen building block for the IDDO is “Style”. Style, in the context of the information dashboard, refers to the visual and interactive design choices that shape how information is presented to users. It includes a range of elements including colour schemes, typography, graphical elements, and an overall aesthetic approach. Style goes beyond mere aesthetics; it plays a crucial role in enhancing data comprehension, user engagement, and the overall effectiveness of the dashboard (Rasmussen et al. 2009). Few (2006) emphasizes the importance of thoughtful design in data presentation, stating that “A dashboard's appearance should support its functionality, not get in its way”. This underscores the idea that style should serve the dashboard's purpose rather than being purely decorative.

The inclusion of style as a key building block in the IDDO is derived from several commonalities in dashboard design best practices. Specifically, it stems from the principles of using color purposefully, minimizing visual effects, and creating intuitive and visually appealing information dashboards.

Style is informed by the dashboard's purpose, tailored to meet the needs of the audience, and constrained by the nature of the data sources and data processing methods employed. The purpose of the dashboard guide stylistic choices to ensure that the visual design supports the intended objectives. For instance, a dashboard designed for quick decision-making might employ a different style compared to one meant for detailed analysis. This shows the interconnection between “style” and the other building block in the IDDO.

The inclusion of style as one of the building blocks of the IDDO, ensures that aesthetic and functional considerations are integrated from the outset of the design process. This approach leads to dashboards that are not only informative but also engaging and easy to use, ultimately enhancing their effectiveness as decision-support tools.

4.4.6 Visualization Technique

"Visualization Technique" is a critical building block in IDDO. It is derived from the commonalities of "effective data visualization", "use of diverse chart types to effectively present information", and "visual display of important information". Visualization technique, in brief, refers to the methods used to visually represent data. The choice of visualization technique can closely influence how effectively the information is conveyed to the user. It plays a crucial role in enhancing data interpretation, understanding, and decision-making processes (Abduldaem & Gravell 2019; Sarikaya et al. 2019; Staron 2015). Different visualization techniques are suited to different types of data and different purposes. Therefore, the choice of technique is an important aspect of dashboard design.

In the IDDO context, once the purpose, audience, data sources, data processing and style have been established, the visualization technique is determined. This technique dictates the appearance and functionality of dashboards (Sedrakyan et al. 2019; Malamed 2015; Few 2012). Although the visualization technique varies depending on the purpose of the dashboard, it is a common discussion included in all related literature (Conrow et al. 2023; Bach et al. 2023; Balletto et al. 2020; Elshehaly et al. 2020; Pestana et al. 2020; Wu et al. 2021; Young & Kitchin 2020; Kokoç & Altun 2019; Syaiful et al. 2019) in subsection 2.6.

The basis for selecting "Visualization Technique" as a building block includes its role in determining how data is visually represented for effective communication. It enables the use of diverse chart types to present information effectively, supporting the visual display of important information in an engaging manner. Furthermore, visualization techniques enhance data interpretation and understanding through appropriate visual representations.

Visualization Technique is closely related to the “Style” building block. While Style sets the overall visual design principles, the Visualization Technique determines the specific methods of data representation. These two elements must work in harmony to create a cohesive and effective dashboard.

Therefore, the inclusion of “Visualization Technique” as a building block in IDDO is essential, as it specifies how data is visually presented and significantly influences both the aesthetic aspect and the functionality of the dashboard. It ensures that data is not just displayed but communicated in the most effective and meaningful way possible.

4.4.7 Layout

The next selected building block for the IDDO is “Layout”. In the context of an information dashboard, layout is about the physical arrangement and visual organization of dashboard elements on the screen. It encompasses how different components are spatially positioned and visually presented to the user (Rasmussen et al. 2009).

Layout serves as an essential building block in the design and development of information dashboards. It draws from commonalities in “optimize screen space” and “balance information display”. The layout is affected by visualization techniques(Jarke & Macgilchrist 2021; Ferdian 2019; Vazquez-Ingelmo et al. 2019), showing the relationship between these two building blocks.

This building block emphasizes the essential features of a dashboard, ensuring that it incorporates must-have functionalities aligned with the intended goals. The layout of the dashboard dictates how information is visually presented to users, influencing their ability to interpret data effectively and derive actionable insights (Alhamadi 2020; Kelly et al. 2023; Kuznetsova et al. 2021).

The basis for selecting layout as a building block includes its role in guiding the optimal use of screen space for information display, ensuring a balanced arrangement of dashboard elements, facilitating logical grouping and positioning of related information, and enhancing overall dashboard readability and user navigation.

The inclusion of layout as a building block underscores its importance throughout the dashboard development process, showing its progression from conceptualization to the deployment of the dashboard. It is a common topic discussed in information dashboard development studies (Bach et al. 2023; Sarikaya et al. 2019). Layout guides the arrangement of visual elements and interactive components, ultimately shaping the user experience and facilitating seamless interaction with the dashboard's content and is thus regarded as an important building block in the IDDO.

4.4.8 Structure

"Structure" is the next selected building block for the IDDO. Derives from the commonalities "Simplify the design" and "Provide context", it refers to the overall organization and hierarchy of elements within the dashboard. It defines how different components are logically grouped, categorized, and related to each other (Janes et al. 2013; Rasmussen et al. 2009).

This building block ensures that the dashboard incorporates a logical organization aligned with the intended goals. The structure of the dashboard determines how information is organized, influencing users' ability to navigate through data effectively and derive meaningful insights (Few 2010; Jarke & Macgilchrist 2021; Wexler et al. 2017).

The basis for selecting Structure as a building block includes its role in defining the overall organization and hierarchy of dashboard elements, simplifying complex information by providing a clear, logical structure, providing context for data interpretation through thoughtful organization, and supporting intuitive navigation and understanding of dashboard components.

The addition of structure as one of the building blocks of the IDDO is vital as it guides the logical organization of dashboard components and navigational aids, shaping how users interact with and understand the dashboard's content, thus making it a crucial building block in the IDDO.

4.4.9 User Interface

User interface is another selected building block for IDDO. Rooted in commonalities of “User-friendly interfaces” and “Use minimal graphical user interface (GUI)”, it is refined as a “User Interface” for the IDDO context. User interface refers to the space where interactions between humans (users) and the dashboard occur. This includes all the controls, buttons, blocks, and elements of the dashboard that allow users to interact with the data being displayed (Few 2003; Rasmussen et al. 2009; Wexler et al. 2017).

The basis of selecting “User interface” as another building block of the IDDO is because it facilitates easy access to dashboard features and functionalities more importantly, it enhances overall user experience and dashboard usability.

Distinct from layout and structure, the user interface is tailored to develop interactive design features that engage and empower users to explore data and derive insights effectively (Alhamadi et al. 2022; Ferdian 2019). User interface is interrelated to layout and structure. The selection of layout and structure will impact the user interface and it goes beyond mere arrangement and organization, focusing on how users interact with the dashboard's interface to extract meaningful information.

This building block is instrumental in creating an intuitive and user-friendly interface that facilitates seamless interaction with the dashboard's content. The inclusion of the user interface as a building block is important in driving user interaction and enabling users to leverage the full potential of the dashboard to gain insights and make informed decisions (Toreini et al. 2022; Yap 2020; Ahn et al. 2019).

4.4.10 Testing

Testing, the next selected building block is a common best practice in dashboard design and development projects (Abduldaem & Gravell 2019; Han et al. 2021). In the context of information dashboards, testing refers to the systematic process of validating the dashboard's functionality, data accuracy, and usability before deployment (Rasmussen et al. 2009; Wexler et al. 2017). It is a critical phase that ensures the dashboard meets its intended requirements and performs as expected.

Testing is derived from the commonalities of “test and validate dashboards for quality assurance” and “testing and evaluation” in dashboard design best practices. The basis for including testing as a building block in the IDDO includes its role in validating data accuracy and visualization correctness, identifying and resolving usability issues before deployment, supporting overall quality assurance of the dashboard, and ensuring dashboard functionality meets intended requirements (Rasmussen et al. 2009; Wexler et al. 2017).

By including testing as a building block of IDDO, it helps the designer validate the information dashboard for quality assurance and deliver meaningful insights to users. It is a proven method for successful dashboard design, aiming to improve usability, functionality, and overall quality, thereby ensuring effective implementation.

From a usability engineering perspective, testing play a vital role in assessing the usability and usefulness of the dashboard. Through rigorous testing processes, designers evaluate how well the dashboard meets user needs and expectations, identifying any usability issues or shortcomings in functionality (Almasi et al. 2023; Hertzum 2020).

4.4.11 Evaluation

The next crucial building block is the evaluation. Evaluation in the context of information dashboards refers to the ongoing process of assessing the dashboard's effectiveness, performance, and ability to meet user needs and business objectives (Almasi et al. 2023; Rasmussen et al. 2009; Wexler et al. 2017). It involves gathering and analyzing feedback from users and stakeholders to identify areas for improvement and ensure the dashboard's continued relevance and value.

Evaluation is derived from the commonalities of “testing and evaluation” and “deliver meaningful insights to users” in dashboard design practices. The basis for including evaluation as a building block in the IDDO includes its role in assessing the dashboard's effectiveness in delivering meaningful insights, measuring user satisfaction and dashboard performance, identifying areas for improvement, and ensuring the dashboard continues to meet evolving user needs and business objectives.

Similar with testing, evaluation is a proven method for successful dashboard design, aiming to improve usability, functionality, and overall quality, thereby ensuring effective implementation (Abduldaem & Gravell 2019; Han et al. 2021). It allows designers to gather valuable feedback from users and stakeholders, providing insights into how the dashboard performs in real-world scenarios and where improvements can be made.

By incorporating evaluation as a building block, designers emphasize the importance of continuous improvement and adaptation to changing user needs and business requirements.

4.4.12 Continuous Improvement

The last selected building block for the IDDO is “Continuous Improvement”, which derives from the commonalities of “iterative process and feedback” and “tailor best practices to the specific requirements of each domain” in dashboard design practices. In the context of information dashboards, continuous improvement refers to the ongoing, iterative process of refining and enhancing the dashboard's design, functionality, and effectiveness based on user feedback, changing requirements, and evolving best practices (Few 2010; Rasmussen et al. 2009; Wexler et al. 2017). It is a dynamic approach that ensures the dashboard remains relevant, useful, and aligned with user needs and business objectives over time.

The basis for including continuous improvement as a building block in the IDDO is multifaceted. It facilitates ongoing refinement of the dashboard based on feedback and evaluation, allowing for adaptation to changing user needs and business requirements. This process ensures the dashboard remains relevant and effective over time. Moreover, it incorporates lessons learned and best practices into future iterations, creating a feedback loop for ongoing optimization. Importantly, it refines the understanding of dashboard purpose and audience needs over time, ensuring that the dashboard continues to align with its core objectives.

Unlike testing and evaluation, which are typically discrete processes conducted at specific points in the development lifecycle, continuous improvement is an ongoing, iterative approach that permeates every stage of dashboard design. It involves regularly evaluating the dashboard's usability and usefulness, collecting feedback from users, and identifying areas for improvement (Jarke & Macgilchrist 2021; Abduldaem & Gravell 2019).

The selection of continuous improvement as a building block is vital to ensure the quality and usefulness of the dashboard to audiences. It is driven by the testing and evaluation building blocks, with a focus on improving usability, functionality, and overall quality over time to ensure effective implementation. This approach allows for the tailoring of best practices to the specific requirements of each domain, ensuring that the dashboard remains optimally suited to its particular context and use case.

By including continuous improvement as a building block, the IDDO becomes a comprehensive method that encourages an ongoing process of refinement and enhancement. This ultimately leads to dashboards that are more user-friendly, useful, and impactful in facilitating data-driven decision-making. It ensures that the dashboard design process is not a one-time effort but a continuous journey of improvement and adaptation, keeping pace with changing user needs, technological advancements, and evolving business requirements.

4.4.13 Conclusion

Through the identification of 12 key building blocks, the IDDO offers a structured approach to the dashboard design and development process. Purpose, audience, data source, data processing, style, visualization technique, layout, structure, user interface, testing, evaluation and continuous improvement form the core elements of the IDDO. By integrating these key building blocks into the IDDO which will later presented as the IDDM, designers are equipped with a robust methodology that facilitates the creation of impactful and user-friendly information dashboards. This approach not only enhances the user experience but also empowers decision-makers with valuable insights for informed decision-making. The next section will discuss grouping these building blocks into a few categories for a better understanding.

4.5 CATEGORIZING THE BUILDING BLOCKS

As briefly discussed in subsection 2.4.3, the IDDM will be developed using an ontological approach. In this study, the IDDO framework, which forms the backbone of the IDDM, will be established. The IDDO is made up of 12 building blocks that have been comprehensively discussed in the previous section. The IDDO will depict the interrelation among each building block.

Osterwalder (2004) employed a similar approach when he established the BMO to formally represent the nine building blocks derived from common business elements. Similarly, Stancin et al. (2020) and Nie et al. (2023) utilized ontology in describing commonly used curriculum modeling and management in the education domain, as well as defining and characterizing demonstration environments in the context of innovation management.

To better understand and utilize the IDDO framework, the 12 identified key building blocks will be categorized. This process aligns with the principles of ontology development, which include defining classes (the key building blocks in this study context), arranging them in a hierarchy if applicable, and establishing their interrelationships (Parlar 2019; Pittet et al. 2012; Noy & Mcguinness 2001). Osterwalder (2004) did the same for the BMO when the nine key building blocks were categorized into four main categories: Product, Customer Interface, Infrastructure Management, and Financial Aspects.

In line with the second objective of this study – "*To develop standardized, domain-independent, ontology-based and governance-aware IDDM that effectively guides the design and implementation of information dashboards",* the categorization of the building blocks of the IDDO is established like stages of the design process to provide a logical and structured approach (Gupta 2023; Nie et al. 2023; Rösch et al. 2023) to guide the information dashboard design work. The suggested categories are defining and planning, design and visualization, and testing and improvement. Table 4.5 below summarizes the categorization of the eight building blocks:

Table 4.5 Categorization of the building blocks

Category		
Defining and Planning	**Design and Visualization**	**Testing and Improvement**
Building Blocks		
• Purpose • Audience • Data Source • Data processing	• Style • Visualization Technique • Layout • Structure • User Interface	• Testing • Evaluation • Continuous improvement

4.5.1 Defining and Planning

Defining and planning constitute the first category of the IDDO's building blocks. As outlined in Table 4.5, this category comprises four building blocks: purpose, audience, data source, and data processing. Defining and planning are common initial stages of any design process, as evidenced by the related works (Lavelle et al. 2025; Poppe et al. 2024; Pamuk & Schumann 2024; Salvi et al. 2024; Conrow et al. 2023; Bach et al. 2023; Balletto et al. 2020; Elshehaly et al. 2020; Pestana et al. 2020; Wu et al. 2021; Young & Kitchin 2020; Kokoç & Altun 2019; Syaiful et al. 2019) listed in Table 2.2, all of which commence with these stages. The defining and planning category is paramount as it will shape the entire development of the information dashboard.

4.5.2 Design and Visualization

The second category of the IDDO is "design and visualization". This is the "heart" of the IDDO as the entire development process of the information dashboard will be built here. As outlined in Table 4.5, this category comprises five building blocks: style, visualization technique, layout, structure, and user interface. Design and visualization are also common stages of any design process, usually taking place after defining and planning, as evidenced by the related works (Lavelle et al. 2025; Poppe et al. 2024; Pamuk & Schumann 2024; Salvi et al. 2024; Conrow et al. 2023; Bach et al. 2023; Balletto et al. 2020; Elshehaly et al. 2020; Pestana et al. 2020; Wu et al. 2021; Young & Kitchin 2020; Kokoç & Altun 2019; Syaiful et al. 2019) listed in Table 2.2, all of which involve these processes. This is further supported by other literature on dashboard design (Alhamadi 2020; Sarikaya et al. 2019; Vazquez-Ingelmo et al. 2019).

In essence, design and visualization are about creating a visually appealing, intuitive, and user-friendly dashboard. It takes the processed data from the defining and planning stage and presents it in a way that maximizes its value for the end-users, showing its interrelation.

4.5.3 Testing and Improvement

The final category of IDDO's building blocks is testing and improvement, which includes three building blocks: testing, evaluation, and continuous improvement. This category completes the categorization of the IDDO building blocks and is crucial in ensuring the usability of the IDDO.

In the testing and evaluation building blocks, it involves evaluating the usability and usefulness of the dashboard, as suggested by best practices in the related works (Lavelle et al. 2025; Poppe et al. 2024; Pamuk & Schumann 2024; Salvi et al. 2024; Conrow et al. 2023; Bach et al. 2023; Balletto et al. 2020; Elshehaly et al. 2020; Pestana et al. 2020; Wu et al. 2021; Young & Kitchin 2020; Kokoç & Altun 2019; Syaiful et al. 2019). It requires collecting feedback from users to identify areas for improvement. From a design and usability engineering perspective, it's also regarded as best practice to incorporate iterative testing throughout the development process (Almasi et al. 2023; Hertzum 2020).

Under continuous improvement, this building block is about defining a strategy for updating and enhancing the dashboard to maintain its relevance and value. This best practice involves establishing a feedback loop with users to continuously gather insights on their needs and challenges. This information is then utilized for incremental enhancements of the dashboard, ensuring that changes align with user expectations.

In conclusion, the testing and improvement category ensures that the dashboard remains effective, relevant, and valuable over time. It involves a continuous process of evaluation and enhancement, guided by user feedback and industry best practices.

4.5.4 Conclusion

Based on the above discussion, the categorization of the building blocks within the IDDO into three distinct categories: defining and planning, design and visualization, and testing and improvement - provides a structured framework aligned with the principles of ontology development. This framework, akin to stages of a design process, offers a logical progression to effectively guide the design and implementation of information dashboards. By systematically organizing the key components of the IDDO, it facilitates a comprehensive understanding of their interrelationships, echoing established practices in related domains such as business modeling and education management. Furthermore, the testing and improvement category ensures the ongoing usability, relevance, and value of the dashboard through iterative evaluation and continuous enhancement, thereby emphasizing the importance of user feedback and industry best practices in maintaining dashboard effectiveness over time. The summary of the category, its building blocks, and its description are summarized in Table 4.6. The next section will discuss the integration of IG principles as the foundation of the IDDO.

Table 4.6 The summary of the category, its building blocks, and its description

Categorization	Building Blocks	Description
Defining and Planning	• Purpose	Defining the primary objectives and goals of the dashboard.
	• Audience	Identifying and characterizing the intended users and their specific needs.
	• Data Source	Determining the origins and types of data that will populate the dashboard.
	• Data Processing	Outlining methods for cleaning, transforming, and preparing data for visualization.
Design and Visualization	• Style	Establishing the visual design principles and aesthetic guidelines for the dashboard. (e.g., color schemes, typography, and overall visual theme).
	• Visualization Technique	Selecting appropriate methods for representing data visually and effectively.
	• Layout	Planning the spatial arrangement of dashboard elements on the screen.
	• Structure	Organizing the logical hierarchy and relationships between dashboard components.
	• User Interface	Designing interactive elements that facilitate user engagement and data exploration.

to be continued…

…continuation

Testing and Improvement	• Testing	Validating the dashboard's functionality, accuracy, and usability.
	• Evaluation	Assessing the dashboard's effectiveness in meeting user needs and objectives.
	• Continuous Improvement	Implementing strategies for ongoing refinement and enhancement of the dashboard.

4.6 IG AS THE FOUNDATION OF IDDO

This section builds upon the preliminary work published in Ahadi et al. (2025a), where relevant IG principles were derived to support the development of an ontologically grounded IDDO. As elaborated in Section 3.4.3, the inclusion of IG will further reinforce the IDDO framework and adhere to the Kernel Theory Fundamentalism's perspective, which emphasizes the development of an artifact founded on established concepts (Gregor 2006; Gregor & Jones 2007; Walls et al. 1992). This study aims to incorporate IG as the cornerstone of IDDO, distinguishing it from the BMO which does not explicitly mention the application of a Kernel Theory.

The crux of any information dashboard lies in its data. The accuracy, reliability, and security of the data displayed on any information dashboard are of utmost importance. These three aspects are critically significant; failure to maintain them can lead to confusion, misinformation, and deception (Cairo, 2019; Correll et al., 2020).

At this stage of the study, there is a noticeable absence of research directly linking IG and information dashboards. This gap is one of the significant areas that this study aims to address. This section will identify the relevant IG principles for IDDO to be integrated as its foundational governance. These derivations will be based on a synthesis of established IG models and insights from previous studies and will be linked to the commonalities of design principles to ensure their relevance and applicability to the information dashboard design context. These relevant IG principles will be integrated with the 12 IDDO building blocks discussed in the previous section.

4.6.1 An Overview of the Established IG Model

Building upon the comprehensive review of three established IG models: Information Governance Reference Model (IGRM), Information Governance Implementation Model (IGIM), and Information Governance Maturity Model (IGMM) - presented in Section 2.3.3 of Chapter 2, this section focuses on synthesizing these models in developing the IDDO. In essence, these three IG models - IGRM, IGIM, and IGMM - each with a unique focus and scope, are widely used and serve different purposes within IG initiatives. It is essential to comprehend the advantages and constraints of each IG model to effectively incorporate them into the IDDO.

The IGRM prioritizes stakeholder cooperation to ensure that dashboards are created with input from all relevant parties, hence improving their usefulness and significance. The organized methodology of the IGIM ensures that governance principles are methodically integrated into the process of designing the dashboard. The IGMM prioritizes the evaluation of maturity to enhance the ongoing improvement of dashboard functionality and data accuracy.

From the synthesis of these three IG models, it can be inferred that there are nine common IG principles covering a broad range of essential aspects, from ensuring data security and compliance with regulations to maintaining data quality and achieving desired outcomes. Table 4.7 below provides a concise explanation of these shared IG principles.

Table 4.7 Summary of shared characteristics of the IGRM, IGIM and IGMM

IG Model	Main Focus	Common IG Principles	Brief Explanation
Information Governance Reference Model (IGRM)	Encourages cross-functional collaboration among key stakeholders to create a unified IG framework	1. Compliance 2. Protection/Security 3. Integrity 4. Availability 5. Retention 6. Transparency 7. Accountability 8. Quality 9. Effectiveness	These principles are standard for effective IG, ensuring cross-functional cooperation and a unified framework.

to be continued…

…continuation

Information Governance Implementation Model (IGIM)	Practical IG implementation guide with detailed guidelines and resources for measuring and benchmarking IG performance	1. Compliance 2. Protection/Security 3. Integrity 4. Availability 5. Retention 6. Transparency 7. Accountability 8. Quality 9. Effectiveness	These principles are widely applicable as they offer a pragmatic approach to implementing IG, with an emphasis on assessing and comparing IG performance.
Information Governance Maturity Model (IGMM)	Assesses and improves IG maturity, providing a structured approach to continuous improvement	1. Compliance 2. Protection/Security 3. Integrity 4. Availability 5. Retention 6. Transparency 7. Accountability 8. Quality 9. Effectiveness	These principles are widely applicable as they prioritize the evaluation and enhancement of the maturity level of information governance practices, offering a systematic method for ongoing improvement.

Synthesizing the insights from the relevant principles of these models will ensure the IDDO is built upon a solid foundation of reliable data, adheres to information quality standards, provides valuable insights to users, and maintains compliance with data security and privacy regulations.

The next section will discuss the diversification of IG principles from previous studies. This exploration is crucial as it will help us understand how IG principles have been adapted and applied in various contexts, providing valuable insights for tailoring these principles specifically to information dashboard design. By examining this diversification, it can ensure that the application of IG principles to IDDO is both comprehensive and relevant to the unique challenges of dashboard design and implementation.

4.6.2 An Overview of Diversification in IG Principles

A review of works related to IG reveals that the IG principles and their application vary, depending on the objective and the context in which they are utilized. Liu et al. (2022) further noted that different organizations may adopt distinct IG principles, standards, and regulations, as well as IG model frameworks suited for various aims and application scenarios. Many IG principles have been documented in several previous studies (Datta et al. 2019; Lomas 2019; Azman et al. 2019; Nordiana et al. 2022; Mukherjee 2019;

Rouzbahani et al. 2020). All these studies discussed IG in different applications and scenarios which proves the universal applicability of the IG across any domain. Although at this point of the study, there were no studies linking IG and information dashboards, the universality of IG applications suggests that it is also relevant and applicable to the context of information dashboard design. The IG principles identified in the previous studies are summarized in Table 4.8 below:

Table 4.8 Summary of the IG principles in the previous study

Study	**Title**	**Domain Application**	**IG Principles**
Nordin et al. (2022)	Information Governance for Enhancing the Performance of Higher Education Institutions	Higher Education	Policy Compliance, Risk Management, Data Classification, Information Quality, and Security
Rouzbahani et al. (2020)	Developing a Model for National Health Information Governance Program in Iran	National Health Information	Information Resource Management, Security, Privacy, Accountability, Trust, Access and Use, Resource Management, Information Organization, Governance Provision, Leadership
Datta et al. (2019)	Information Governance: A Necessity in Today's Business Environment	Business	Governing Employee Performance, Adhering to Regulations, Evaluating Policy Effectiveness, Creating IG policies, Governing Contractors and Workers, responsibility handling, enabling eDiscovery, and utilizing technological updates.
Azman et al. (2019)	Managing Evidence of Public Accountability: An Information Governance Perspective	Public Accountability	Accountability, Responsibility, Responsiveness, Participation, Information Quality, Information Value, Information Compliance, and People
Lomas (2019)	Information Governance and Cybersecurity: Framework for securing and managing information effectively and ethically	Cybersecurity	Information Management, Privacy, Cybersecurity, Ethical Delivery, Compliance with Laws and Regulations, and Stakeholder Needs
Mukherjee (2019)	Information Governance for the Implementation of Cloud Computing: A Review	Cloud Computing	Compliance, Business Objectives, Collaborative Contracts, Change Management, and Constant Improvement

Table 4.8 illustrates that each study presents distinct IG principles, reflecting the unique needs and contexts of their respective domains. In their study on higher education, Nordin et al. (2022) identified several IG principles, including Policy Compliance, Risk Management, Data Classification, Information Quality, and Security. These principles highlight the importance of institutions following policies, mitigating risks, categorizing data, guaranteeing information accuracy, and safeguarding information (Nordin et al. 2022).

Rouzbahani et al. (2020) highlighted several key principles in the field of healthcare, including Information Resource Management, Security, Privacy, Accountability, Trust, Access and Use, Resource Management, Information Organization, Governance Provision, and Leadership. The principles emphasize the significance of effectively handling information resources, guaranteeing security and privacy, taking responsibility, establishing trust, regulating access and usage of information, structuring information, implementing governance, and exhibiting leadership (Rouzbahani et al. 2020).

In the corporate setting, Datta et al. (2019) have identified key principles including managing employee performance, complying with regulations, assessing policy effectiveness, establishing IG policies, overseeing contractors and workers, handling responsibilities, facilitating eDiscovery, and leveraging technological advancements. These principles emphasize the need of businesses managing employee performance, complying with rules, assessing the effectiveness of policies, establishing IG policies, overseeing contractors and workers, fulfilling duties, facilitating eDiscovery, and incorporating technology advancements (Datta et al. 2019).

Azman et al. (2019) put up a set of principles in the field of public accountability, including Accountability, Responsibility, Responsiveness, Participation, Information Quality, Information Value, Information Compliance, and People. The principles emphasize the importance of accountability, responsibility, responsiveness, participation, information quality, information value, information compliance, and people (Azman et al. 2019).

Lomas (2019) recognized several key principles in the field of cybersecurity, including Information Management, Privacy, Cybersecurity, Ethical Delivery, Compliance with Laws and Regulations, and Stakeholder Needs. The principles underscore the importance of managing information, safeguarding privacy, ensuring cybersecurity, delivering ethically, according to laws and regulations, and addressing the demands of stakeholders (Lomas 2019).

In the cloud computing domain, Mukherjee (2019) proposed principles like Compliance, Business Objectives, Collaborative Contracts, Change Management, and Constant Improvement. These principles highlight the importance of compliance, aligning with business objectives, having collaborative contracts, managing change, and constantly improving (Mukherjee, 2019).

In summary, it can be concluded that there are various principles of IG, with each domain adopting relevant IG principles to suit their unique needs. Data Classification is specific to higher education (Nordin et al. 2022), Trust is specific to the national health information domain (Rouzbahani et al. 2020), Governing Employee Performance is specific to the business environment (Datta et al., 2019), Responsiveness is specific to the public accountability sector (Azman et al. 2019), Ethical Delivery is specific to the cybersecurity domain (Lomas 2019), and Business Objectives is specific to the cloud computing domain (Mukherjee 2019). This highlights the significance of adopting context-specific IG principles and this insight further suggests that IDDO should also adopt the relevant IG principles related to the information dashboard context.

4.7 DERIVATION OF RELEVANT IG PRINCIPLES AS THE FOUNDATIONAL GOVERNANCE OF THE IDDO

The derivation of IG principles as the foundational governance of the IDDO is not straightforward. This complexity arises from the lack of existing studies linking IG with information dashboards. Additionally, an analysis of three established IG models and previous IG studies reveals that IG principles and their applications vary based on the context and objectives of their implementation. The primary challenge, therefore, is to identify the relevant IG principles for the IDDO from the diverse range of IG principles recognized across various domains.

A method for deriving relevant IG principles for the IDDO is established by linking the diversification of IG principles to common design principles. The selection of these principles is guided by two key components: (1) the synthesis of three established IG models and insights from prior studies, which reflect the diverse applications and contextual variations of IG principles, and (2) commonly recognised design principles identified in prior study conducted by the researcher. By linking these diverse IG principles with common design principles, relevant IG principles for the IDDO can be derived. The selected IG principles, based on the commonalities in design principles, will help ensure that these design principles are adhered to during the information dashboard design and development process. This approach is illustrated in Figure 4.3 below.

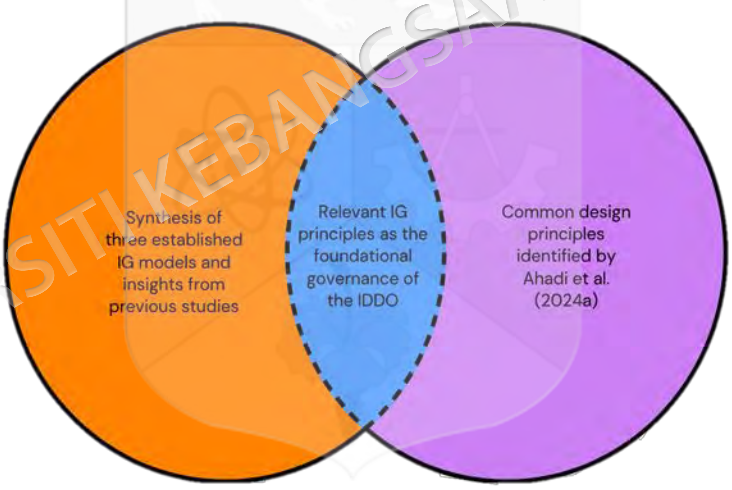

Figure 4.3 Components for the derivation of IG Principles for IDDO

The eight identified commonalities in design principles are depicted in Figure 4.4 below:

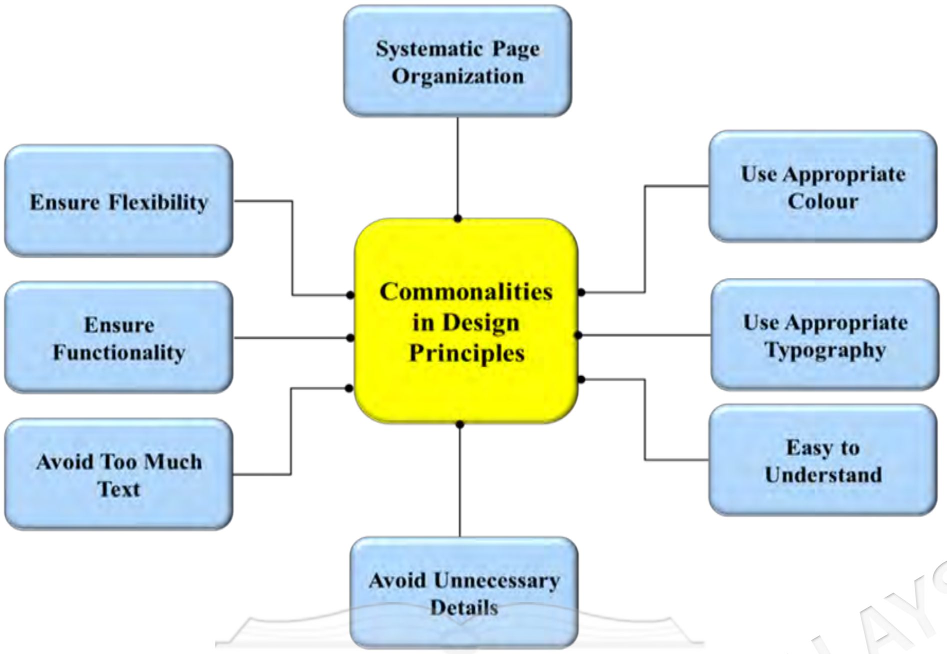

Figure 4.4 Commonalities in design principles

The identification of these commonalities in design principles as depicted in Figure 4.4 highlights the possibility of a more efficient and cohesive method for designing information dashboards. To adhere to these design principles, IG can play a significant role as the governance foundation. Therefore, within the scope of this study, these widely recognized design principles will be linked with the synthesis of three established IG models - namely IGRM, IGIM, and IGMM, and insights from previous studies as the basis for deriving the relevant IG principles to be integrated as the foundational governance of the IDDO.

Based on the commonalities identified across these design principles, eight IG principles relevant to the information dashboard context are proposed as the foundational governance for the IDDO. These IG principles are illustrated in Figure 4.5.

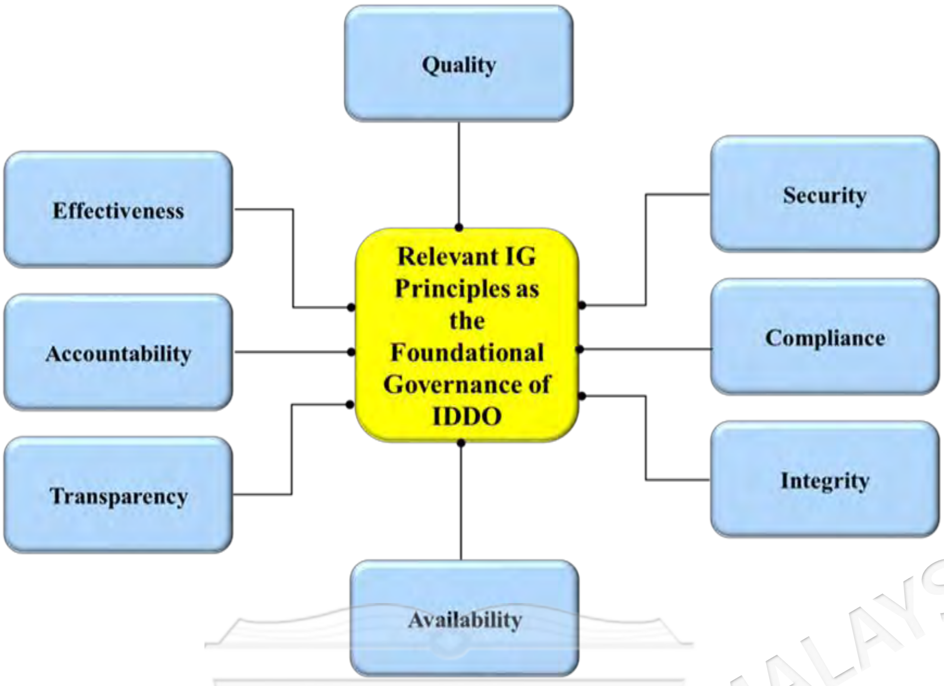

Figure 4.5 Suggested relevant IG principles as the foundational governance of the IDDO

Further to Figure 4.5 above, a concise overview of the derivation of these IG principles, the common design principles they align with, and a brief explanation in Table 4.9 below:

Table 4.9 The proposed IG principles, the common design principles they align with, and a brief explanation

Proposed IG Principles	**Alignment with Common Design Principles**	**Brief Explanation**
Quality	Easy to understand, Avoid unnecessary details	Ensures that the data presented on the dashboard is accurate, reliable, and timely, forming the basis for informed decision-making and effective operations.
Security	Ensure functionality	Involves protecting the information on the dashboard from unauthorized access or breaches, guiding the implementation of access controls, encryption, and other security measures.
Compliance	Systematic page organization	Ensures that the dashboard adheres to all relevant laws, regulations, and standards, guiding the design and operation of the dashboard.
Integrity	Avoid unnecessary details, Easy to understand	Ensures the completeness and wholeness of the data presented, guiding the data collection and management processes.

to be continued…

…continuation

Availability	Ensure functionality	Makes sure the dashboard is accessible when needed, guiding the design of the dashboard to ensure it is reliable and available.
Transparency	Easy to understand	Provides clear and understandable data, guiding the presentation of data on the dashboard.
Accountability	Systematic page organization	Assigns responsibility for different data and processes, guiding the assignment of roles and responsibilities for data management and governance.
Effectiveness	Ensure functionality, Ensure flexibility	Ensures the dashboard fulfills its intended purpose efficiently, guiding the design and operation of the dashboard to ensure it effectively supports decision-making and operations.

The proposed IG principles as briefly explained in Table 4.9 above will serve as the foundational governance for effective IDDO, ensuring the creation of reliable, secure, and effective information dashboards. Nonetheless, although there are many IG principles available, to maintain a standard nomenclature, a standard terminology from the common IG principles derived from the three established IG models are used as a reference.

In conclusion, the derivation of these foundational IG principles for IDDO ensures that the information dashboard is built upon a solid foundation of reliable data, adheres to information quality standards, provides valuable insights to users, and maintains compliance with data security and privacy regulations.

Following the comprehensive discussion in the previous section, where the suitable building blocks of IDDO and IG Principles were derived, these two components need to be presented in a formal representation. Consequently, the subsequent section will comprehensively discuss the use of ontology as a knowledge representation tool to formalize these components, ultimately forming the IDDO. This will serve as the primary knowledge contribution in this study before it is developed into the actionable form, the IDDM.

4.8 APPLYING ONTOLOGICAL APPROACH

This section is imperative as it delves deeply into the design and development of the IDDO using an ontological approach. As previously mentioned, the IDDO will serve as the foundation for the creation of the IDDM.

The use of ontology is in line with its definition as an explicit specification of a conceptualization (Gruber 1995). This concept has found extensive application across various disciplines, including computer science, software engineering, and business. In the field of information science, ontology is viewed as a formal representation of knowledge, encompassing a set of concepts within a specific domain and the relationships that bind these concepts together (Noy & Mcguinness 2001).

In the context of this study, ontology is employed as a tool to formally represent the 12 established building blocks and the eight relevant principles of IG in the context of the information dashboard. The derivation of these building blocks and IG principles has been extensively discussed in the preceding section. The focus on the design and development of the IDDO is crucial as it lays the groundwork for the creation of the IDDM. This innovative artifact and the knowledge it imparts are the primary outcomes of this study, which is anchored in the DSRM. By applying an ontological approach, this section will elucidate the formation of the IDDO in a structured manner, understanding and representing the relationships between different elements of the building blocks and IG as the foundational governance.

Fernández-López and Gómez-Pérez (2002) expand the use of ontologies beyond their traditional applications, leveraging them to enhance communication, collaboration, and decision-making among various stakeholders and systems. The shared understanding facilitated by ontologies can be instrumental in promoting effective communication, fostering collaboration, and guiding decision-making processes across different stakeholders and systems. Such applications underscore the significance and versatility of ontologies in numerous fields, with a particular emphasis on information and computer science.

In conclusion, the versatility and applicability of ontologies in numerous fields, particularly in information and computer science, underscore their significance. They not only facilitate the modeling and analysis of domain knowledge but also enhance communication, collaboration, and decision-making among various stakeholders and systems. In the context of this study, the principles of ontology are instrumental in the establishment of the IDDO and ultimately the IDDM. By providing a structured way to represent and understand the relationship between the identified building blocks and relevant principles of IG, ontology serves as a crucial tool in the design and development of the IDDO and later the IDDM.

4.8.1 A Snapshot of Ontology Development Methods

Ontology Development Methods (ODMs) are vital in the creation of an ontology framework, with numerous methodologies examined in prior studies. These include well-known methodologies such as Ontology Development 101 (OD101), OntoSpec, Upon Lite, Methontology, NeON methodology, Uschold and King Methodology, and recently developed ones like Linked Open Terms (LOT) Methodology and Agile Ontology Engineering Methodology (AgiSCont).

ODMs can be categorized as lightweight, or heavyweight based on their formality and coverage of formal language elements (Studer et al. 1998). Lightweight ontologies provide basic-level information on the terms and concepts in a domain and are less formal, including fewer formal axioms and constraints. They are easier to understand and share and can grow into useful ontologies through a process of natural selection (Lassila & Mcguinness 2001). In contrast, heavyweight ontologies explicitly represent more complex relationships, such as part-whole relationships and inheritance hierarchies. They are more formal, comprehensive, and include many formal axioms and constraints (Corcho 2006; Fernández-López & Gómez-Pérez 2002).

Most ODMs do not explicitly mention their categorization as either lightweight or heavyweight, but their characteristics can be analyzed to determine their category. The LOT methodology, however, directly reveals that they are a lightweight ontology (Poveda-Villalón et al. 2022). In developing a lightweight ontology, the employed

ODMs tend to be simpler and more accessible, while for heavyweight ontologies, the ODMs used are more detailed and comprehensive(Femi Aminu et al. 2020).

A comprehensive study was conducted to examine various ODMS. The findings of this study, including a characteristic and categorization of the aforementioned ODMs, are encapsulated in Table 4.10.

Table 4.10 ODM's category and characteristics

Reference	**ODM**	**Category**	**Characteristic**
(Noy & Mcguinness 2001)	Ontology Development 101 (OD101)	Lightweight	▪ Basic-level information ▪ Iterative approach ▪ Suitable for novices
(De Nicola & Missikoff 2016; Kassel 2005)	OntoSpec	Lightweight	▪ Emphasizes formalization ▪ Less formal ▪ Uses structured natural language
(De Lille & Roelens 2021; De Nicola & Missikoff 2016)	UPON Lite	Lightweight	▪ Rapid engineering ▪ Accessible to domain experts ▪ Minimal intervention from ontology engineers during the ontology development process
(Fernandez Lopez et al. 1997, 1999)	Methontology	Heavyweight	▪ Involves a systematic approach ▪ Suitable for a more complex ontology development
(Fernández-Lépez et al. 2012; Suárez-Figueroa et al. 2015)	NeOn Methodology	Combination	▪ Scenario-based ▪ Flexible processes ▪ Combines lightweight and heavyweight characteristics
(Uschold & Gruninger 1996; Uschold & King 1995)	Uschold and King Methodology	Heavyweight	▪ Involves a systematic approach ▪ Includes comprehensive phases ▪ Suitable for a more complex ontology development
(Poveda-Villalón et al. 2022)	LOT (Linked Open Terms) Methodology	lightweight	▪ Focuses on flexibility and adaptability. ▪ Involves a detailed view of ontology requirements specification.

to be continued…

…continuation

(Spoladore et al. 2023)	Agile Ontology Engineering Methodology (AgiSCont)	lightweight	▪ Focuses on flexibility and adaptability. ▪ Supports iterative development ▪ Fits the various ontology activities into the phases of the Scrum agile methodology

In conclusion, there are many ODMs available, each with unique characteristics. Understanding the category and characteristics of these ODMs provides valuable insights for any ontology development project. Whether an ODM is lightweight, heavyweight, or a combination of both, all methods share the common goal of creating structured and effective ontologies. The next subsection will discuss the ODM to be employed in this study.

4.8.2 Ontology Development Method for IDDO

The IDDO is envisaged to be established as a top-level ontology. As posited by Guarino (1998), the theoretical underpinning suggests the feasibility of unified top-level ontologies that can serve extensive user communities. While the immediate context of this study will demonstrate and test the IDDO within the domain of smart waste management, the broader application of the IDDO is aimed at a substantial community of dashboard designers. The objective is to provide an effective guide for the design and implementation of information dashboards, as articulated in the second research objective.

As previously explained, the IDDO is inspired by the BMO, which is categorized as a paradigmatic lightweight ontology. This offers inspiration for the development of ODMs characterized by simplicity, accessibility, and comprehensibility, without compromising reliability and actionability. Taking the insights and success of the BMO as a globally recognized business model development tool, the IDDO will therefore be categorized as a lightweight ontology with a simple and accessible ontology structure that can be user-friendly, including to non-experts.

The development of the IDDO will use a UOA, a customized ODM developed by the researcher in Ahadi et al. (2024b). The use of a customized ODM is not new, as it has been employed in previous ontology development works (Osterwalder 2004; Abdul Sattar et al. 2021; Youcef et al. 2021).

The UOA is developed from a seamless integration and synthesis of common characteristics from various ODMs and insights from the BMO, resulting in a more holistic and inclusive ODM. The UOA aims to facilitate the ontology development process by providing a step-by-step process. The common characteristics integrated into the key steps will serve as the best practices that can be adopted or adhered to in each step. There are nine steps involved in UOA which are depicted in Figure 4.6 below:

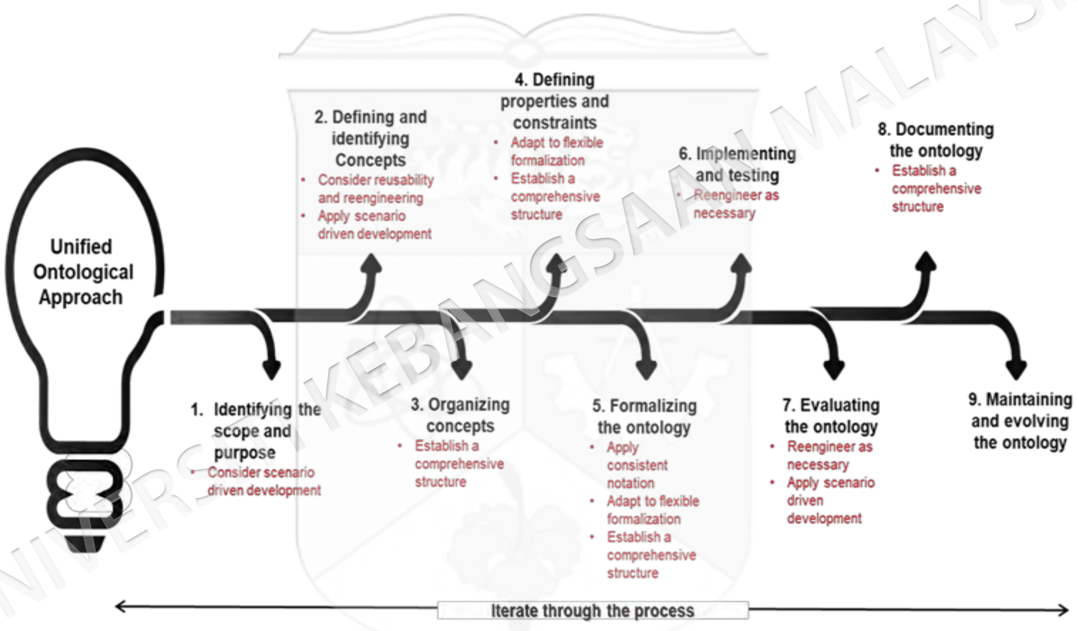

Figure 4.6 Unified ontological approach (UOA)

Table 4.11 below briefly explains the strength of the UOA as compared with other existing ODMs. It justifies the basis of the selection of the UOA as the ODM to develop IDDO in this study.

Table 4.11 The strength of the UOA compared with existing ODMs

Aspect	Existing ODMs	UOA
Synergy of Diverse Methodologies	Each ODM has its own focus and limitations.	Integrates strengths from various ODMs, leveraging diverse methodologies for robust ontology development.

to be continued…

…continuation

Formal Clarity and Precision	Varies in emphasis on formalization.	Ensures unambiguous representation and reasoning of ontological knowledge through consistent notation and formal languages.
Flexibility in Formalization	Flexibility ranges across ODMs.	Adopts a flexible formalization approach, allowing for construction from scratch or reuse of existing ontologies, promoting inclusivity and adaptability
Efficiency Through Reusability	Reusability is emphasized in some ODMs.	Emphasizes reusability and reengineering for efficiency, leveraging existing ontologies and knowledge resources to streamline development.
Scenario-Driven Customization	Scenario-driven approaches vary.	Utilizes scenario-driven principles for customization, enhancing relevance and applicability in ontology engineering based on common situations.
Comprehensive Structural Representation	Varies in depth of structural representation.	Emphasizes comprehensive and systematic structure in ontology development, ensuring nuanced representation of both structural and dynamic aspects for complex domains.

In conclusion, the development of IDDO will leverage the comprehensiveness of the UOA. This approach combines the strengths of existing ODMs and BMO. The comprehensiveness of the UOA ensures a structured development process for the IDDO, ultimately leading to the development of a robust IDDM. This robustness is expected to significantly contribute to the effectiveness and efficiency of information dashboard design and implementation.

After a comprehensive discussion of the building blocks, IG, ontology, and ODM, the next section will delve into the design and the development of the IDDO and IDDM, the key contribution of this study. The building block and IG will be systematically organized using ontology as a formal knowledge representation tool to create a "meaningful" IDDO and later translated to IDDM.

4.9 DESIGNING AND DEVELOPING THE IDDO

As outlined in Subsection 4.8.3, the IDDO will be developed following the UOA. The UOA is a customized and alternative ODM that consists of nine steps. However, for this study, the development of the IDDO will reach a satisfactory level at the sixth stage, "Implementing and Testing". This stage ensures that the IDDO adheres to the OntoUML rules, is free from syntactical errors, and provides a solid foundation to proceed to the crucial phase of this research: transforming the IDDO into a practical version for users, the IDDM. This process mirrors the relationship between the BMC and its foundational BMO.

The next stage of the UOA, "Evaluating the Ontology" – will not be explicitly covered within the context of the IDDO development. However, these stages will be addressed in chapter 5, which aligns with the "Evaluation" phase of the DSRM (Peffers et al. 2007). The DSRM is the overarching methodology that will be employed in this study.

The final two phases of the UOA, "Documenting the Ontology" and "Maintaining and Evolving the Ontology," are relevant in comprehensive ontology development. However, they will be beyond the scope of this study. The derivation of the IDDO, to be achieved through the first five steps of the UOA, and tested in the sixth step, will be deemed sufficient for the creation of the IDDM. The IDDM will be the primary focus and contribution of this research. Therefore, these final two phases of the UOA will not be discussed further in this study.

4.9.1 Identifying the Scope and Purpose

The design and development of the IDDO begin with the crucial step of identifying its scope and purpose. This is the key initial point of any ontology development work, where it involves understanding the reasons behind the development of the ontology and its intended objectives, as well as defining the ontology's scope, which includes the concepts it will cover and the level of detail it will provide.

As extensively discussed in Chapter 1, the second objective of this research is *"To develop a standardized, domain-independent, ontology-based and governance-aware IDDM that effectively guides the design and implementation of information dashboards".* This objective explicitly outlines the scope and purpose of IDDO's development. The scope is defined as the development and standardization of the IDDO, while the purpose is to guide the design and implementation of information dashboards.

The main user of the IDDO will be the information dashboard designer regardless of their level of expertise. Drawing insights from the BMO, the IDDO will be positioned as a lightweight ontology. This approach emphasizes simplicity and accessibility, making it suitable for both expert and novice users. Therefore, the design and development of the IDDO are guided by the scope and purpose identified at the early stage of this research. A clearly defined scope and purpose will ultimately ensure that the IDDO and, subsequently, the IDDM are usable and effective tools for information dashboard design and implementation.

4.9.2 Defining and Identifying Concepts

The building blocks extensively discussed in section 4.4 are the key concepts of the IDDO. The 12 building blocks derived from synthesizing the commonalities in the information design-related works reviewed in section 2.6 are the essence of the IDDO. It is a set of general concepts that will be used to define specific domain concepts of the IDDO.

These 12 building blocks, which have been identified and discussed in Section 4.4, depicted in Figure 4.2 will serve as a basis for developing the upper ontology. They provide a foundational structure or common system for the IDDO, offer rich semantics for knowledge representation systems, and enhance ontological adequacy and accuracy.

Alongside 12 building blocks elaborated in Section 4.4, IG principles form an additional building block underpinning the IDDO. In the context of this research, IG serves as a foundational governance mechanism, enhancing the credibility and reliability of the IDDO.

Derived from the synthesis of established IG models, and diverse IG principles, which are then linked to the common design principles, eight relevant IG principles have been selected to form the governance foundation of the IDDO in the context of this study. These selected IG principles, as depicted in Figure 3.11, not only enhance the accuracy and completeness of the 12 key building blocks but also serve as the governance foundation of the IDDO, contributing to its accuracy, completeness, and effectiveness in governing the design and development of information dashboards.

4.9.3 Organizing Concepts

In designing and developing the IDDO, the organization is manifested through the categorization of 12 building blocks and eight selected IG principles previously discussed in sections 4.5 and 4.7. These elements – the building blocks and the foundational governance, identified as the main concepts of the IDDO, are organized under specific categories that represent different stages or aspects of the information dashboard design process.

In the context of IDDO, this organization is manifested through the categorization of the 12 building blocks and eight selected IG principles. These elements, identified as the main concepts of the IDDO, are organized under specific categories that represent different stages or aspects of the information dashboard design process.

The 12 building blocks are categorized under three main groups: Defining and Planning, Design and Visualization, and Testing and Improvement. Each category encapsulates a set of related building blocks that guide different stages of the IDDO.

In addition to these building blocks, the IDDO is also underpinned by IG principles, which serve as a foundational governance mechanism. These principles are not part of the sequential steps (building blocks), but they underpin and guide the entire process. These principles underpin and guide the entire process, governing all building blocks within the IDDO framework.

The organization of concepts into specific categories not only provides a clear and intuitive structure for the IDDO, but it also facilitates its understanding and use. Categorizing the building blocks and depicting them in a concise diagram will pave the way for a more detailed ontology framework at the advanced stage of this study. This framework will clearly define the relationships between concepts in an ontology(Noy & Mcguinness 2001).

This approach will ensure that the ontology accurately represents the relationships among the concepts in the domain, thereby enhancing its ontological adequacy and accuracy (Gruber 1993). The categorization of IDDO is depicted in Figure 4.7. This initial structure helps to illustrate the initial relationships between different concepts, setting the stage for the next step of defining properties and constraints for a clearer and more intuitive organization of the concepts.

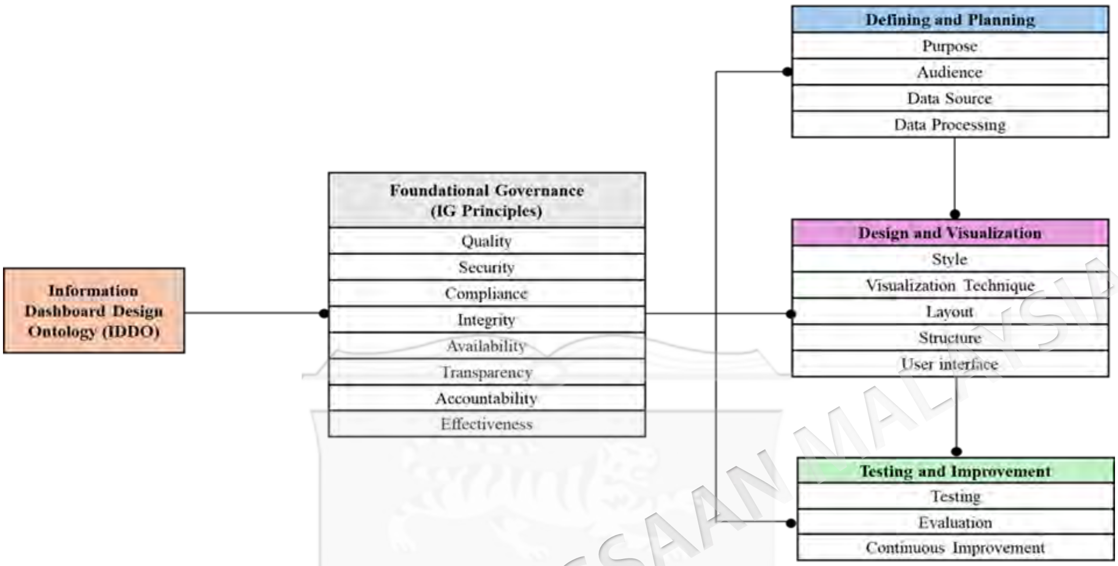

Figure 4.7 The categorization of the IDDO

4.9.4 Defining Properties and Constraints

In the pursuit of developing the IDDO, the identified building blocks and the IG principles as the properties of the IDDO will be defined, organized, and represented in the form of the ontology framework. This process is aligned with the fourth UOA.

Defining properties is one of the common processes in any ontology development works. In addition to defining properties, this process also involves defining any constraints of the properties (Rudnicki 2016). This stage is critically important as it provides detail and specificity to the IDDO. By defining properties and constraints, the IDDO can represent not just what concepts exist in the ontological framework but also what characteristics those concepts in the IDDO have and how they are related to each other. Furthermore, it also ensures IDDO’s effectiveness and usability (Rudnicki 2016; Noy & Mcguinness 2001).

a. The initial conceptual framework of the IDDO

Figure 4.10 below represents the initial IDDO framework, depicting an interconnected boxes representing the properties and the "heart" of the IDDO, the interrelated building blocks. The IDDO properties represented in Figure 4.8 below initially define the IDDO concept, constraints and how it relates to each other.

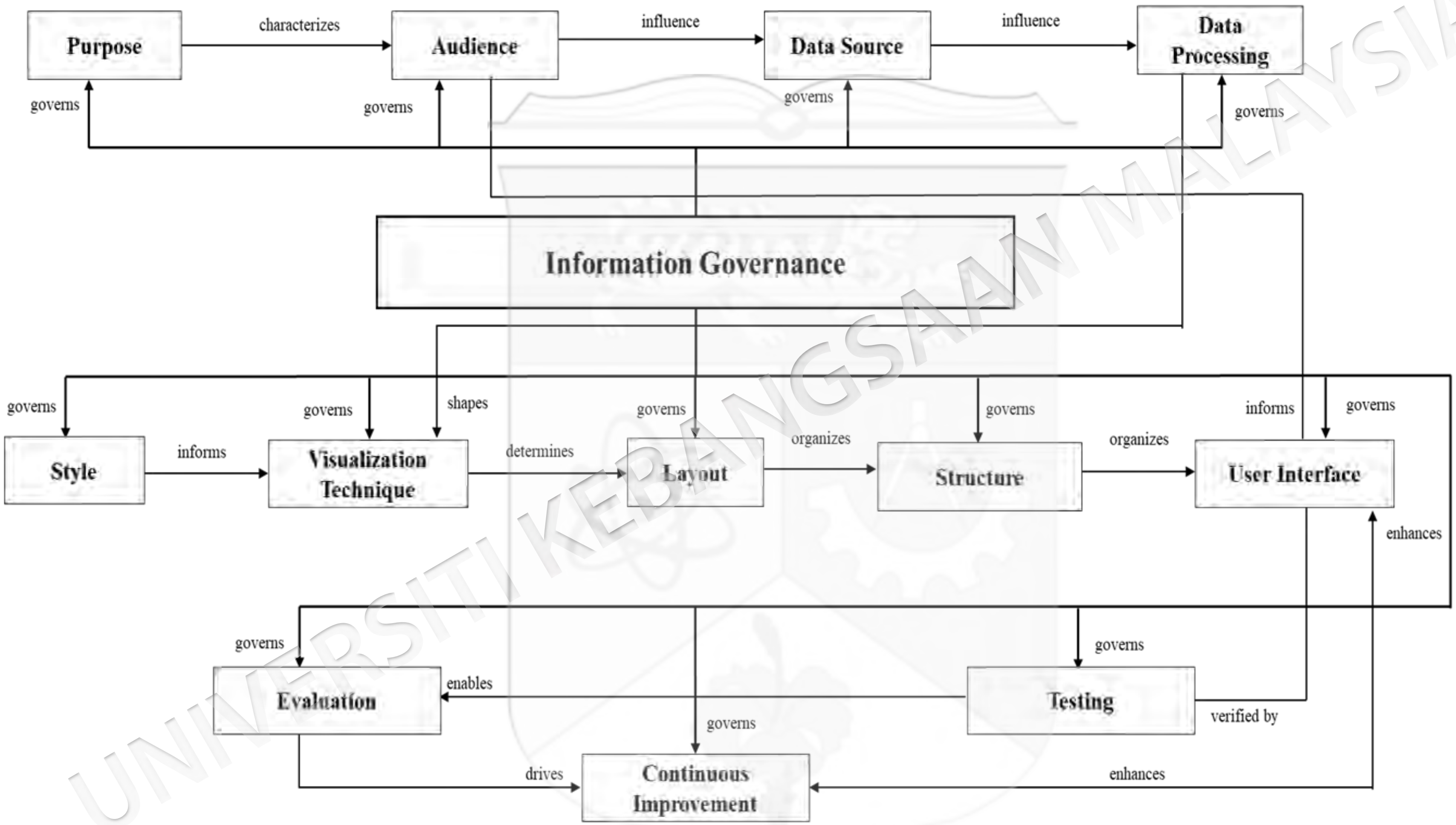

Figure 4.8 The initial conceptual framework of the IDDO

At the center of the IDDO conceptual framework, there is one single block that serves as the foundational governance building block, the IG principles. This IG single block is very general and have yet to be fragmented into a more specific governance but sufficient to provide an overview of the role of IG as the foundational governance of IDDO where all the interconnected arrows depict the “governs” relationship. The next sub-section provides a more detailed IDDO framework, including the addition of eight selected and relevant IG principles that have been discussed previously in section 4.7.

b. The refined IDDO framework

Figure 4.8 presents an initial ontology framework of the IDDO. This conceptual IDDO framework serves as an initial representation of the knowledge within the IDDO, showcasing its comprehensive properties (the building blocks) and defining their interrelationships. This framework aligns with the assertions of Pietranik and Kozierkiewicz (2023), who posit that ontologies comprise concepts and relations that outline the properties and relationships between objects. By structuring and organizing the properties of the IDDO in a formal and organized manner, a shared quality standards will be established, thereby facilitating interoperability (Matentzoglu et al. 2022).

The foundational governance framework in the conceptual IDDO, as illustrated in Figure 4.8, is composed of a single building block, the IG at the centre. As previously discussed, the conceptual IDDO aims to provide an initial understanding of the common elements involved in information dashboard design process. This is achieved by organizing the building blocks and defining their relationships, thereby ensuring a clear flow and the establishment of a meaningful ontological framework (Ghosh Mitra et al. 2024; Rudnicki 2016).

Figure 4.9 below presents the refined IDDO framework. Compared to the initial IDDO framework in Figure 4.8, the refined IDDO further specifies IG principles into eight principles: (1) Effectiveness; (2) Transparency; (3) Accountability; (4) Quality; (5) Integrity; (6) Compliance; (7) Security; and (8) Availability. These selected IG principles form the bedrock of governance for the entire IDDO framework, providing a clear and structured organization of properties in an ontology to establish shared quality standards and enable interoperability (Barrass 2021). The relationship between these IG principles and the 12 core building blocks of the IDDO is uniformly labeled as "governs" to clearly define its role as the foundational governance, governing the entire IDDO. By integrating IG principles, an established governance model for managing the data and the information with the key building blocks, it will further reinforce the IDDO and ensure that the actual information dashboard that derives from an actionable version of the IDDO, the IDDM is effective and reliable in providing the swift insights for the audience. The derivation of these eight relevant IG principles has been discussed comprehensively in Section 4.7.

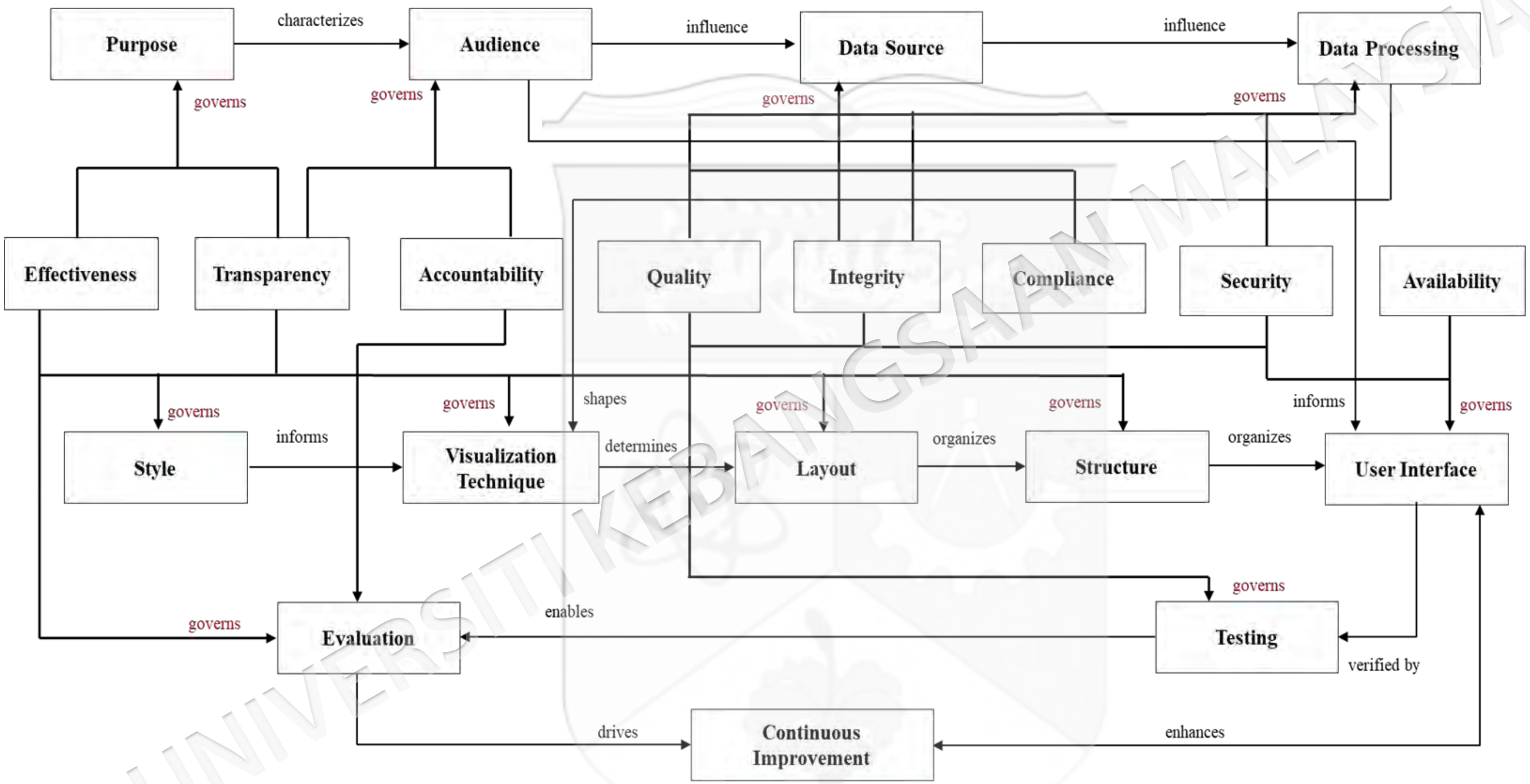

Figure 4.9 The refined IDDO framework

In the refined IDDO framework depicted in Figure 4.9, the inclusion of eight IG principles has further defined the IDDO’s properties and constraints. The importance of defining these relationships within an ontology cannot be overstated. As noted by Noy and Mcguinness (2001), a clear definition of the properties in the ontological framework is crucial for sharing a common understanding of the structure of information and knowledge represented in the ontologies. In the context of information dashboard design, this shared understanding enables more efficient and productive communication of the IDDO, which in turn helps in producing an effective and usable information dashboard. To ensure the relationships between each building block are clear, the use of appropriate semantics in defining these relationships is equally critical. Semantic helps create a common understanding of the meaning of things, which aids in better understanding of the building blocks and more accurately interpreting what the IDDO means (Guizzardi & Guarino 2023). The next sub-section will focus on and discuss the relationship of each building block in the IDDO, and the semantics used to define its relationship.

c. IDDO: Relationships and semantics

The IDDO is a comprehensive framework that encapsulates common processes and their interrelationships, aimed at facilitating the development of effective information dashboards. As previously discussed in Section 4.9.3, the IDDO comprises four primary categories: Defining and Planning, Design and Visualization, Testing and Improvement, and Foundational Governance, which collectively incorporate eight IG principles governing 12 key building blocks.

The categories Defining and Planning, Design and Visualization, and Testing and Improvement represent the distinct stages in the information dashboard design process. Meanwhile, Foundational Governance serves as the cornerstone of the framework, ensuring consistency, coherence, and alignment across all stages. At the advanced phase of this study, where the IDDM will be established, the Foundational Governance will no longer explicitly appear in the structure. This aligns with its role as the governing foundation rather than an operational component of the dashboard design process. Unlike in the IDDO, where Foundational Governance is explicitly represented, its principles will be implicitly embedded within the IDDM framework. This shift reflects a deliberate design choice, mirroring the simplification seen in tools such as the BMC, which distills the theoretical BMO into a more practical, user-friendly format. Similarly, the IDDM is intended to simplify the theoretical underpinnings of the IDDO into an accessible and actionable methodology for practitioners, ensuring that governance principles are seamlessly integrated without burdening users with excessive complexity.

To effectively model the complex interdependencies within the IDDO, the framework adopts a flexible approach to semantics. Relationships such as “influence”, “shapes”, “informs”, “determines”, and “enhances” are introduced to capture the dynamic interactions between its building blocks. These specific semantic relationships were carefully selected to reflect the nature of interactions in dashboard design. For example, “influence” captures the subtle yet significant impact that one component has on another, such as how the “Audience” influences the selection of the “Data Source” without strictly determining it. Meanwhile, “shapes” denote a stronger formative relationship, where one element actively molds another, as seen in how “Data Processing” shapes the choice of “Visualization Technique”. The relationship “informs” is used to indicate knowledge transfer between components, such as how the “Style” informs the choice of “Visualization Technique”. Similarly, “determines” represents direct causal relationships, as exemplified by how the selected “Visualization Technique” determines the “Layout”. Lastly, enhances captures bidirectional improvement relationships, such as how “Continuous Improvement” enhances and is simultaneously enhanced by the “User Interface”.

While these relationships are domain-specific extensions, the IDDO will be formalized using the Unified Foundational Ontology (UFO) and developed using OntoUML. By leveraging these foundational tools, the framework ensures ontological rigor and semantic precision. This approach aligns with Guizzardi’s (2005) principle of ontological adequacy**,** which emphasizes the need for modeling languages to be expressive, domain-relevant, and adaptable to the complexities of real-world phenomena. Furthermore, the dynamic feedback loops within the IDDO framework further reinforce its iterative and practical nature. For example, the Primary Feedback

Loop begins with interactions on the “User Interface”, which generate Testing data that enable “Evaluation”, driving “Continuous Improvement” that ultimately enhances the “User Interface”. In parallel, the Design Refinement Loop shows how the implementation of a “Visualization Technique” can reveal Layout constraints, which then influence Structure and inform future Visualization choices. Similarly, the Data-driven Loop highlights how “Data Processing” outcomes influence Visualization choices, with visualization effectiveness feeding back into “Data Processing” requirements, and User Interface interactions potentially triggering new Data Processing needs.

These semantic relationships and feedback loops ensure that the framework is not only theoretically robust but also practical and reflective of the real-world, iterative processes inherent in dashboard development. The following Figure 4.10 provides a visual representation of these relationships, illustrating the categorization and interrelationships among these building blocks.

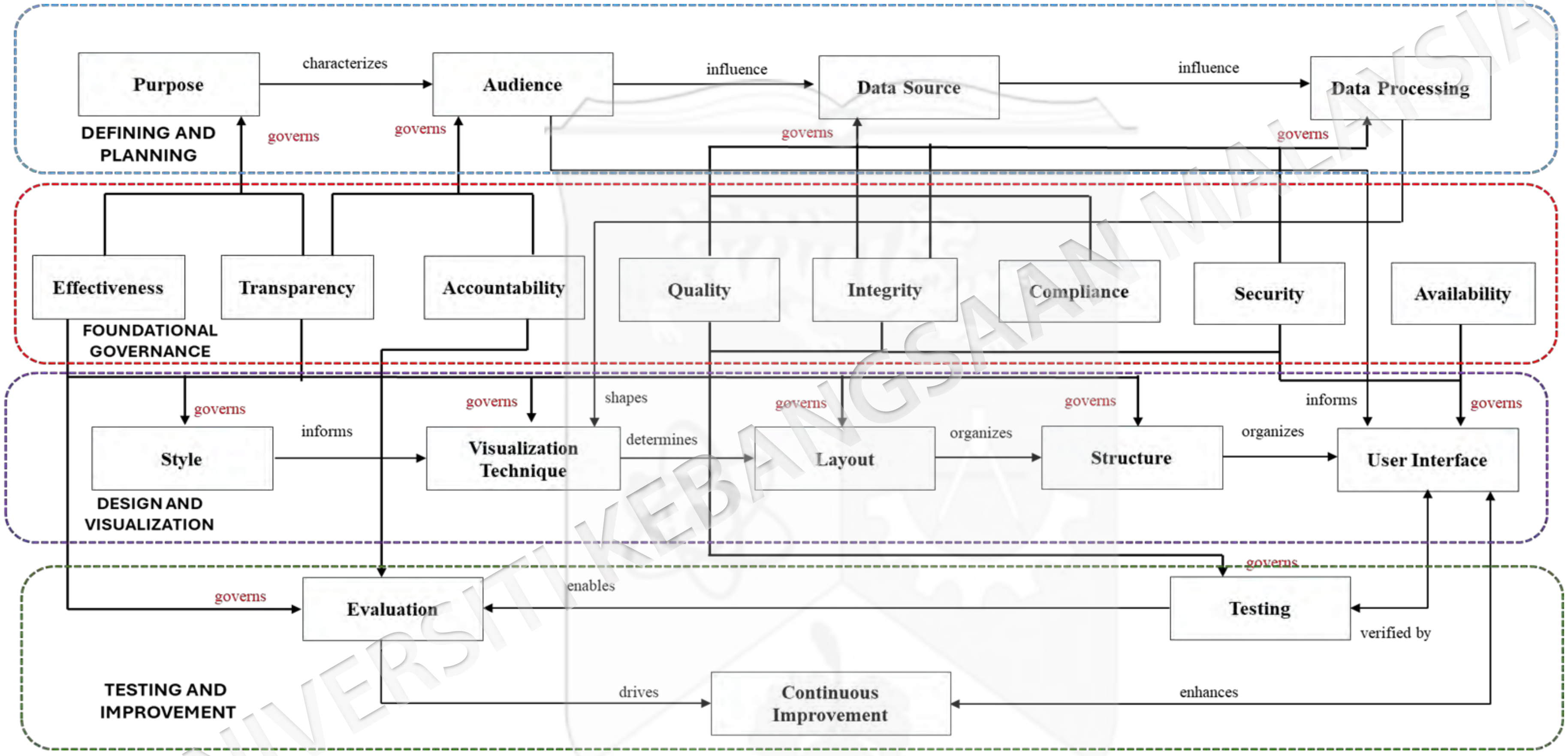

Figure 4.10 The categorization of the IDDO building blocks

i. Defining and planning

The first category in the IDDO, namely "Defining and Planning", comprises four fundamental building blocks: "Purpose", "Audience", "Data Source" and "Data Processing". This category sets the groundwork for the entire process of information dashboard design. It begins with clearly defining the "Purpose" which will then characterize the "Audience". The "Audience" will subsequently influence the selection of "Data Sources". These chosen "Data Sources" then influence the "Data Processing" stage. The "Data Processing" will shape the "Visualization Technique", a building block under the "Design and Visualization" category.

The relationships among these building blocks are defined using semantics such as "characterizes", "influence" and "shapes", which signify a directional interconnection from one building block to another. The properties of the 'Defining and Planning' category are summarized in Table 4.12 below:

Table 4.12 Summary of defining and planning category properties

Building Blocks	Relationship	Related Building Blocks	Description
Purpose	*characterizes*	Audience	Purpose characterizes Audience by defining user profiles and information needs
Audience	*influence*	Data Source	Audience influences Data Source by determining required data types and sources
Data Source	*influence*	Data Processing	Data Source influences Data Processing by dictating necessary transformation and analysis steps
Data Processing	*shapes*	Visualization Technique	Data Processing shapes Visualization Technique by informing appropriate data representation methods

ii. Design and visualization

The "Design and Visualization" category of the IDDO encompasses five key building blocks: "Style", "Visualization Technique", "Layout", "Structure", and "User Interface". In this category, "Style" informs the "Visualization Technique", which determines "Layout". "Layout" organizes "Structure", and "Structure" organizes the "User Interface". The "User Interface" is then verified by "Testing", ensuring its effectiveness and usability. The "User Interface" also enhances "Continuous Improvement" by providing user interaction insights for further improvements.

This framework represents the interdependent relationships between design elements, where each component influences or shapes the next. The "Testing" phase serves as a crucial verification step for the "User Interface", validating its functionality and user-friendliness within the overall design and visualization process.

The semantics used to articulate these intricate relationships among building blocks include terms like "informs", "determines", "organizes", "verified by" and "enhances" signifying a unidirectional influence that underscores their interdependence. Table 4.13 elucidates the properties and constraints associated with each element within the "Design and Visualization" category.

Table 4.13 Summary of design and visualization category properties

Building Blocks	Relationship	Related Building Blocks	Description
Style	*informs*	Visualization Technique	Style informs Visualization Technique by guiding the visual approach and aesthetic choices.
Visualization Technique	*determines*	Layout	Visualization Technique determines Layout by specifying how data representations are arranged.
Layout	*organizes*	Structure	Layout organizes Structure by defining the overall arrangement and hierarchy of dashboard elements.
Structure	*organizes*	User Interface	Structure organizes User Interface by establishing the framework for user interaction elements
User Interface	*verified by*	Testing	User Interface is verified by Testing to ensure functionality and user-friendliness
User Interface	*enhances*	Continuous Improvement	User Interface enhances Continuous Improvement by providing user interaction insights for further improvements

iii. Testing and improvement

The "Testing and Improvement" category within the IDDO framework aims to ensure that the dashboard functions as intended and continuously improves. This category comprises three key building blocks: “Evaluation”, “Testing”, and “Continuous Improvement”.

The “Testing” building block verifies the “User Interface”. It enables the “Evaluation Process” and drives “Continuous Improvement” by examining the dashboard's functionality. The “Evaluation” building block assesses the dashboard's performance and effectiveness based on testing results. It further drives the “Continuous Improvement” process by providing comprehensive insights. The “Continuous Improvement” building block involves ongoing enhancements to the dashboard. It is driven by “Evaluation”, creating a systematic process of verification, assessment, and refinement. Crucially, there is a bidirectional “enhances” relationship between “Continuous Improvement” and the “User Interface” as well as “Testing". This means that improvements inform and refine the “User Interface”, while user interaction with the interface provides valuable insights for further improvements.

The semantics used to define these relationships include terms like “enables”, “verified by”, “drives”, and “enhances”, indicating specific directional and bidirectional influences between building blocks. The “Testing and Improvement” phase is paramount as it ensures a comprehensive and dynamic approach, integrating feedback from various stages of dashboard development and use, and fostering an evolving user-centric design.

Overall, this phase is important as it denotes the best practices in the information dashboard design and development process, balancing the aesthetic, functionality, and usability aspects of the information dashboard. Table 4.14 below provides a summary of the properties of the “Testing and Improvement” category within the IDDO framework.

Table 4.14 Summary of testing and improvement category properties

Building Blocks	**Relationship (Semantics)**	**Related Building Blocks**	**Description**
Testing	*enables*	Evaluation	Testing enables Evaluation by providing data on dashboard performance.

to be continued…

…continuation

Evaluation	*drives*	Continuous Improvement	Evaluation drives Continuous Improvement by providing comprehensive insights based on testing results
Continuous Improvement	*enhances*	User Interface	Continuous Improvement enhances User Interface by implementing refinements based on evaluation and testing

iv. Foundational governance

Interwoven within the three primary categories of the IDDO are eight pivotal IG principles: 1. “Effectiveness”, 2. “Transparency”, 3. “Accountability”, 4. “Quality”, 5. “Integrity”, 6. “Compliance”, 7. “Security” and 8. “Availability” serve as the foundational governance of the IDDO, underpinning the entire framework.

These principles, distinct from the other building blocks within the three broad categories previously discussed, are categorized under the “Foundational Governance Category” underscoring their role as the cornerstone of the IDDO. Their strategic placement within the framework signifies their pervasive influence across all processes, reinforcing the importance of governance in the design and implementation of effective information dashboards.

“Effectiveness” governs six building blocks: “Purpose”, “Style”, “Visualization Technique”, “Layout”, “Structure”, and “Evaluation”. It ensures the dashboard's purpose aligns with organizational goals, style choices enhance effectiveness, visualizations effectively communicate insights, layout maximizes comprehension, structural elements support effective presentation, and evaluation methods accurately measure dashboard effectiveness.

“Transparency” governs six building blocks: “Purpose”, “Audience”, “Style”, “Visualization Technique”, “Layout”, and “Structure”. It ensures clear communication of objectives, open understanding of user needs, unambiguous data representation, clear conveyance of data, transparent information flow, and clear data organization.

"Accountability" governs "Audience" and "Evaluation", ensuring clear responsibility in user roles and access, and traceable assessment processes.

"Quality" governs "Data Source", "Data Processing", and "Testing", ensuring high-quality data inputs, accurate data transformation, and rigorous quality checks.

"Integrity" governs "Data Source", "Data Processing", and "Testing", ensuring trustworthy data sources, maintaining accuracy throughout processing, and verifying data integrity in testing.

"Compliance" governs "Data Source" and "Data Processing", ensuring data sources meet regulatory requirements and data handling complies with relevant standards.

"Security" governs "Data Processing" and "User Interface", ensuring secure handling and storage of data, and secure user interactions and data display.

"Availability" governs the "User Interface", ensuring consistent accessibility of the dashboard interface.

This comprehensive governance structure ensures that every aspect of the information dashboard design aligns with best practices in information governance, from initial conceptualization through to implementation and user interaction. Table 4.15 below provides a summary of the properties associated with each principle within the 'Foundational Governance' category.

Table 4.15 Summary of foundational governance category properties

IG Principles	Relationship	Governs Building Blocks	Description
Effectiveness	*governs*	Purpose	Ensures the dashboard's purpose aligns with organizational goals
	governs	Style	Ensures style choices enhance the dashboard's effectiveness
	governs	Visualization Technique	Ensures visualizations effectively communicate data insights
	governs	Layout	Ensures layout design maximizes information comprehension

to be continued…

…continuation

	governs	Structure	Ensures structural elements support effective data presentation
	governs	Evaluation	Ensures evaluation methods accurately measure dashboard effectiveness
Transparency	*governs*	Purpose	Ensures clear communication of the dashboard's objectives
	governs	Audience	Ensures open understanding of user needs and expectations
	governs	Style	Ensures style choices promote clear and unambiguous data representation
	governs	Visualization Technique	Ensures visualizations clearly convey data without obscurity
	governs	Layout	Ensures layout design promotes transparent information flow
	governs	Structure	Ensures structural elements support clear data organization
Accountability	*governs*	Audience	Ensures clear responsibility in user roles and access
	governs	Evaluation	Ensures traceable and responsible assessment processes
Quality	*governs*	Data Source	Ensures high-quality, reliable data inputs
	governs	Data Processing	Ensures accurate and consistent data transformation
	governs	Testing	Ensures rigorous quality checks in the testing phase
Integrity	*governs*	Data Source	Ensures trustworthy and unaltered data sources
	governs	Data Processing	Maintains data accuracy throughout processing
Compliance	*governs*	Testing	Verifies data integrity in the testing phase
	governs	Data Source	Ensures data sources meet regulatory requirements
	governs	Data Processing	Ensures data handling complies with relevant standards
Security	*governs*	Data Processing	Ensures secure handling and storage of data
	governs	User Interface	Ensures secure user interactions and data display
Availability	*governs*	User Interface	Ensures consistent accessibility of the dashboard interface

In conclusion, the identified building blocks and IG principles represent the key properties that underpin the concept of IDDO. These properties are carefully defined, structured, and organized within the ontology framework to provide a cohesive representation of the framework's core ideas. This approach is consistent with the fourth step of the UOA,which underscores the importance of clearly defining properties in ontology development. By doing so, the IDDO is able to outline not only the existence of its concepts but also their characteristics and the relationships between them in a systematic manner.

To better capture the nuanced dynamics and interactions within the IDDO, flexible semantic relationships such as “influence”, “shapes”, “informs”, “determines”, and “enhances” have been introduced. These domain-specific extensions, while not standard in foundational ontologies, are in line with the principle of ontology adequacy as outlined by Guizzardi (2005). He emphasizes that a modeling language must be sufficiently expressive and adaptable to accurately represent the real-world complexities of its subject domain. By extending the semantic relationships to include such interactions, the IDDO ensures that it remains relevant and reflective of the dynamic processes inherent in dashboard design while maintaining ontological rigor. These extensions are carefully aligned with the framework’s goal of balancing practical applicability with theoretical soundness, ensuring that even subtle influences and causal relationships are well-represented.

The next sub-section will discuss the process of formalizing the ontology. This involves expressing the IDDO in a formal language, offering a structured and application-independent view to ensure the framework’s consistency and scalability as it evolves. By formalizing the ontology, the aim is to provide a robust tool that supports the accurate representation of interdependencies and processes within dashboard design.

4.9.5 Formalizing the Ontology

In line with the fifth step of the UOA process, the IDDO will be formalized using a formal representation language. For this study, the Unified Modeling Language (UML) has been selected as the tool to model the IDDO. UML was chosen due to its widespread adoption in both academia and industry, making it a highly accessible and practical tool for representing complex systems. Its ability to visually represent intricate structures and its extensibility for domain-specific modeling provide the flexibility required for capturing the unique characteristics of the IDDO framework (Elekes et al. 2023; Mkhinini et al. 2020; Pérez-Castillo & Piattini 2022).

Furthermore, UML's object-oriented approach aligns well with the principles of ontological modeling, particularly in its capacity to define entities, relationships, and constraints in a structured manner (Wang & Chan 2001). While UML was not originally designed as an ontology modeling language, its adaptability and visual capabilities make it a suitable choice for formalizing the conceptual structures and interrelationships within the IDDO framework.

UML, a general-purpose and standard modeling language can serve as a bridge between ontological models and software engineering artifacts (Elekes et al. 2023; Wang & Chan 2001). Researchers have extended UML specifically for ontology development, allowing ontology developers to leverage established UML-based methodologies and create visual diagrams (Mkhinini et al. 2020; Pérez-Castillo & Piattini 2022; Wang & Chan 2001). These diagrams enhance comprehension and facilitate communication among stakeholders, highlighting UML's pragmatic approach to representing complex relationships and constraints inherent in ontologies (Pérez-Castillo & Piattini 2022; Baclawski et al. 2002).

However, while UML is widely used, its application in constructing conceptual models for ontologies often requires enhancements to improve ontological adequacy. To address this limitation, the use of upper-level ontology representations is necessary(Guizzardi 2005). Specifically, the UFO proposed by Guizzardi (2005) provides a rigorous foundation for understanding essential concepts, constraints, and relationships within a given domain of discourse (Guizzardi et al. 2022). Guizzardi's work involves evaluating and redesigning portions of the UML 2.0 metamodel, particularly focusing on the construction of structural conceptual models. By aligning UML with UFO, Guizzardi sought to enhance the ontological soundness of UML-based conceptual models, leading to the development of OntoUML, an extension of UML that incorporates UFO's ontological principles.

OntoUML builds upon UML by embedding ontological principles, ensuring that conceptual models accurately represent the underlying reality (Fonseca et al. 2022). It offers advanced capabilities beyond those of standard UML, particularly for modeling types, wholes and parts, roles, and other complex relationships. These capabilities are grounded in the robust theoretical foundations of UFO (Guizzardi et al. 2022). As a result, OntoUML has become widely recognized across various domains as a powerful tool for ontology-driven conceptual modeling. By integrating UFO and OntoUML, the formalization of the IDDO framework can achieve a higher degree of ontological clarity, precision, and alignment with real-world phenomena.

In conclusion, the adoption of UML as the tool for modelling the IDDO framework, supplemented by UFO and OntoUML, provides a comprehensive approach to ontology formalization. This combination ensures that the IDDO not only benefits from the practicality and widespread adoption of UML but also achieves the rigor and expressiveness required for representing complex ontological relationships (Guizzardi et al. 2022).

a. Formalization of the IDDO

Formalizing the IDDO is imperative to ensure its accuracy and representation in a formal model. This process is guided by the work of Guizzardi (2005), utilizing a UFO and its modelling language, OntoUML.

The UFO, developed by Guizzardi (2005), serves as the theoretical foundation. UFO provides a set of ontological distinctions and principles for understanding and categorizing various aspects of reality in a rigorous and semantically rich manner. These include key concepts such as endurants (entities that persist through time), perdurants (events/processes), relators, and roles, which are foundational for modeling both the structural and behavioural aspects of systems. Within UFO, entities are broadly categorized as either endurants (objects that persist with their full identity through time, such as a dashboard interface) or perdurants (events or processes that unfold over time, such as the testing phase). While this distinction underpins UFO's theoretical foundation, the IDDO framework primarily employs UFO's stereotype system to categorize dashboard components and their relationships. UFO has been widely applied in conceptual modeling across multiple domains and is particularly valued for its support of socio-technical constructs (Guizzardi 2005; Guizzardi et al. 2022).

OntoUML, an ontologically well-founded extension of the Unified Modeling Language (UML), operationalizes UFO by embedding its micro-theories into modeling constructs through the use of formal stereotypes (Guizzardi & Guarino 2024). It provides a graphical and logically coherent language for expressing ontological commitments in conceptual models, making it highly suitable for formalizing IDDO. OntoUML has been widely adopted by academic, industrial, and governmental institutions for modelling complex systems (Mkhinini et al. 2020).

Compared to other foundational ontologies such as Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE), Basic Formal Ontology (BFO), and the Suggested Upper Merged Ontology (SUMO), UFO was selected for this study due to its expressiveness and practical suitability in modeling information dashboards. Unlike DOLCE, which emphasizes cognitive representations (Masola et al. 2002) or BFO, which is tailored for biomedical contexts (Arp et al. 2015), UFO offers a broader capability to represent both static information structures and dynamic processes, a duality that is central to dashboard systems. Furthermore, its ability to model social roles, contexts, and events makes it ideal for capturing the socio-technical nature of dashboard design.

In this study, the IDDO is formalized using OntoUML, thus embedding the ontological principles of UFO into its structure. This formalization positions IDDO as a form of upper-level ontology, offering an abstract framework for organizing dashboard-related knowledge across multiple domains. By formalizing IDDO through OntoUML, the framework benefits from enhanced conceptual clarity, improved alignment with real-world dashboard design processes, and provides a solid foundation for future extensions and adaptations across diverse applications. Figure 4.11 illustrates the OntoUML representation of IDDO, highlighting its key conceptual components and interrelationships.

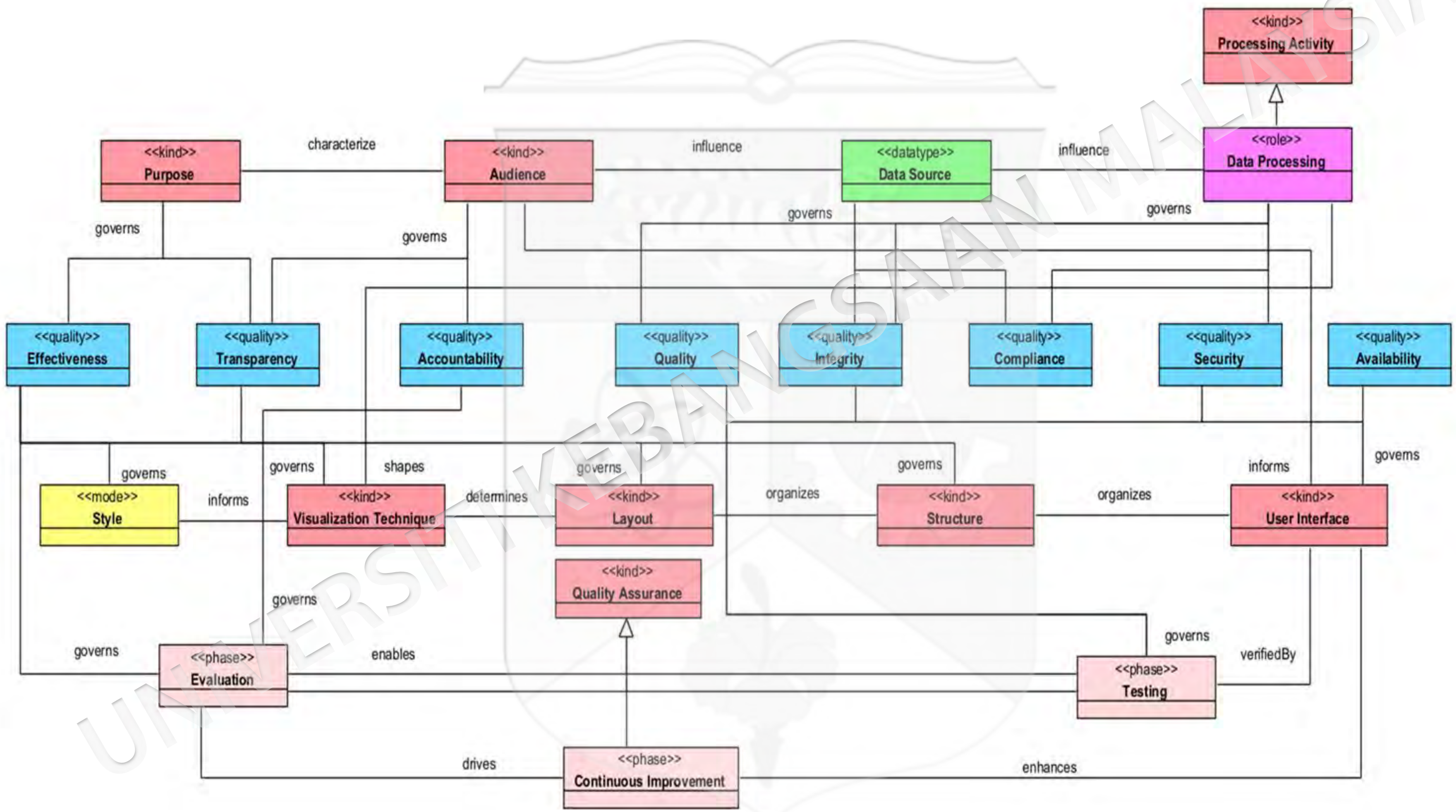

Figure 4.11 IDDO framework

Compared with the non-formalized IDDO framework in Figures 4.9 and 4.10, the formalized IDDO framework depicted in Figure 4.11 has two new additional elements, namely “Processing Activity” and “Quality Assurance”. Both elements, stereotyped as <<kind>>, are not considered as an addition to the existing 12 core building blocks but rather to adhere to OntoUML rules and avoid syntactical errors. This framework will be tested in the sixth step of the UOA, “Implementing and Testing”.

By leveraging OntoUML for its formalization, IDDO ensures several critical aspects: conceptual clarity, a comprehensive framework, enhanced interoperability, a robust ontological structure, facilitated ontological engineering, and alignment with best practices based on UFO principles (Guizzardi et al. 2022).

In OntoUML, stereotypes are crucial modeling constructs that represent specific ontological categories derived from UFO. These stereotypes allow for more precise and semantically rich modeling, enabling the capture of nuanced distinctions in the nature and behavior of entities within the domain being modeled (Guizzardi 2005).

According to Guizzardi (2005), a key concept in understanding these stereotypes is rigidity. A type is considered rigid if it necessarily applies to its instances throughout their entire existence. Conversely, a type is anti-rigid if its instances can cease to be of that type while still existing.

In the process of formalizing the IDDO framework using OntoUML, specific stereotypes have been applied to categorize different entities and their relationships. The use of <<kind>>, <<role>>, <<mode>>, <<phase>>, and <<quality>> follows OntoUML’s ontological distinctions, ensuring that the framework remains aligned with foundational ontological principles. These stereotypes play distinct roles in capturing the structural and dynamic aspects of the IDDO framework.

In the IDDO model, arrows are only used where necessary, mainly to show generalization (like between Data Processing and Processing Activity) and temporal or procedural flow for elements marked as <<phase>>, such as Evaluation and Testing. Most other relationships are bilateral by nature, in line with UFO principles, where elements influence each other. Avoiding one-way arrows helps preserve ontological accuracy and avoids oversimplifying complex design interdependencies. Table 4.16 below summarizes the key OntoUML stereotypes applied in IDDO:

Table 4.16 Key OntoUML stereotypes (Guizzardi 2005) used in IDDO formalization

Stereotype	Description
<<kind>>	Represents rigid, identity-providing types that are essential to the identity of their instances throughout their entire existence (e.g., Person, Organization).
<<role>>	Represents anti-rigid types that an entity plays in a certain context or relationship and can cease to play while continuing to exist (e.g., Student, Employee).
<<mode>>	Represents existentially dependent intrinsic properties or qualities of other entities (e.g., Skill, Belief).
<<phase>>	Represents anti-rigid types that capture temporal changes in the intrinsic properties of an entity, which the entity can transition between while maintaining its identity (e.g., Child, Adult).
<<quality>>	Represents intrinsic properties that can be directly measured or observed and are existentially dependent on their bearer (e.g., Weight, Color).

While the stereotypes applied in IDDO largely align with OntoUML's standard ontological categories, one notable extension is the inclusion of <<datatype>> to represent Data Source. Unlike the other stereotypes, <<datatype>> is not part of OntoUML's predefined set. However, its introduction is necessary to accurately model the role of Data Source within IDDO, ensuring that it is not misrepresented as an independent entity with a persistent identity.

Guizzardi (2005) emphasizes that ontological modeling should capture the true nature of entities within a domain, distinguishing between those that possess intrinsic identity and those that function primarily as carriers of data or informational artifacts. In this context, Data Source does not exhibit the existential independence characteristic of <<kind>> or the contextual adaptability of <<role>>. Instead, it behaves as an informational entity that influences other components within the IDDO framework but does not transition through different states or roles.

By classifying Data Source under <<datatype>>, the IDDO framework ensures that it is treated as an informational construct that provides structured and unstructured data without being misinterpreted as an entity that plays an active role in governance or decision-making. This aligns with Guizzardi's principle of ontological adequacy, which stresses that formal models should accurately reflect real-world distinctions while maintaining conceptual clarity.

This formalization process ensures that IDDO serves as a solid and effective foundation for organizing information and defining general concepts across diverse domains, fulfilling its role as an upper-level ontology (Le 2020). The application of UFO's principles through OntoUML enhances the adequacy and clarity of the IDDO conceptual model, making it comprehensive, precise, and capable of accurately reflecting real-world complexities (Guizzardi 2005).

4.10 DETAILED IDDO FRAMEWORK COMPONENTS

In this section, the overview diagram of the IDDO framework will be broken down into its constituent parts to explain each property comprehensively. A similar approach was utilized by Guizzardi (2005), where he deconstructed the ontology framework into an auxiliary view and explained it in detail. Although the IDDO is considered a lightweight ontology compared to Guizzardi's work, which is more complex and interdisciplinary, the fragmentation will allow for a clear and precise understanding of the framework.

a. Purpose and audience

Figure 4.12 below depicts the first concept of the IDDO, "Purpose". The purpose is stereotyped as <<kind>> as it represents the essential identity for a dashboard instance. Defining the purpose is fundamental because it is a foundational aspect from which other characteristics of the dashboard (like audience, data sources, and visualization techniques) are derived. Each unique purpose defines a distinct type of dashboard. Stereotyping "Purpose" as <<kind>> is also in line with the rigidity nature as explained by Guizzardi (2005) which means that for any particular dashboard instance, its purpose is essential throughout its entire existence. If the purpose changes significantly, it could be argued that it becomes a new dashboard entity.

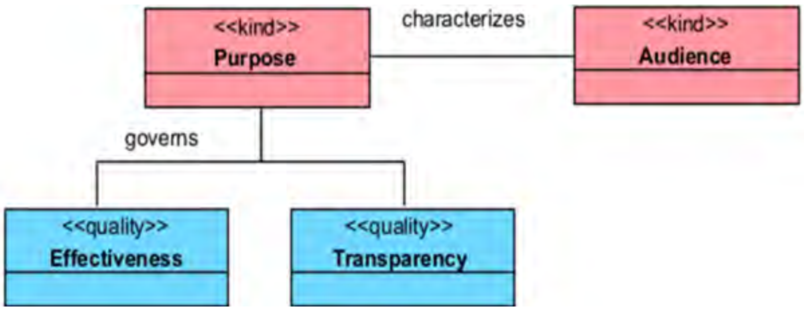

Figure 4.12 Fragment of the IDDO framework - purpose, audience, and governing IG principles

As the purpose provides the fundamental identity of a dashboard, it is directly associated with the “Audience”. “Audience” is profiled as <<kind>> as it also provides a principle of identity for its instances. Each unique audience type defines a distinct category of dashboard users. The bidirectional relationship between “Purpose” and “Audience” is defined as “characterize” because the purpose determines who the primary users of the dashboard will be. The “characterizes” relationship between “Purpose” and “Audience” implies a strong, defining connection. The Purpose, being rigid as a <<kind>>, establishes a similarly rigid characterization of the Audience. The Audience's identity is, in a sense, dependent on the Purpose. A change in Purpose would necessitate a redefinition of the Audience, reinforcing the <<kind>> nature of both.

Both “Effectiveness” and “Transparency” and all IG principles in the IDDO are stereotyped as <<quality>> as they represent an intrinsic, measurable property that is existentially dependent on its bearer (Guizzardi 2005).

“Effectiveness” and “Transparency” are specifically chosen to “govern” “Purpose” because they are crucial for ensuring that the dashboard's fundamental aim is both impactful and clear. “Effectiveness” ensures that the purpose aligns with organizational goals and user needs, while “Transparency” guarantees that the dashboard’s intent is clearly communicated and understood by all stakeholders.

b. Audience, data source, and user interface

This fragment of the IDDO depicted in Figure 4.13 below focuses on the relationships between “Audience”, “Data Source”, and “User Interface”, governed by the IG principles of “Transparency” and “Accountability”.

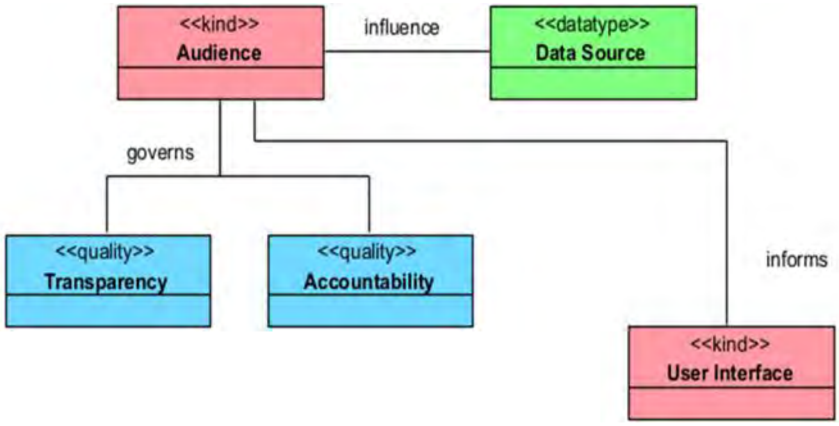

Figure 4.13 Fragment of the IDDO framework - audience, data source, user interface and governing IG principles

The “Audience” is stereotyped as <<kind>>, reinforcing its role as an essential, identity-providing element within the dashboard design. As a fundamental entity, the Audience plays a crucial role in shaping various aspects of the dashboard ecosystem, particularly by influencing the “Data Source”, which is stereotyped as <<datatype>>.

Unlike <<kind>> entities, Data Source does not function as an independent conceptual entity but rather as an informational construct that provides structured or unstructured data. The selection of Data Source is directly influenced by the characteristics and needs of the Audience, as different user groups require varying types of data to facilitate decision-making and interaction with the dashboard. This influence relationship reflects how user expectations dictate what kind of data should be collected, stored, and processed to ensure the dashboard delivers relevant insights. By adopting the <<datatype>> stereotype for Data Source, the IDDO framework ensures that data sources are modeled as informational elements rather than identity-providing entities. This classification maintains conceptual clarity and adheres to Guizzardi’s principle of ontological adequacy, which emphasizes that formal modeling should accurately reflect the real-world roles of entities within a system.

In addition to influencing the Data Source, the Audience also governs by two IG principles, namely “Transparency” and “Accountability”, both of which are stereotyped as <<quality>>. These intrinsic, measurable properties guide how the audience's needs are defined and considered throughout the dashboard design process. The governance relationship ensures that the dashboard provides clear visibility into the data processes (Transparency) while also maintaining responsibility in how user roles and access are managed (Accountability).

Furthermore, the Audience informs the “User Interface”, which is stereotyped as <<kind>>. This relationship highlights how the expectations, preferences, and interaction behaviors of users shape the design and functionality of the dashboard's interface. A user-centric interface is essential to ensuring that information is presented in a way that is accessible, intuitive, and aligned with the cognitive and operational needs of the audience.

c. Data source and data processing

The next fragmented IDDO diagram, shown in Figure 4.14 below illustrates the relationship between Data Source and Data Processing, along with the governing IG principles.

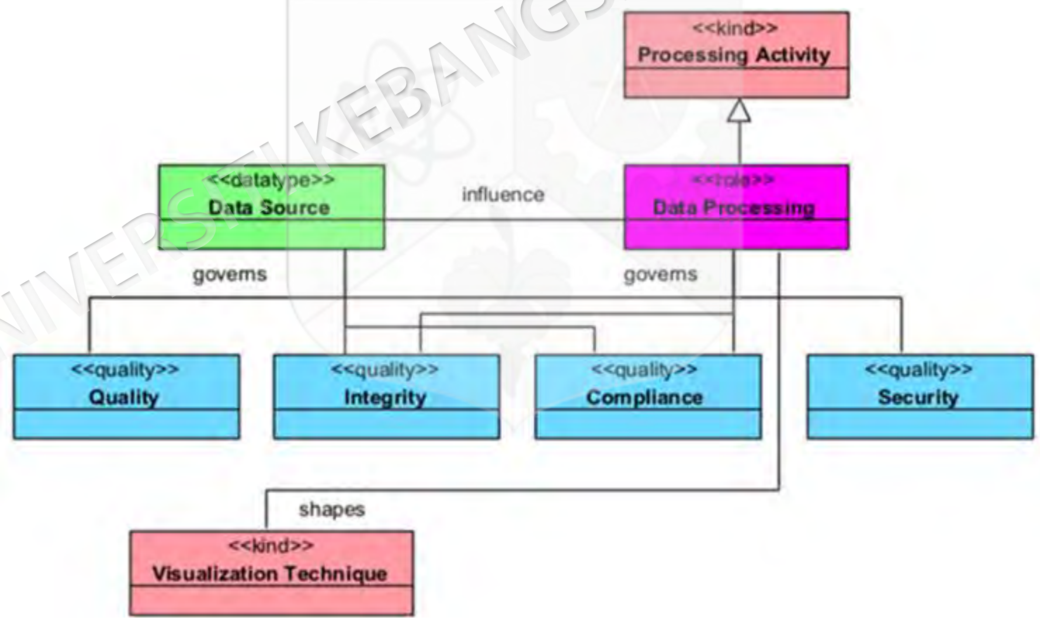

Figure 4.14 Fragment of the IDDO framework - data source, data processing and governing IG principles

The “Data Source”, as <<datatype>>, plays a crucial role in influencing “Data Processing”, which is assigned the <<role>> stereotype. This distinction is significant because, unlike identity-providing entities, the Data Source does not function as an independent conceptual entity but rather as an informational construct that provides structured or unstructured data. The type of data available from a Data Source directly affects how it is processed. For instance, if the Data Source originates from a real-time IoT sensor network, it influences Data Processing to adopt real-time data streaming and live analytics. Conversely, if the Data Source consists of historical sales data, the influence extends toward batch processing and trend analysis, demonstrating how data sources dictate different approaches to processing within the dashboard framework.

In alignment with OntoUML modeling principles, the “Processing Activity”, stereotyped as <<kind>>, serves as the superclass for “Data Processing”, ensuring that Data Processing is correctly categorized as a <<role>>. According to Guizzardi (2005), the <<role>> stereotype must always be associated with a foundational category such as <<kind>>, <<collective>>, <<quantity>>, <<relator>>, <<quality>>, or <<mode>>. Without such an association, a role cannot exist independently. Therefore, the inclusion of Processing Activity (<<kind>>) is necessary to provide an ontological anchor for Data Processing, ensuring structural correctness within the IDDO framework. The Processing Activity conceptually generalizes various forms of Data Processing, encompassing different data handling methods that may change depending on context, use case, or operational requirements.

The relationship between “Data Source” and “Data Processing” is modeled as “influence”, which signifies that the nature and characteristics of the data source shape the way data is processed. However, unlike other semantic relationships explicitly labeled in the diagram, the association between “Processing Activity” and “Data Processing” does not carry an explicit semantic label. This follows Guizzardi’s ontological principles, which state that superclass-subclass relationships in a conceptual model do not require explicit semantic relationships because they are inherently characterized by generalization. The absence of an explicit semantic relationship does not imply the absence of meaning; rather, it signifies that “Processing Activity” is a more general category that naturally encompasses “Data Processing” without requiring an interaction-based association. This modeling choice maintains the ontological clarity of the framework while ensuring that relationships are structurally sound.

In addition to its role in shaping Data Processing, the Data Source is governed by three IG principles: Quality, Integrity, and Compliance, all of which are stereotyped as <<quality>>. These IG principles are critical in ensuring that the Data Source remains a reliable foundation for decision-making and visualization. The Quality principle ensures that the data is accurate, complete, and reliable, contributing to the overall effectiveness of the dashboard. The Integrity principle maintains data consistency, preventing corruption or unauthorized modifications that could compromise the accuracy of insights. Meanwhile, the Compliance principle ensures that the handling and usage of data adhere to regulatory requirements, policies, and best practices, mitigating risks related to governance and accountability.

By governing both “Data Source” and “Data Processing”, these IG principles ensure that data remains trustworthy and maintains high standards of accuracy and consistency throughout its lifecycle, from acquisition to visualization. Furthermore, “Data Processing” shapes “Visualization Technique”, reinforcing the idea that the way data is processed directly impacts how it can be represented visually. The specifics of this relationship will be explored further in the sections discussing “Visualization Technique” and “Layout”, where the transformation of raw data into meaningful insights is elaborated.

d. Style and visualization technique

Figure 4.15 below depicts the “Style” and “Visualization Technique” concepts in the IDDO.

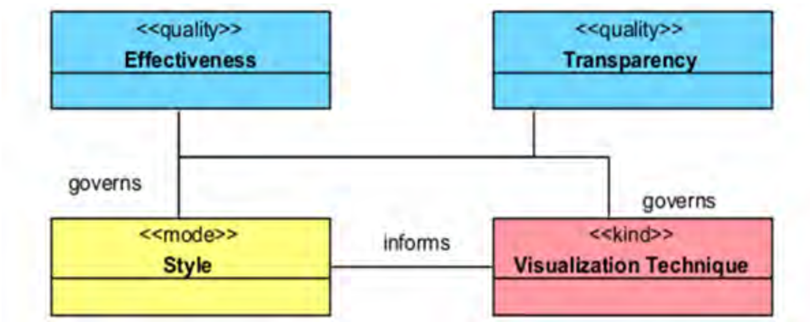

Figure 4.15 Fragment of the IDDO framework – style, visualization technique, and governing IG Principles

The fragmented diagram above illustrates the relationship between “Style”, stereotyped as <<mode>>, and “Visualization Technique”, which is stereotyped as <<kind>>. “Style” represents the overall aesthetic and functional approach of the dashboard, influencing how data is visually presented. Meanwhile, “Visualization Technique” refers to the method used to graphically represent data, aiding in the communication of complex information in a manner that is easily interpretable for users.

The “informs” relationship between “Style” and “Visualization Technique” signifies that the chosen style guides the selection and implementation of specific visualization methods. For instance, a minimalist dashboard style might inform the use of simple, clean charts with minimal color and clutter, while a more elaborate style might suggest detailed, multi-layered visualizations with intricate graphical elements. This relationship ensures a cohesive visual language throughout the dashboard, aligning visualization techniques with the overall style while maintaining effectiveness in representing data.

Two IG principles, “Effectiveness” and “Transparency”, govern both “Style” and “Visualization Technique” to ensure that design choices are both visually appealing and functionally effective. These principles play a crucial role in maintaining clarity and usability in data presentation, ensuring that the dashboard not only conveys insights accurately but also supports user comprehension and decision-making.

“Effectiveness” governs these concepts by ensuring that the chosen style and visualization techniques optimally convey information, enhancing the ability of users to analyze and interpret data efficiently. “Transparency” governs by ensuring that visual representations present data clearly and honestly, avoiding distortion or misleading graphical elements. For instance, an effective and transparent bar chart would use consistent scales, clear labeling, and proportional representations to provide an accurate and unbiased depiction of data comparisons.

e. Visualization Technique and Layout

Figure 4.16 below illustrates the relationship between “Visualization Technique” and “Layout”.

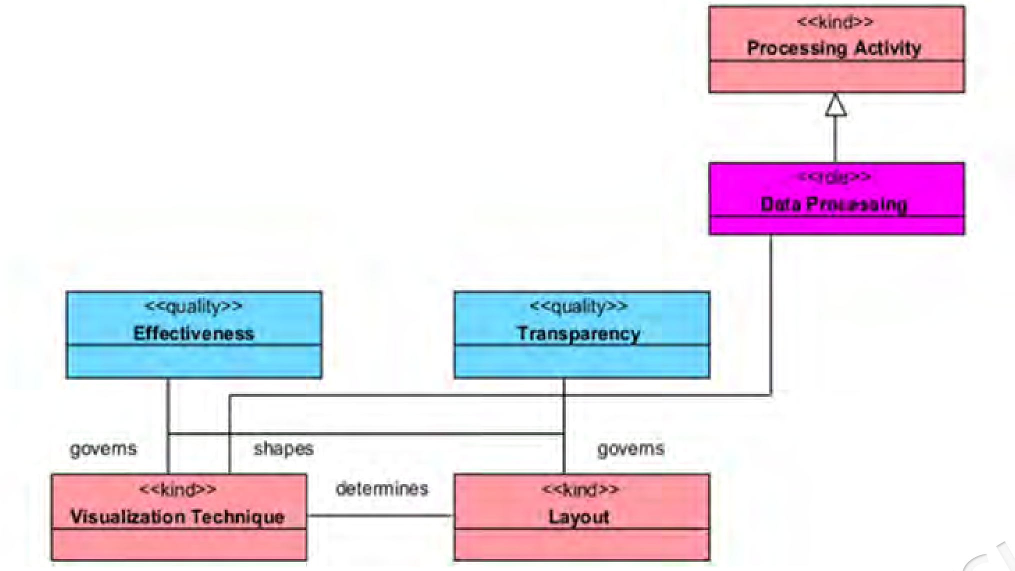

Figure 4.16 Fragment of the IDDO framework – visualization technique, layout and governing IG principles

The "determines" relationship between "Visualization Technique" and "Layout" signifies a stronger dependency compared to the "informs" relationship in previous diagrams. This suggests that the selection of visualization techniques has a direct and substantial impact on how the dashboard's layout is structured. For example, choosing a geographical map visualization would necessitate a significant portion of the layout to accommodate spatial data, whereas a simple bar chart would require far less space and allow for a different organizational approach.

The diagram also illustrates the "shapes" relationship between "Data Processing" and "Visualization Technique", highlighting how processed data informs the choice of visualization methods. The inclusion of "Processing Activity" as a superclass of "Data Processing" and its governance by IG principles has been previously discussed. This relationship emphasizes that insights derived from data processing influence the selection of visualization techniques, ensuring that information is presented in a manner that enhances interpretation and decision-making. In this context, data processing plays a crucial role in shaping visualization strategies, ensuring that complex datasets are communicated effectively within an information dashboard.

Both "Visualization Technique" and "Layout" continue to be governed by Effectiveness and Transparency, reinforcing the dashboard's overall design philosophy.

This dual governance ensures that visualization methods and their spatial arrangement are not only aesthetically consistent but also effectively communicate insights with clarity. The Effectiveness principle ensures that visualization techniques and layout choices optimize user comprehension and decision-making, while Transparency guarantees that data is represented accurately, without distortion or misleading graphical elements.

f. Layout and structure

The “Layout” that “organizes” the “Structure” relationship is depicted in Figure 4.17 below:

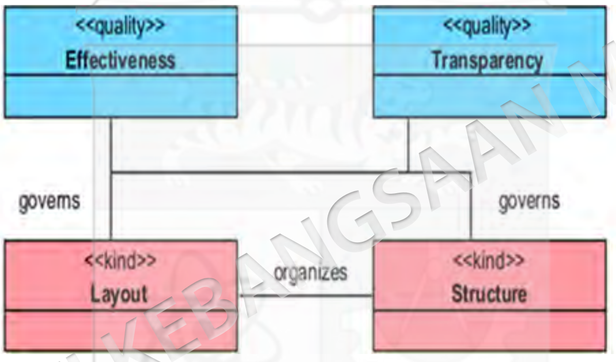

Figure 4.17 Fragment of the IDDO framework – layout, structure, and its governing IG principles

In this relationship, “Layout” organizes the overall “Structure” of the dashboard, another element stereotyped as <<kind>>. The “organizes” relationship signifies that the layout provides the framework within which the structural elements of the dashboard are arranged and connected. Instead of rigidly determining specific elements, Layout ensures that the structural components of the dashboard are positioned in a way that maintains usability, coherence, and logical flow.

For instance, if a bar chart is chosen to display sales data, it might be placed at the top of the dashboard to provide a quick visual summary. This decision reflects how Layout organizes Structure by ensuring that key insights are positioned prominently while maintaining a consistent arrangement of elements within the dashboard.

The governance of both “Layout” and “Structure” by “Effectiveness” and “Transparency” ensures that the organization of dashboard components is both efficient in conveying information and clear in presentation. This governance promotes a logical flow of information and an intuitive user experience, ensuring that data is displayed in a way that is both functional and visually accessible.

g. Structure and user interface

The next fragmented diagram, depicted in Figure 4.18 below illustrates the “organizes” relationship between “Structure” and “User Interface”.

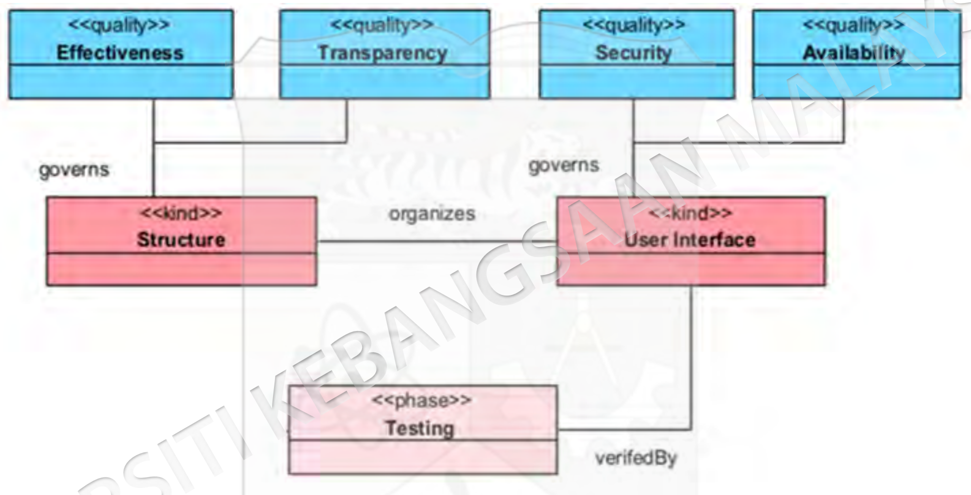

Figure 4.18 Fragment of the IDDO framework – structure, user interface and its governing IG principles

Both “Structure” and “User Interface” are stereotyped as <<kind>>, representing core identity-providing elements of the dashboard. The “organizes” relationship between these concepts indicates that the underlying structure of the dashboard provides the framework within which the user interface is designed and implemented. Rather than dictating individual UI components, Structure ensures that UI elements align with the overall architectural foundation of the dashboard to maintain consistency, usability, and logical flow.

For instance, if a temperature graph is positioned at the top of the dashboard within the structural framework, the User Interface might extend this by enabling users to interact with the graph, such as clicking on data points to view precise temperature values at different times. This highlights the interactive nature of the dashboard, where Structure, through its organization, facilitates user engagement with UI components. The relationship between Structure and Layout (discussed earlier) further reinforces how these elements work in tandem to create an intuitive user experience.

The “Structure” is governed by the IG principles of “Effectiveness” and “Transparency”, both stereotyped as <<quality>>. This governance ensures that the structural organization of the dashboard effectively conveys information and maintains clarity, preventing design choices that may obscure critical insights.

Meanwhile, the “User Interface” is governed by “Security” and “Availability”, both also stereotyped as <<quality>>, reflecting its role as the primary interaction layer between users and the dashboard. Security ensures that user access and data handling within the interface remain protected, preventing unauthorized modifications or data breaches. Availability guarantees that the dashboard remains consistently accessible, ensuring users can reliably interact with its functionalities without disruptions.

The “User Interface” is verified by the “Testing” phase, which is stereotyped as <<phase>>, indicating an iterative evaluation process. As a recurring stage in the dashboard lifecycle, Testing validates UI functionalities, particularly in ensuring compliance with security and availability requirements. This relationship underscores that Testing is not a one-time event but an ongoing mechanism for refining user interactions, identifying vulnerabilities, and improving accessibility. The role of Testing and its impact on other dashboard components will be elaborated in the next subsection.

h. Testing, evaluation, and continuous improvement

The last fragmented diagram, depicted in Figure 4.19 below explains the relationship between three concepts of the IDDO – “Testing”, “Evaluation” and “Continuous Improvement”.

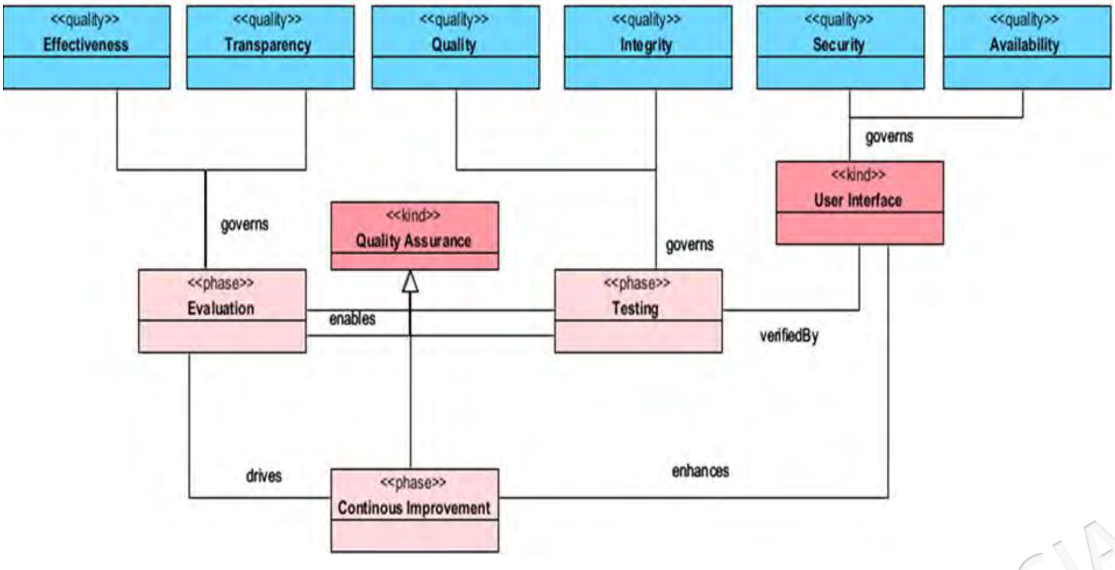

Figure 4.19 Fragment of the IDDO framework – testing, evaluation, continuous improvement and its governing IG principles

“Testing”, “Evaluation”, and “Continuous Improvement” are all stereotyped as <<phase>>, representing temporal stages within the dashboard's lifecycle. In OntoUML, <<phase>> is used to model non-permanent states that an entity transitions through over time, rather than static, identity-providing concepts. According to Guizzardi (2005), every <<phase>> must be ontologically anchored to a foundational category, such as <<kind>>, <<collective>>, <<quantity>>, <<relator>>, <<quality>>, or <<mode>>. This ensures that phases are not floating concepts but structurally integrated into a well-founded ontological framework.

To satisfy this ontological requirement, “Quality Assurance” is introduced as a <<kind>> and serves as the superclass for “Testing”, “Evaluation”, and “Continuous Improvement”. In OntoUML, a superclass-subclass relationship signifies that the subclass inherits fundamental characteristics from the superclass, while still maintaining unique properties specific to each phase. This means that “Testing”, “Evaluation”, and “Continuous Improvement” are all specialized instances of “Quality Assurance”, ensuring that each phase is part of a structured quality management framework rather than independent processes.

The structured superclass-subclass relationship creates a hierarchical improvement cycle. The “User Interface” is “verified by” Testing, confirming that UI components undergo structured validation. Testing then enables Evaluation, ensuring that the dashboard is assessed for effectiveness, usability, and compliance with user expectations. Evaluation, in turn, drives Continuous Improvement, demonstrating how assessment insights guide refinements and feature enhancements. Finally, Continuous Improvement enhances the User Interface, incorporating refinements that improve usability, functionality, and overall user experience based on findings from evaluation and testing.

Each phase within this cycle is governed by relevant IG principles, ensuring that it adheres to quality and transparency standards. “Testing” is governed by “Quality” and “Integrity”, ensuring that testing procedures meet high standards and maintain data integrity. “Evaluation” is governed by “Effectiveness” and “Transparency”, ensuring that assessment methods align with dashboard objectives and that results are communicated clearly. These governance mechanisms collectively ensure that Quality Assurance functions as the overarching framework that integrates testing, evaluation, and continuous improvement into the dashboard lifecycle, ensuring that it remains reliable, usable, and secure over time.

The IDDO’s ontology-driven approach to dashboard design provides a structured framework where each element is conceptually aligned, semantically clear, and ontologically sound. By employing OntoUML, the framework maintains its integrity while offering flexibility for domain-specific adaptations. This approach supports the development of information dashboards that balance governance, usability, and adaptability.

4.10.1 Implementing and Testing

The “Implementing and Testing” phase is a crucial step in ontology development, as outlined in the UOA. This phase involves putting the formalized ontology into practice and verifying its functionality (Uschold 1996).

In the context of the IDDO, this phase has been implemented and tested using “tool-based evaluation” specifically the OntoUML Plugin in Visual Paradigm. This tool is particularly suited for ontology testing as it can detect syntactical errors and ensure compliance with OntoUML rules. The report generated by this tool confirmed that no syntactical errors were detected in the IDDO framework. This absence of errors indicates that the IDDO has been correctly formalized and is in full accordance with OntoUML rules. The screenshot proving that the IDDO diagram is syntactically error-free is depicted in Figure 4.20.

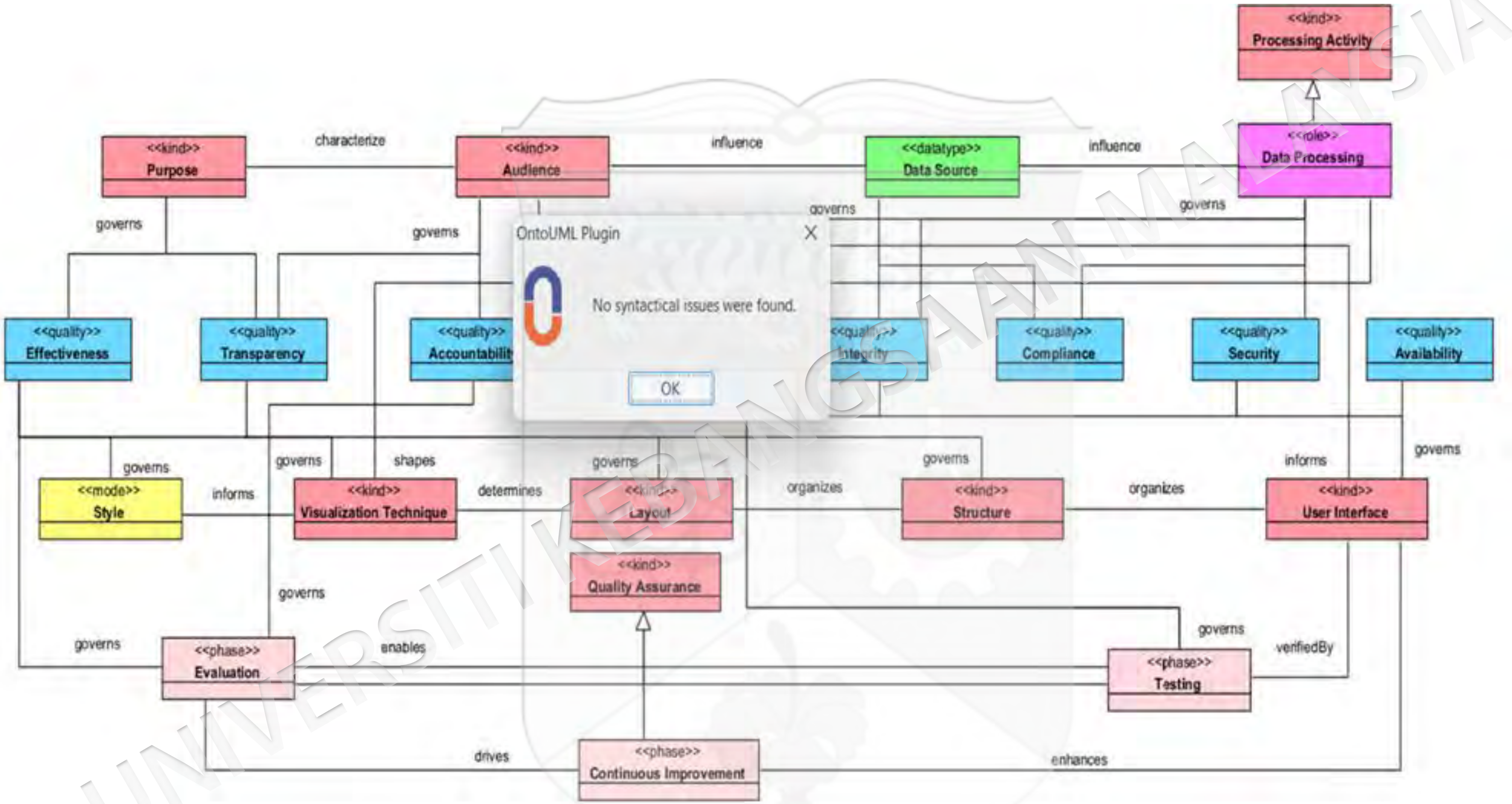

Figure 4.20 Syntactical validation results of the IDDO framework using the OntoUML plugin in visual paradigm

4.10.2 Conclusion

As a conclusion, the IDDO provides a comprehensive framework for conceptualizing and developing effective information dashboards. By fragmenting the IDDO into its constituent parts, a clear understanding of how each component contributes to the overall design and functionality of a dashboard is gained. The use of OntoUML stereotypes such as <<kind>>, <<quality>>, <<mode>>, <<role>>, and <<phase>> allows for a nuanced representation of dashboard elements, capturing their essential nature and relationships. The governance of key components by IG principles ensures that dashboards adhere to critical standards of effectiveness, transparency, accountability, quality, integrity, compliance, security, and availability. The IDDO's structure, from defining purpose to the cyclical process of testing, evaluation, and continuous improvement, provides a robust foundation for creating dashboards that are not only functionally sound but also adaptable to changing needs. This ontological approach to dashboard design facilitates a systematic, principle-driven development process that can lead to more effective, user-centric, and governable information dashboards across various domains.

The next section holds significant importance as it will detail the transformation of the IDDO into the IDMM, a practical and actionable version for users. This transition marks a critical step in making the theoretical framework of the IDDO accessible and applicable in real-world scenarios.

4.11 TRANSFORMING THE IDDO INTO THE IDDM

The transformation of a conceptual ontology into a practical, user-friendly tool is a crucial step in bridging theoretical frameworks with real-world applications. This process is exemplified by the evolution of the BMO into the widely adopted BMC (Osterwalder et al. 2010). The BMC's success lies in its ability to translate complex ontological concepts into an intuitive, visual tool that entrepreneurs and business strategists can easily apply (Massa et al. 2017).

Similarly, this study aims to transform the IDDO into the IDDM. This transformation makes ontological knowledge more accessible to practitioners who may not be versed in formal ontology languages (Hepp 2008). It also facilitates the practical application of the ontological framework in real-world dashboard design scenarios (Few 2006). Lastly, it bridges the gap between theoretical conceptualization and practical implementation, a critical step in DSR (Hevner et al. 2004).

The IDDM, as a practical and actionable version of the IDDO, aims to provide dashboard designers with a structured approach to creating effective information dashboards. This transformation process not only enhances the usability of the ontological knowledge but also contributes to the field by offering a standardized method for dashboard design, potentially improving the quality and effectiveness of information dashboards across various domains (Yigitbasioglu & Velcu 2012).

In this section, the process of transforming the IDDO into the IDDM will discussed comprehensively, highlighting how key ontological concepts are translated into practical information dashboard design guidelines and tools. This transformation represents a critical step in realizing the full potential of IDDO and in providing tangible value to the information dashboard design community.

4.12 INTRODUCING THE IDDM CANVAS

The IDDM represents a significant advancement in the field of information dashboard design, offering a structured and practical framework that builds upon the foundational concepts of the IDDO. Similar to how Osterwalder et al. (2010) transformed the BMO into the widely adopted BMC, the IDDM aims the same, to translate complex ontological concepts into an intuitive and actionable tool for practitioners.

Osterwalder's BMC became renowned for its ability to simplify and visualize business model concepts, making them accessible to entrepreneurs and business strategists (Osterwalder et al. 2010). The success of the BMC lies in its user-friendly design and practical applicability, which have made it a staple in business model innovation (Massa et al. 2017). In a similar vein, the IDDM seeks to make ontological knowledge more accessible and practical for dashboard designers.

The IDDM is characterized by its emphasis on usability and practicality, ensuring that the complex ontological concepts of the IDDO are translated into actionable design principles. This model serves as a unified method for dashboard design, aiming to enhance the quality and effectiveness of information dashboards across various domains. Mirroring the BMC, the IDDM is represented in the form of a canvas, where users are required to jot down their ideas in all 12 sections of the IDDM. Ultimately, all information contained in these 12 sections will be used as a guideline to design and develop a real and usable information dashboard. Figure 4.21 below shows the IDDM base canvas template.

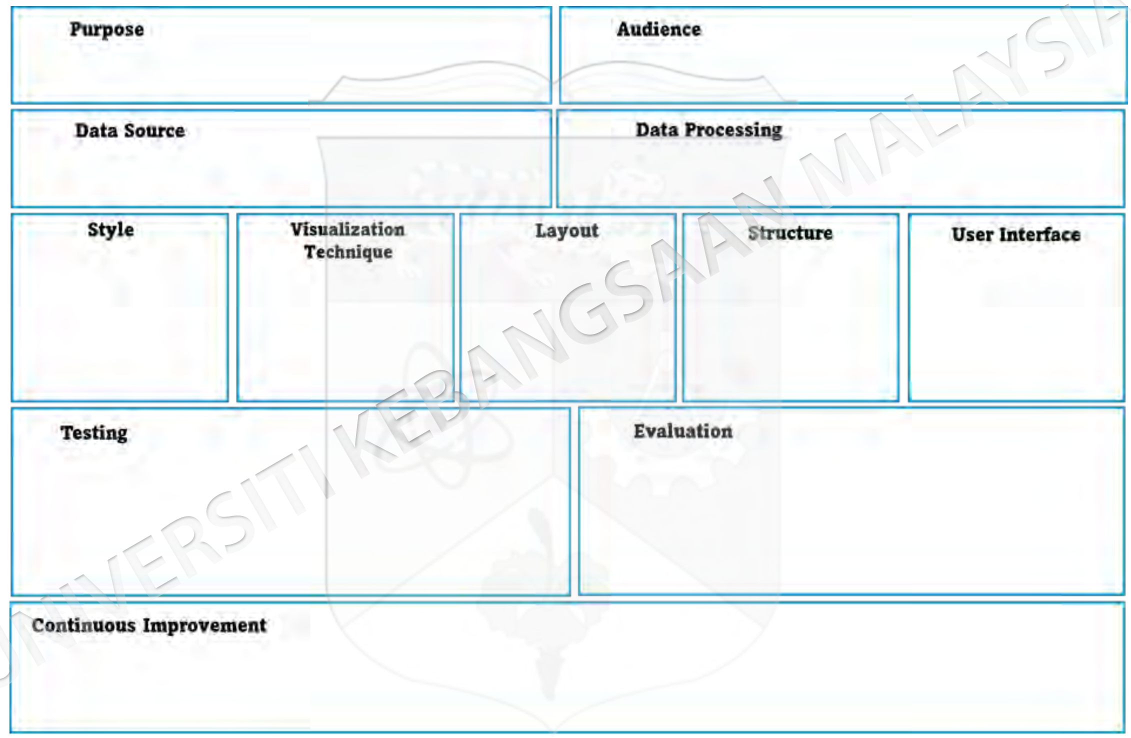

Figure 4.21 The IDDM base canvas template

The IDDM base canvas template depicted in Figure 4.21 above represents a brief visualization of the IDDM, where there are 12 sections organized in boxes. These 12 sections are the key building blocks of the IDDO. The organization of the IDDM into 12 sections ensures comprehensive coverage and a structured approach, similar to the BMC, facilitating ease of use and iterative development. This base template serves as the initial outlook of how the IDDM will look in the form of a canvas.

The arrangement of the IDDM sections is slightly different from the IDDO. While the IDDO as depicted in Figure 4.11 places “Testing” on the right, “Evaluation” on the left, and “Continuous Improvement” at the bottom, the IDDM reorganizes these elements to fit a more intuitive and user-friendly canvas format. In the IDDO, association lines show the connection and flow between sections, whereas the canvas does not. By slightly reorganizing “Testing” and “Evaluation,” users can better understand the process. Typically, after completing the line on the right, people start the new line from the left, making the workflow more logical and easier to follow.

Figure 4.22 below depicts a refined IDDM canvas. The refined IDDO framework shows several enhancements compared to the base template. It is divided into three main categories: “Defining and Planning,” “Design and Visualization,” and “Testing and Improvement,”. This categorization aids in organizing the process more clearly and systematically. Each main category contains specific elements, paramount in information dashboard design and development.

The Defining and Planning category encompasses the initial stages of the dashboard design and development process, including elements such as establishing the primary goals and objectives (Purpose), identifying the target users and their specific needs (Audience), determining the sources of data (Data Source), and outlining the methods for processing and preparing data for visualization (Data Processing).

The Design and Visualization section focuses on the creative and technical aspects of dashboard creation, involving elements like defining the overall aesthetic and design principles (Style), selecting appropriate visualization methods (Visualization Technique), planning the arrangement of different components (Layout), organizing the information logically (Structure), and designing an intuitive user interface (User Interface).

The Testing and Improvement category is dedicated to the iterative process of testing and refining the dashboard, including conducting usability tests (Testing), gathering feedback to assess performance (Evaluation), and lastly, the “Continuous

Improvement," emphasizing the ongoing process of refining and enhancing the dashboard based on user feedback and evolving requirements.

Apart from the categorization, all sections are color-coded, visually distinguishing different types of activities and making the framework easier to navigate. These refinements make the IDDM canvas more user-friendly and ensure comprehensive coverage of all critical components, facilitating a structured and iterative development process.

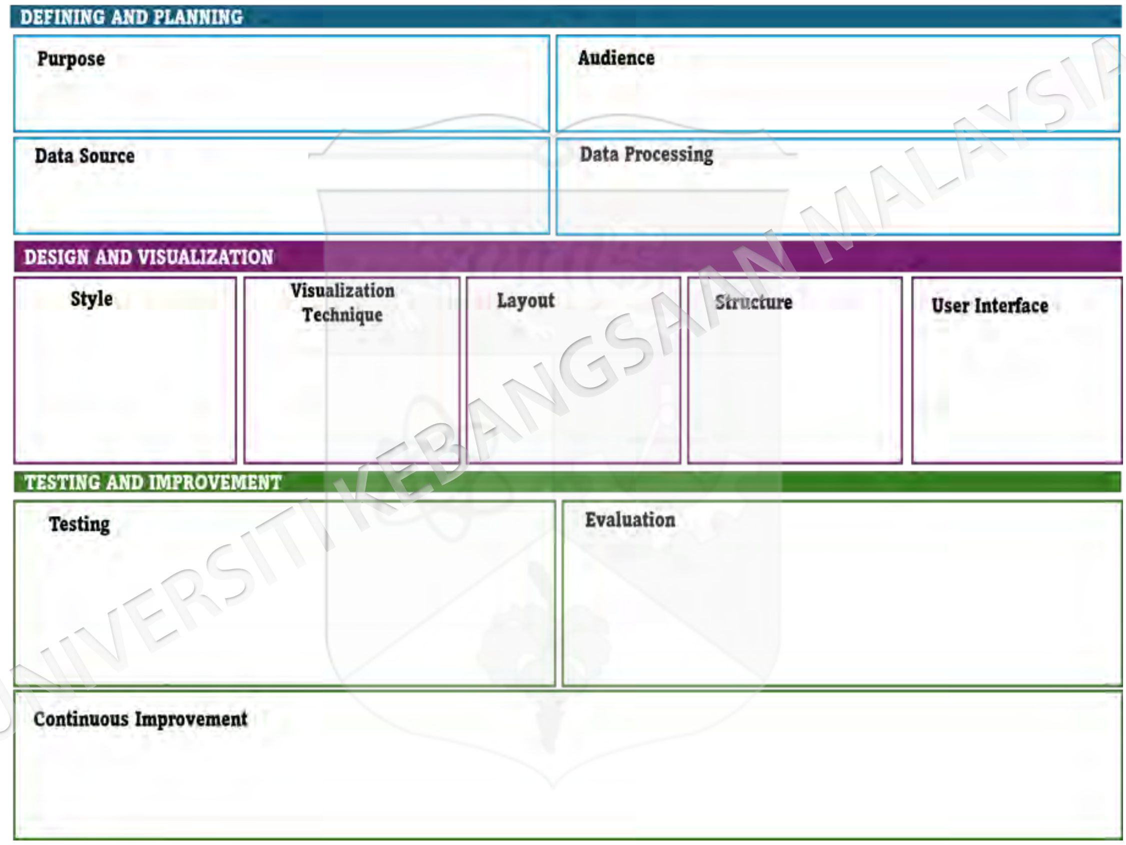

Figure 4.22 The refined IDDM canvas template

In a nutshell, the refined IDDM aims to facilitate the creation of dashboards that are not only visually appealing but also functionally robust and user-centric. The IDDM derives from the key ontological concepts of the IDDO, providing a theoretical foundation that enhances the practical application of design principles. It promotes standardization and consistency in dashboard design, enabling designers to create dashboards that adhere to best practices and industry standards. Additionally, the IDDM is designed to be flexible and adaptable, allowing designers to tailor the model to the specific contexts and requirements of different projects.

In the next sub-section, the focus will be on providing guidance on how to effectively use the IDDM.

4.13 GUIDELINES FOR USING THE IDDM

To effectively utilize the IDDM, it is essential to follow the structured guidelines embedded within the framework. These guidelines ensure that the dashboard development process is both systematic and adaptable, allowing for the creation of visually appealing, functionally robust, and user-centric dashboards.

As discussed previously, in addition to the 12 building blocks that constitute the IDDO, there are also eight IG principles integrated into the framework as foundational governance elements. These IG principles govern each element of the IDDO to ensure adherence to certain standards, thereby producing effective dashboards.

In the IDDM depicted in Figure 4.22, only the 12 key elements are displayed, without the explicit integration of IG principles. As explained earlier, the role of IG in the IDDO is to provide foundational governance for the entire dashboard development process. Therefore, it is not visually represented in the IDDM canvas template.

However, in the guidelines embedded within the IDDM canvas shown in Figure 4.23, the IG principles are indirectly included in the form of directive statements. These statements, written in red, make the guidelines clearer and more actionable. For instance, the “Defining and Planning” section emphasizes the importance of aligning the dashboard’s purpose with organizational objectives and ensuring data sources are accurate and reliable. The “Design and Visualization” section includes directives on maintaining a consistent style, choosing appropriate visualization techniques, and ensuring the layout facilitates easy navigation. The “Testing and Improvement” section highlights the need for thorough testing, regular evaluation, and continuous improvement based on user feedback. Table 4.15 below summarizes these guidelines:

Table 4.17 Summary of guidelines for using the IDDM

Category	Element	Directive Statement
Defining and Planning	Purpose	State your dashboard's primary goal here. Ensure the purpose is clearly defined and aligned with organizational objectives.
	Audience	Define your intended users here. Ensure user roles and information needs are clearly identified and addressed.
	Data Source	Specify your data sources here. Ensure data is accurate, reliable, and obtained from authorized sources.
	Data Processing	Describe your data transformation methods here. Ensure data handling complies with relevant regulations and maintains data integrity.
Design and Visualization	Style	Define your visual style here. Ensure the design enhances data comprehension and maintains consistency.
	Visualization Technique	List your chosen visualization methods here. Ensure visualizations accurately represent data and are easily interpretable.
	Layout	Describe your dashboard layout here. Ensure the arrangement of elements promotes logical flow and easy navigation.
	Structure	Outline your information organization here. Ensure the structure facilitates quick understanding and supports data relationships.
	User Interface	Detail your user interaction design here. Ensure the interface is secure against unauthorized access and consistently available to users.
Testing and Improvement	Testing	Outline your functionality verification methods here. Ensure thorough testing of all features and data accuracy before deployment.
	Evaluation	Specify your effectiveness measurement methods here. Ensure regular assessment of the dashboard's performance and user satisfaction.
	Continuous Improvement	Define your update and refinement process here. Ensure a systematic approach to incorporating user feedback and emerging best practices.

For ease of reference, the guidelines for using the IDDM in Table 4.15 above are embedded in the IDDM canvas illustrated in Figure 4.23 below:

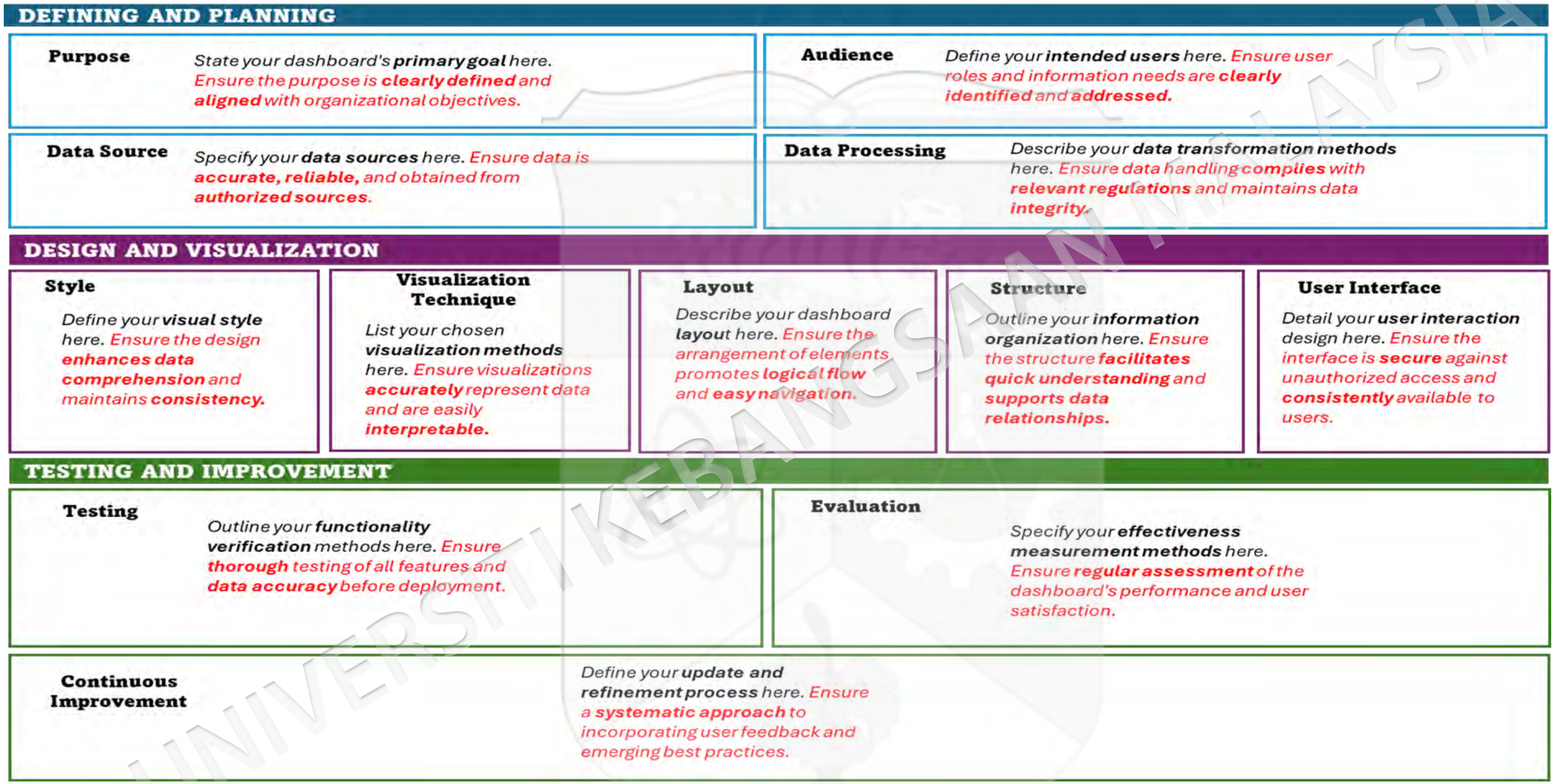

Figure 4.23 IDDM canvas with embedded guidelines

The derivation of the IDDM canvas in this chapter signifies that the artefact of the study has been successfully developed. The IDDM Canvas, developed using the ontological approach represented in the IDDO, demonstrates a structured and comprehensive framework for dashboard development. This framework integrates key elements and IG principles to ensure that the resulting dashboards are not only visually appealing but also functionally robust and user-centric.

As part of the DSRM processes, this IDDM should undergo the Demonstration and Evaluation phases, which will be discussed in detail in the next chapter. The demonstration of the IDDM will involve developing a conceptual mock-up dashboard called Intelligent Monitoring Recycle System (I-MORSYS), a smart waste management system, specifically focusing on recycling and sustainability. The selection of a smart waste management system is due to the fact that there have been no studies focusing on developing such a dashboard so far. This demonstration will provide a clearer view of how the IDDM can be utilized to develop a dashboard, showcasing its practical application and effectiveness.

The demonstration will not only validate the IDDM framework but also highlight its adaptability and relevance in addressing real-world challenges. By focusing on a smart waste management system, the study aims to contribute to the field of environmental sustainability, providing valuable insights and tools for better resource management. The evaluation process will further assess the usability, functionality, and overall impact of the developed dashboard, ensuring that it meets the intended goals and standards.

4.14 DIFFERENTIATING IDDM FROM NARRATIVE TOOLS

In the context of dashboard design, the IDDM offers a structured framework that differs significantly from narrative-driven tools like storyboarding. While storyboarding is commonly used in UX design to visualize user journeys and interactions, IDDM focuses on organizing essential dashboard components to produce a Dashboard Design Blueprint (DDB) that guides developers in creating functional and effective dashboards.

Unlike storyboarding, which follows a linear narrative approach to illustrate step-by-step interactions, IDDM captures high-level requirements such as data sources, key metrics, and user roles. This approach ensures that the dashboard design remains focused on delivering actionable insights through structured visualizations rather than predefined interaction flows. According to Few (2006), dashboard development is fundamentally a data-driven process that prioritizes clarity and usability. Few emphasizes that the use of structured models, rather than narrative-driven approaches, is essential for ensuring the effectiveness of dashboards.

Eckerson (2010) further supports this view by highlighting the importance of benchmarking tools and structured frameworks in dashboard development. His study recommends using comprehensive models to capture the core elements required for an effective dashboard. Interestingly, storyboarding is notably absent from Eckerson's recommendations, indicating that it is not considered a critical component of the dashboard design process. Instead, Eckerson advocates for models that focus on identifying and organizing dashboard elements to achieve optimal user experience and functionality.

IDDM addresses key considerations in dashboard design by emphasizing modular components that can be adapted to meet varying user needs. Few (2006) underscores that dashboards should prioritize user experience through clear and interactive data visualizations. The goal is to present information in a way that users can easily interpret and act upon. IDDM serves this purpose by providing a practical canvas for capturing user requirements and visualizing the overall structure of the dashboard. Unlike narrative tools, it allows for the flexible arrangement of data and visual components without imposing a sequential user journey.

Therefore, based on existing literature, the use of structured frameworks like IDDM aligns more closely with best practices in dashboard development. Storyboarding, while valuable in other contexts such as UX design or guided workflows, is not essential for creating a Dashboard Design Blueprint (DDB). IDDM's focus on high-level requirements and modular design makes it a more suitable tool for developing dashboards that are clear, actionable, and user-centric.

4.15 SUMMARY

The process of designing and developing the IDDO within this chapter has culminated in the establishment of a potentially comprehensive framework that aims to guide the creation of effective information dashboards. By synthesizing insights from a wide array of related works, the chapter demonstrates a structured approach to identifying key building blocks that are essential for dashboard design. The iterative refinement of these components suggests that the resulting IDDO framework may be both theoretically sound and practically applicable.

This chapter represents a pivotal stage in this study, as it is here that the primary artifact - the IDDM is introduced. The development of the IDDM is achieved through an ontological approach, encapsulated in the IDDO framework, which formalizes the essential building blocks for information dashboard design. By adopting an ontological representation, this chapter provides a structured and systematic foundation for the subsequent implementation and application of the IDDM.

A key outcome of this chapter lies in the articulation of 12 critical building blocks that underpin the IDDO. These blocks, ranging from defining the dashboard's purpose and audience to continuous improvement, collectively form a holistic methodology that potentially accommodates both the technical and user-centric dimensions of dashboard development. Each building block was derived from commonalities in existing literature, suggesting that the IDDO framework is grounded in best practices while allowing flexibility for contextual adaptations.

This chapter also highlights the potential importance of a user-centered and iterative approach to dashboard design. The IDDO framework is not intended to be a static model but a dynamic one that evolves through continuous evaluation and feedback. This adaptability is essential in addressing the varying needs of different application domains and ensuring that dashboards remain relevant in rapidly changing environments. The iterative nature of the framework aligns with the principles of DSR, where artifacts undergo repeated cycles of development, testing, and refinement.

The addition of Section 4.4.13 further distinguishes IDDM from narrative-driven tools such as storyboarding, emphasizing that the IDDM framework prioritizes high-level requirements and modular design over linear user journeys. This differentiation highlights the practical relevance of structured frameworks in creating actionable and user-centric dashboards, aligning with the overall objectives of the IDDO framework.

Furthermore, the categorization of building blocks into defining and planning, design and visualization, and testing and improvement provides a logical structure that reflects the typical stages of dashboard development. This structured categorization potentially enhances the usability of the IDDO framework, making it a practical tool for dashboard designers and developers.

One notable aspect of this chapter is the proposed integration of IG principles into the IDDO framework. The inclusion of IG principles aims to ensure that the dashboards developed using the IDDO framework adhere to data quality, security, and compliance standards. By embedding these governance principles into the design process, the IDDO framework seeks to address critical issues related to data accuracy, privacy, and transparency, which are increasingly important in today's data-driven environments.

The derivation of IG principles from established models and related works further suggests the robustness of the IDDO framework. This integration of IG principles is expected to enhance the reliability and integrity of information dashboards and ensure their long-term sustainability and relevance. The alignment of IG principles with key design elements underscores the holistic nature of the IDDO framework, where technical, aesthetic, and governance aspects are seamlessly integrated.

Overall, this chapter potentially contributes to the field of information dashboard design by presenting a comprehensive and adaptable framework that addresses both the practical and theoretical aspects of dashboard development. The IDDO framework, with its 12 building blocks and embedded IG principles, offers a methodology for creating dashboards that are user-friendly, functionally effective, and compliant with governance standards. The insights and methodologies presented in this chapter lay a foundational basis for the subsequent stages of this research, where the IDDO will be further refined and transformed into the actionable IDDM.

As this study progresses into Chapter 5, the focus will shift towards the Demonstration and Evaluation of the IDDM Canvas. This next chapter will showcase how the IDDM Canvas can potentially be utilized to produce mock-up dashboards, highlighting its practical applicability in guiding the dashboard design process. The demonstration aims to provide insights into the effectiveness of the proposed framework and offer a step-by-step walkthrough of the IDDM Canvas in action.

CHAPTER V

PUTTING IDDM CANVAS TO WORK: DEMONSTRATION AND EVALUATION IN REAL-WORLD SCENARIOS

5.1 INTRODUCTION

This chapter focuses on demonstrating and evaluating the IDDM canvas developed in Chapter 4. As part of the DSRM process outlined by Peffers et al. (2007), it is crucial to apply the artifact created in this study - the IDDM framework to real-world scenarios to validate its effectiveness and practicality.

The demonstration of the IDDM framework is conducted through the development of two mock-up dashboards for the Intelligent Monitoring Recycle System (i-MORSYS), a conceptual dashboard designed for smart waste management, with a strong emphasis on recycling and sustainability. The name i-MORSYS is uniquely coined to reflect the system's core objectives and envisioned design.

A mock-up refers to a full-scale or scaled model used for demonstration, design evaluation, and user feedback before final development. In the context of visualization and interface design, mock-ups visually represent the final look of a system without incorporating full functionality(Nurulhuda et al. 2024). According to Snyder (2003), mock-ups help designers and developers refine the visual structure and layout before the system is fully implemented. By using mock-ups, this study ensures that the dashboard's design and usability can be assessed and refined before proceeding with full-scale development (Sharp et al. 2019).

It is important to highlight that the primary artifact and key research contribution of this study is the IDDM framework, which provides a structured methodology for dashboard design and development. The mock-up dashboard serves solely as a demonstration tool to showcase how IDDM can be applied in a real-world scenario.

Since the purpose of the demonstration and evaluation process in this study is to evaluate the effectiveness of IDDM rather than to develop a fully functional dashboard, mock-ups are sufficient for validation. A similar approach was employed by Nurulhuda et al. (2024) in showcasing the initial stage of a community dashboard, where mock-ups served as prototyping tools to obtain early feedback. In the broader context of DSR, this approach can also be understood as a form of prototyping-based evaluation. Prototyping, whether in the form of low-fidelity sketches, conceptual frameworks, or system mock-ups, provides a means to externalize design ideas, obtain feedback, and iteratively refine artefacts before full-scale development (Snyder 2003; Sharp et al. 2019). Within this study, the IDDM Canvas itself can be viewed as a methodological prototype—a structured representation of dashboard design processes that requires validation through application in real-world scenarios. The i-MORSYS mock-up dashboards, therefore, serve as system-level prototypes instantiated from this methodological prototype.

The choice of employing prototyping as the evaluation strategy is consistent with established practice in design and innovation research. Prototyping has long been regarded as the heart of the innovation process, enabling both analytical refinement and creative exploration of design artefacts (Lee 2020; Yu et al. 2018) . Beyond serving as a tangible representation, prototypes play a critical role in generating design knowledge and facilitating iterative improvement (Real et al. 2022) . This perspective positions the IDDM Canvas not merely as a static blueprint, but as a prototype in its own right—an evolving methodological artefact that can be tested, refined, and validated through application in practical contexts. Similar to how prototyping has been used to validate complex frameworks in other domains (Sanz-Blasco et al. 2025) , the demonstration of IDDM through mock-up dashboards serves as a mechanism to assess its usability, clarity, and transferability. Moreover, involving independent dashboard designers as evaluators is aligned with the recommendation that prototypes be used as externalizable knowledge tools, reducing the novice tendency to underutilize them and ensuring unbiased assessment of the artefact (Deininger et al. 2017).

In this study, the mock-up dashboards demonstrated are instances derived from the main artefact— the IDDM Canvas. The mock-ups (two dashboard types across two platforms) provide sufficient demonstration scope consistent with DSR principles (Hevner et al. 2004), focusing on utility and efficacy rather than exhaustive coverage. The mock-ups demonstrate the usability of the IDDM, and in line with the core objective, to assess whether IDDM can effectively guide the dashboard development process.

The i-MORSYS mock-up dashboard will be developed using the IDDM Canvas, where all required specifications are documented. The IDDM Canvas serves as a structured framework for defining key elements in i-MORSYS dashboard design. Once completed, the canvas will be considered as the Dashboard Design Blueprint (DDB), which serves as an official documentation for the dashboard developer to construct the i-MORSYS mock-up dashboard accordingly.

To ensure an objective evaluation and demonstrate the transferability of the IDDM framework, two independent professional dashboard designers were engaged to develop the mock-up dashboards rather than having them created by the researcher. This approach was deliberately chosen to assess whether the IDDM Canvas provides sufficient clarity and guidance for independent designers to translate the DDB into a mock-up dashboard. If the designer can successfully interpret and apply the framework with minimal clarification, it signifies that the IDDM Canvas is both practical and well-structured. Additionally, this approach avoids potential research bias that might occur if the researcher were to both develop the methodology and implement it.

The selection of i-MORSYS as the demonstration platform directly addresses the identified research gap, as no prior studies have specifically explored dashboard development for smart waste management systems. This study aims to bridge that gap by developing two distinct types of dashboards using the IDDM framework, with each type implemented on different visualization platforms. A brief description of these dashboards is outlined in Table 5.1 below.

Table 5.1 A brief description of the two dashboard types developed using the IDDM

Type of Dashboard	Description
1. Operational Dashboard	Focuses on real-time monitoring of recycling activities. Designed for waste management operators and collection teams to optimize daily operations.
2. Analytical Dashboard	Provides in-depth analysis of recycling trends, performance metrics, and sustainability indicators over time. Developed for decision-makers at waste management companies, local councils, and state government levels.

Operational dashboards are designed for real-time monitoring of key performance indicators (KPIs), enabling managers to make data-driven decisions efficiently (Gröger et al. 2013). These dashboards are particularly essential for day-to-day operations management, as they provide instant access to performance metrics (Ernie et al. 2018).

Analytical dashboards, on the other hand, are used to process and analyze large volumes of data, enabling users to identify trends, insights, and patterns for strategic decision-making (Nadj et al. 2020). These dashboards typically incorporate graphical representations and interactive functionalities, allowing users to explore data in depth (Dobraja & Kraak 2020).

To demonstrate the versatility and platform-independence of the IDDM framework, each dashboard type was implemented using two different visualization platforms chosen by the professional dashboard designers themselves. The designers selected platforms they were most familiar with and proficient in - one choosing Tableau and the other selecting Looker Studio based on their respective expertise. This approach not only showcases the adaptability of the IDDM across different development environments but also illustrates how the same methodological guidance can lead to different yet effective implementations based on platform capabilities and designer interpretation.

Following the demonstration, a comprehensive evaluation will be conducted to assess the usability, functionality, and overall impact of the developed dashboards. This evaluation will involve feedback from the dashboard designers who developed the mock-up dashboards and a waste management expert. The dashboard designers will share their firsthand experience in using the IDDM Canvas to construct the dashboards, providing valuable insights into the methodology's practical application from an implementer's perspective. The waste management expert will evaluate the dashboards from a domain-specific viewpoint. This multi-perspective approach ensures that the dashboards meet the intended goals and standards set forth by the IDDM. Through this process, valuable insights into the practical application of the IDDM will be provided, contributing to more effective, user-centric dashboard design in the field of smart waste management and beyond.

5.2 DEMONSTRATION CONTEXT: INTELLIGENT MONITORING RECYCLE SYSTEM (i-MORSYS)

To effectively demonstrate the application of the IDDM, it is essential to first provide context about the system for which the dashboards are being designed. This section explains the i-MORSYS, outlining its purpose, key components, and the specific needs that the dashboards aim to address.

In a nutshell, i-MORSYS is a conceptual smart waste management system that aims to integrate mobile technology, data analytics, and real-time tracking to enhance recycling efforts and sustainability monitoring. The term "intelligent" in i-MORSYS reflects the system's intended smart and data-driven operational orientation, rather than the implementation of advanced autonomous or artificial intelligence features in the current demonstration.

In this study, the demonstration focuses on mock-up dashboards developed to illustrate how the proposed IDDM Canvas effectively guides the design and implementation of information dashboards, rather than on realizing the full intelligent capabilities of the system. It is also noted that i-MORSYS represents an actual proof-of-concept (PoC) initiative led by the author in practice and is adopted in this research as a real-world application context for validating the proposed method. The system showcases real-time tracking of collection activities, waste diversion analytics, and engagement tools for various stakeholders involved in waste management such as local councils, waste management companies, the state government, and the general public.

5.2.1 Overview of i-MORSYS

The i-MORSYS is a conceptual waste management system developed to support recycling operations by integrating real-time monitoring and data-driven decision-making. By leveraging mobile technology and analytics, i-MORSYS is intended to assist in improving recycling collection efficiency, enhancing stakeholder collaboration, and facilitating sustainability tracking and monitoring.

Designed for local councils, waste management companies, state governments, and the general public, i-MORSYS aims to provide data-driven insights that contribute to more informed resource management and sustainability practices. The key features of i-MORSYS are summarized in Table 5.2 below:

Table 5.2 Key features of i-MORSYS

Features	Description
1.User-Driven Recycling Requests	A mobile application enabling users to request recycling collection services, fostering active participation in sustainable waste practices.
2. Real-time Tracking and Monitoring	GPS-enabled tracking enhancing collection transparency, schedule adherence, and efficiency monitoring.
3. On-Site Weighing and Data Entry	Collectors weigh the recyclables on-site and input all relevant information into the mobile application, ensuring accurate data collection.
4. Data Collection and Analysis	Continuous data gathering for trend analysis, predictive modeling, and performance evaluation.
5.User Engagement Platform	Public can track personal recycling impact, request collections, and view their contributions to sustainability.
6. Multi-Stakeholder Monitoring	Different stakeholder views allow waste companies, councils, and policymakers to monitor performance.
7. Comprehensive Sustainability Reporting	The system generates reports aligned with SDGs, including recycling rates, carbon credit tracking, and waste diversion statistics.

The key features outlined in Table 5.2 represent the full capabilities of the i-MORSYS system as a comprehensive waste management solution. These features encompass various functionalities, from user-driven recycling requests and real-time tracking to data-driven decision-making and sustainability reporting.

However, for the purpose of this study, only the mock-up dashboard will be developed as part of the demonstration. Since a mock-up is a static representation rather than a fully functional system, not all features listed in Table 5.2 can be fully visualized or demonstrated.

The mock-up dashboard will primarily serve to illustrate how data is presented, structured, and visualized based on the IDDM framework. While it can represent the intended layout, user interface components, and information flow, it does not possess interactive functionalities such as real-time tracking, user requests, or automated reporting.

Thus, this demonstration focuses on evaluating the usability and design aspects of the dashboard, rather than testing its functional performance. The goal is to assess whether the IDDM framework effectively supports dashboard design and can be reliably used to guide the development of a fully operational system in the future.

To ensure that the mock-up dashboard accurately represents the principles outlined in the IDDM framework, a structured approach is required during its development. The following section details the process of translating the IDDM Canvas into a Dashboard Design Blueprint (DDB) and how it serves as structured guidance for designing the i-MORSYS dashboard mock-ups.

5.3 APPLYING THE IDDM TO i-MORSYS DASHBOARD DEVELOPMENT

This section demonstrates the practical application of the IDDM in designing two distinct mock-up dashboards for i-MORSYS: the Operational Dashboard and the Analytics Dashboard, serving as Proofs of Concept (POCs) for the IDDM Canvas. According to the Cambridge dictionary, a mock-up is a full-size model of something large that has not yet been built, showing how it will look or operate. In the information dashboard context, the mock-up dashboard can be described as a static yet detailed visualization of an interface that demonstrates the initial design concept before full implementation. Similar to mock-ups used in hospital design, as discussed by Dunston et al. (2011), these representations enable stakeholders to evaluate layouts and design details effectively, facilitating informed decision-making before full-scale development. Shultz and Jha (2021) found that mock-ups serve as effective evaluation tools, enabling design teams to assess planned designs, make evidence-based decisions, and validate design methodologies by translating principles into visual and structural elements without the complexity of technical implementation.

The decision to develop mock-up dashboards rather than functional prototypes is supported by several factors identified in visualization design research. Building on their earlier findings, Shultz and Jha (2021) further emphasize that mock-ups enable rapid iteration and refinement based on stakeholder feedback. Their research demonstrates the effectiveness of mock-ups in assessing critical metrics, such as workflow patterns, task completion times, and user interaction efficiency, especially during early-stage validation.

Vazquez-Ingelmo et al. (2019) highlight that structured design methodologies significantly improve dashboard development outcomes, particularly when dealing with complex information systems. Their systematic review demonstrates that mock-ups play a crucial role in validating design frameworks and ensuring that resulting dashboards meet user requirements. This is particularly relevant for the IDDM Canvas validation, as mock-ups will help to evaluate the effectiveness and practicality of this canvas in designing the dashboard.

Mock-ups excel at communicating design concepts and layout decisions, making them ideal for evaluating the effectiveness of design frameworks in guiding visual organization and information hierarchy (Sarikaya et al., 2019). Moreover, Shultz and Jha (2021) underscore the value of mock-ups in facilitating stakeholder collaboration and iterative feedback, which are essential for refining and validating design methodologies.

The filled IDDM Canvas is employed as a DDB, providing a structured framework to guide the development of each dashboard. This process ensures a comprehensive approach to design that addresses the diverse needs of different stakeholders in the waste management ecosystem. With the DDBs as guidance, each dashboard designer proceeded to implement their assigned dashboards using their preferred visualization platform tools.

To support the development of the mock-up dashboards, data from a real-world PoC project was given to both designers. The data was collected through an actual pilot project conducted in collaboration with a waste management company, involving the collection of recyclable materials from various residential areas throughout Selangor. This PoC project was led by the researcher as the Project Head, forming part of the official responsibilities. As a member of the senior management team, the use of the PoC data falls within the researcher's authorization limits. The dataset includes operational records such as item categories, weight, estimated CO_2 equivalent, revenue generated, collection timestamps, and geolocation coordinates spanning from January 2024 to December 2024.

5.3.1 Distinguishing Operational and Analytic Dashboards in i-MORSYS

In the context of i-MORSYS, the distinction between operational and analytics dashboards is crucial for effectively addressing the diverse needs of waste management stakeholders.

The i-MORSYS Operational Dashboard focuses on monitoring and managing day-to-day recycling operations, providing real-time or near-real-time data to support immediate decision-making (Few 2006). This dashboard is primarily used by waste management operators and collection teams to track key performance indicators (KPIs) related to current recycling activities, such as collection requests, route efficiency, and daily recycling volumes (Eckerson 2010). For instance, it would display real-time locations of collection vehicles, pending collection requests, and immediate performance metrics like collections completed and on-time percentage.

In contrast, the i-MORSYS Analytics Dashboard is designed to provide a strategic and high-level view of recycling performance over time, supporting long-term planning and strategic decision-making in waste management (Yigitbasioglu & Velcu 2012). The decision-makers at waste management companies, local councils, and state government levels use this dashboard to monitor progress towards strategic recycling goals and identify long-term trends. It would typically display aggregated data on recycling rates, progress towards Sustainable Development Goals (SDGs), carbon credits generated, and comparative analyses of recycling performance across different areas over extended periods.

The time frame for data presentation in the i-MORSYS Operational Dashboard is real-time or near-real-time, with frequent updates (hourly or daily), while the analytical dashboard presents data over longer periods (months or years) with less frequent updates (weekly or monthly) (Few 2006). The Operational Dashboard provides detailed, granular data about specific recycling activities, whereas the Analytics Dashboard offers more aggregated data to support broader waste management strategies (Eckerson 2010).

In terms of key focus, the i-MORSYS Operational Dashboard emphasizes immediate performance metrics and alerts, such as urgent collection requests or route deviations. The analytical dashboard, however, concentrates on trends, forecasts, and benchmarks, such as year-over-year recycling rate improvements or progress towards specific sustainability targets (Yigitbasioglu & Velcu 2012).

By clearly distinguishing between these two types of dashboards, i-MORSYS can effectively cater to the diverse information needs of its stakeholders, from day-to-day operational efficiency to long-term strategic planning in waste management and sustainability. Table 5.3 summarizes the key differences between operational and analytic dashboards in the context of i-MORSYS:

Table 5.3 Comparison of operational and analytics dashboards in i-MORSYS

Aspect	**i-MORSYS Operational Dashboard**	**i-MORSYS Analytics Dashboard**
Purpose	Monitor daily recycling operations	Track long-term recycling goals and sustainability targets
Time Frame	Real-time or near-real-time	Long-term (months, years)
Update Frequency	Frequent (hourly, daily)	Less frequent (weekly, monthly)
Data Granularity	Detailed (e.g., individual collection requests)	Aggregated (e.g., monthly recycling rates)

to be continued…

…continuation

Primary Users	Waste management operators, collection teams	Decision-makers at waste collector companies, local councils, state government
Key Focus	Immediate performance (e.g., route efficiency), alerts (e.g., urgent collection requests)	Trends (e.g., year-over-year recycling improvements), forecasts, benchmarks
Example Metrics	Real-time vehicle locations, pending collections, daily recycling volumes	Progress towards SDGs, carbon credits generated, comparative area performance

5.3.2 Application Scenario 1: i-MORSYS Operational Dashboard Development

The first application scenario demonstrates the development of the i-MORSYS Operational Dashboard. This dashboard aims to provide real-time monitoring and management of daily recycling activities, supporting waste management operators and collection teams in their day-to-day operations.

a. IDDM canvas application for operational dashboard

The IDDM Canvas was applied to develop two slightly different Dashboard Design Blueprints (DDBs) for the Operational Dashboard, each tailored for a specific visualization platform. This approach demonstrates how the IDDM methodology accommodates different implementation environments while maintaining consistent core requirements. The first DDB was developed to guide the implementation of the Operational Dashboard in Tableau. Figure 5.1 presents this completed canvas.

The second DDB was developed to guide the implementation of the Operational Dashboard in Looker Studio, with adjustments to accommodate the platform's specific capabilities. Figure 5.2 presents this completed canvas.

While these DDBs contain minor variations to accommodate different platform capabilities, they remain aligned with the core IDDM methodology, indicating the framework's potential to offer consistent guidance while allowing for platform-specific adaptations.

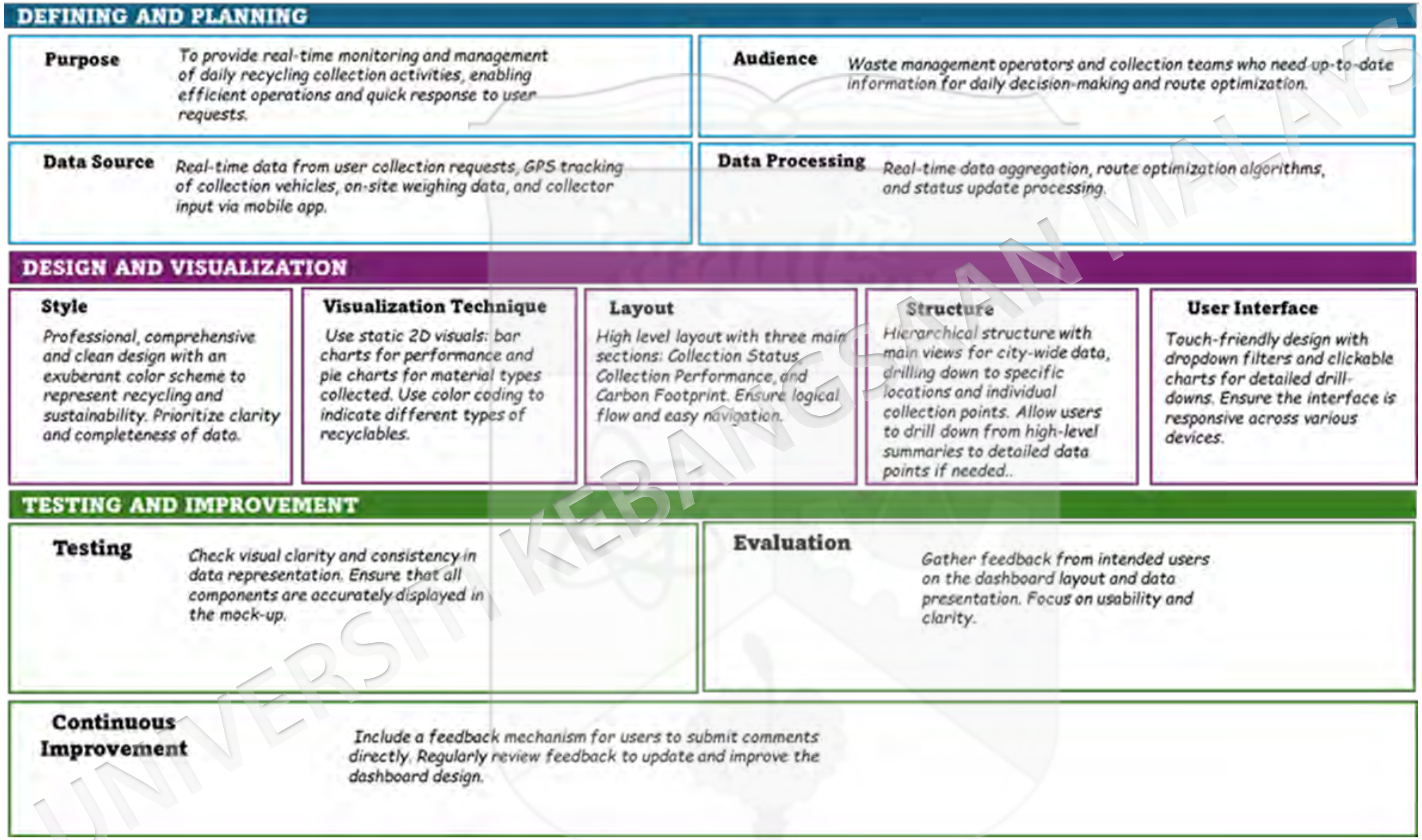

Figure 5.1 The filled IDDM Canvas (DDB) for the i-MORSYS operational dashboard - Tableau implementation

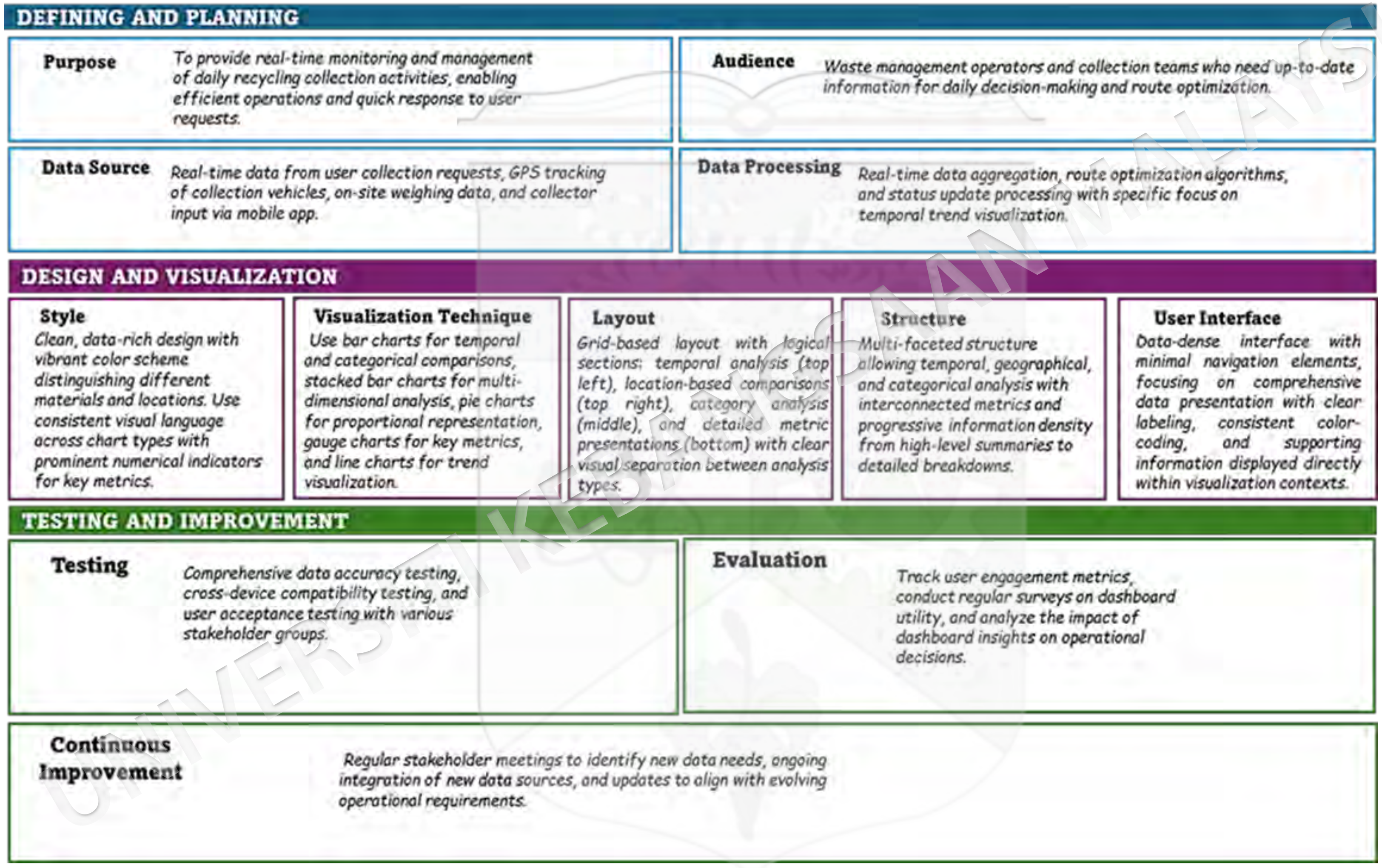

Figure 5.2 The filled IDDM canvas (DDB) for the i-MORSYS operational dashboard – Looker Studio implementation

b. Key design decisions

Based on the DDBs, several key design decisions were made for each implementation. These decisions reflect how the IDDM methodology guided the dashboard designers' choices while accommodating platform-specific capabilities. To clearly illustrate the differences and similarities in design decisions across platforms, Table 5.4 presents a side-by-side comparison of key design elements.

Table 5.4 Key design decisions for operational dashboard mock up implementations

Design Element	Tableau Implementation	Looker Studio Implementation
Purpose and Audience Focus	Real-time operational monitoring with clear status indicators to support waste management operators in daily decision-making.	Comparative operational analytics with emphasis on operational monitoring for field teams and supervisors.
Data Sources and Processing	Current collection status, operator performance, and carbon footprint metrics with supporting historical context.	Temporal trends and material-type breakdowns integrated with operational metrics to support multi-dimensional analysis.
Visualization Techniques	Donut charts for status indicators, line graphs for performance trends, bar chart for type of recyclables collected and tabular data for location details.	Gauge charts for key metrics, bar charts for temporal and comparative analysis, and pie charts for proportional representation.
Layout and Structure	Three-panel horizontal layout with clear visual separation between Collection Status, Collection Performance, and Carbon Footprint.	Grid-based layout with thematic quadrants for temporal analysis, location comparison, category analysis, and detailed metrics.
User Interface	Touch-friendly navigation panel with clear section indicators to support field use on various devices.	Data-dense interface with integrated filtering and comparison capabilities to support detailed operational analysis.

This side-by-side comparison shows how the IDDM helped guide design decisions while accommodating platform-specific considerations. Although the implementations differ in visualization techniques and layout approaches, both address the requirements specified in their respective DDBs. The comparison suggests that the IDDM framework can be adapted to different platform capabilities while still focusing on user needs and IG principles.

c. Implementation in Tableau and Looker studio

Based on the DDBs, two independent dashboard designers developed mock-up versions of the Operational Dashboard. Each designer selected the visualization platform they were most familiar with and proficient in - one choosing Tableau and the other selecting Looker Studio. Figure 5.3 presents the Tableau implementation of the i-MORSYS Operational Dashboard, developed based on the DDB shown in Figure 5.1.

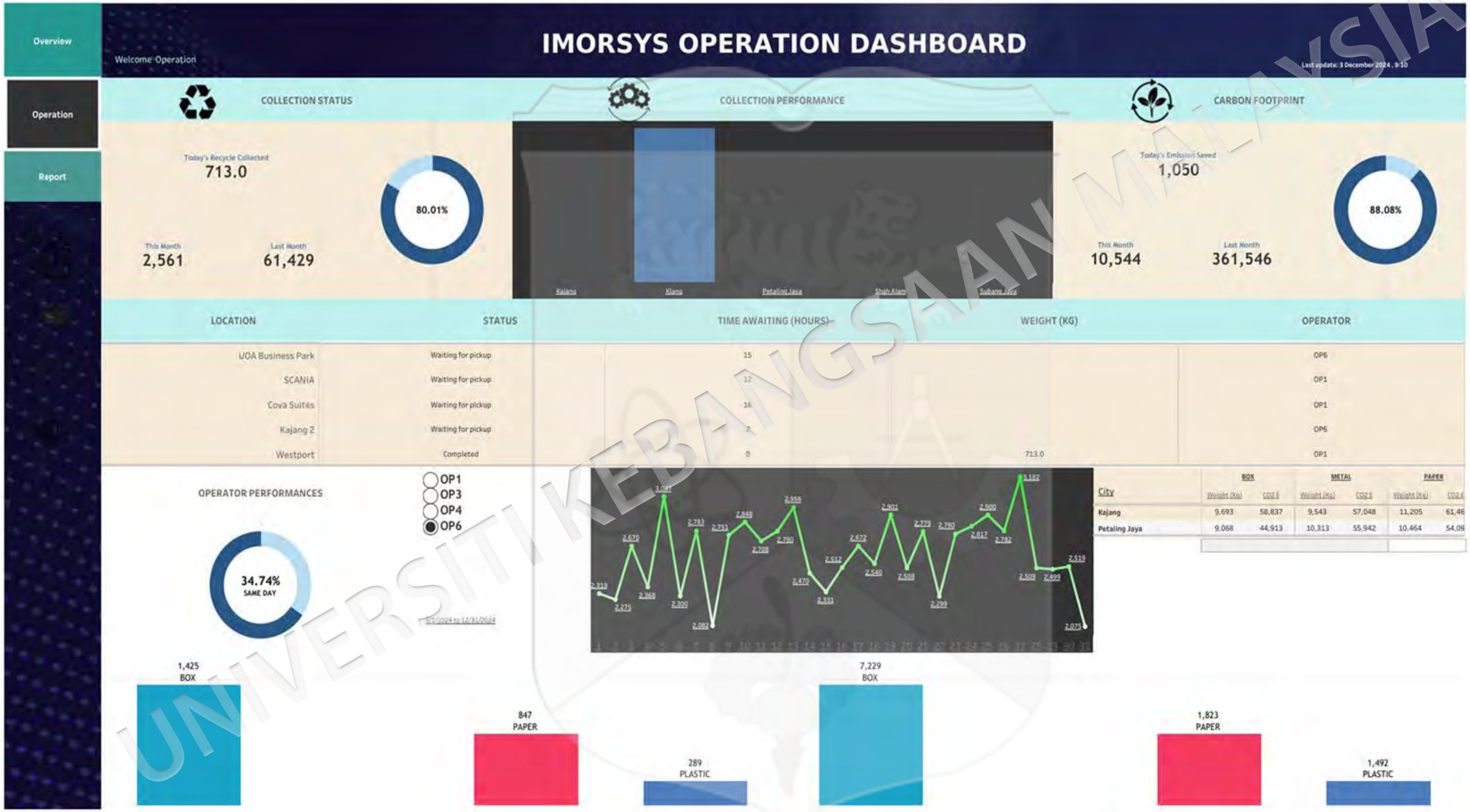

Figure 5.3 Tableau implementation of the i-MORSYS operational dashboard

The Tableau implementation follows the three-section layout specified in the DDB. For clarity, each key section is presented as an enlarged view with a brief explanation.

Figure 5.3a presents the Collection Status section, which displays today's recycling collection total (713.0 kg), monthly collection figures, and collection completion rate (80.01%) visualized as a donut chart. While the DDB in Figure 5.1 specified 'donut charts for status indicators,' the implementation extends this concept by combining the donut chart with prominent numerical displays that weren't explicitly detailed in the canvas. This adaptation demonstrates how dashboard designers interpret and expand upon the canvas specifications to meet the underlying purpose. The implementation still fulfills the core “Purpose” element of providing “real-time operational monitoring with clear status indicators to support waste management operators in daily decision-making,” though with some variations in visualization approach.

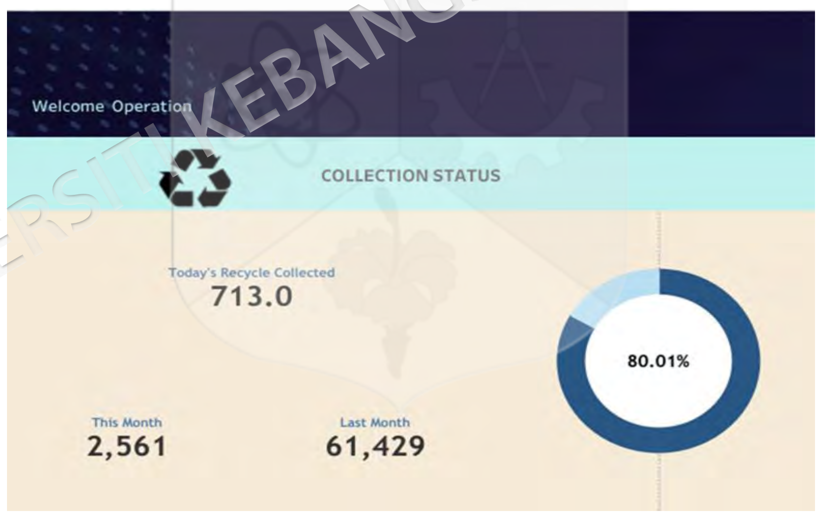

Figure 5.3a Collection status section

Figure 5.3b shows the Collection Performance section, featuring a bar chart that highlights daily collection volumes across different locations. Examining how this implements the Design and Visualization elements from the DDB (Figure 5.1), it can be seen that the “Style” specification called for a “Professional and polished design with a focus on data visualization clarity”. The implementation reflects this through its clean, structured bar chart presentation with clear data labels. While the specific visualization technique used (bar chart) represents an adaptation from what may have been outlined in the “Visualization Technique” section of the DDB, it effectively serves the purpose of comparative analysis.

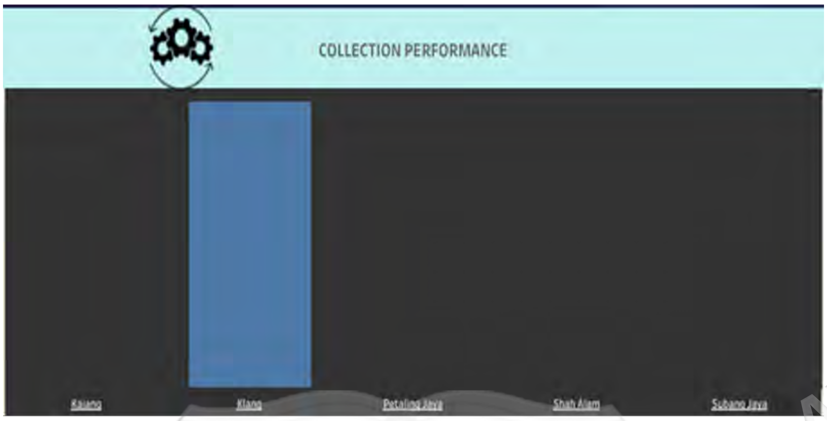

Figure 5.3b Collection performance section

Figure 5.3c illustrates the Carbon Footprint section, which presents today's emissions saved (1,050 units) with historical comparisons (10,544 this month, 361,546 last month) and environmental impact score (88.08%) visualized as a donut chart. This section implements key elements from the Design and Visualization category of the DDB (Figure 5.1). The donut chart visualization aligns with the “Visualization Technique” specification, which likely included circular visualizations for key performance indicators. The implementation follows the “Layout” requirement for structured organization of dashboard elements by maintaining a consistent design approach while creating a visually distinct section for environmental metrics.

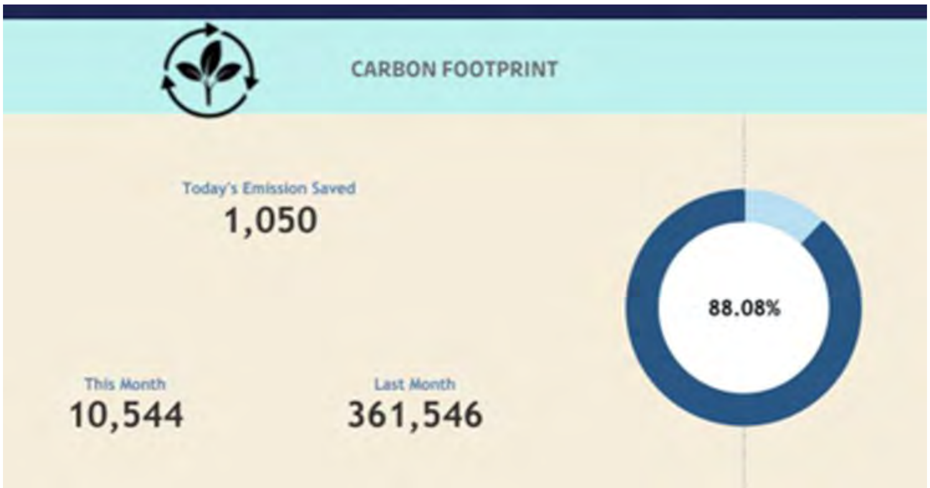

Figure 5.3c Carbon footprint section

Figure 5.3d depicts the Location Status Table and Operator Performance indicator, providing detailed information about collection points and displaying operator efficiency (34.74% same-day completion rate) with supporting material type breakdowns. This implementation addresses several elements from the Design and Visualization category specified in the DDB. The visualizations are presented in segmented views to enhance clarity.

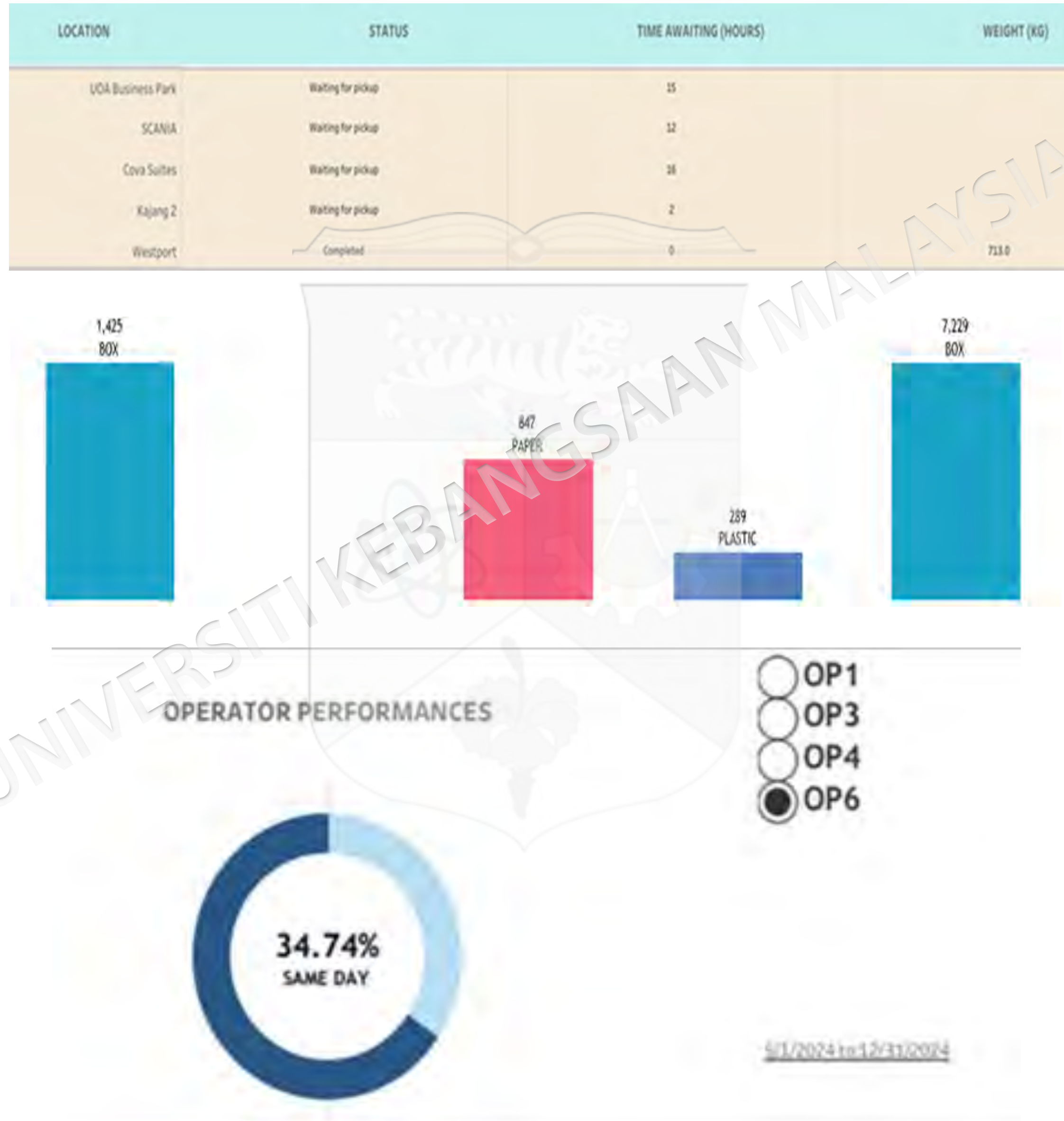

Figure 5.3d Segmented views of location status table and operator performance indicator

These segmented views demonstrate how the Tableau implementation effectively translates the DDB requirements into a cohesive operational dashboard that focuses on collection status, performance tracking, and environmental impact. The implementation provides waste management operators with clear visualizations of key metrics while maintaining a consistent visual language throughout the interface. Figure 5.4 below presents the mock-up using Looker Studio based on DDB in Figure 5.2.

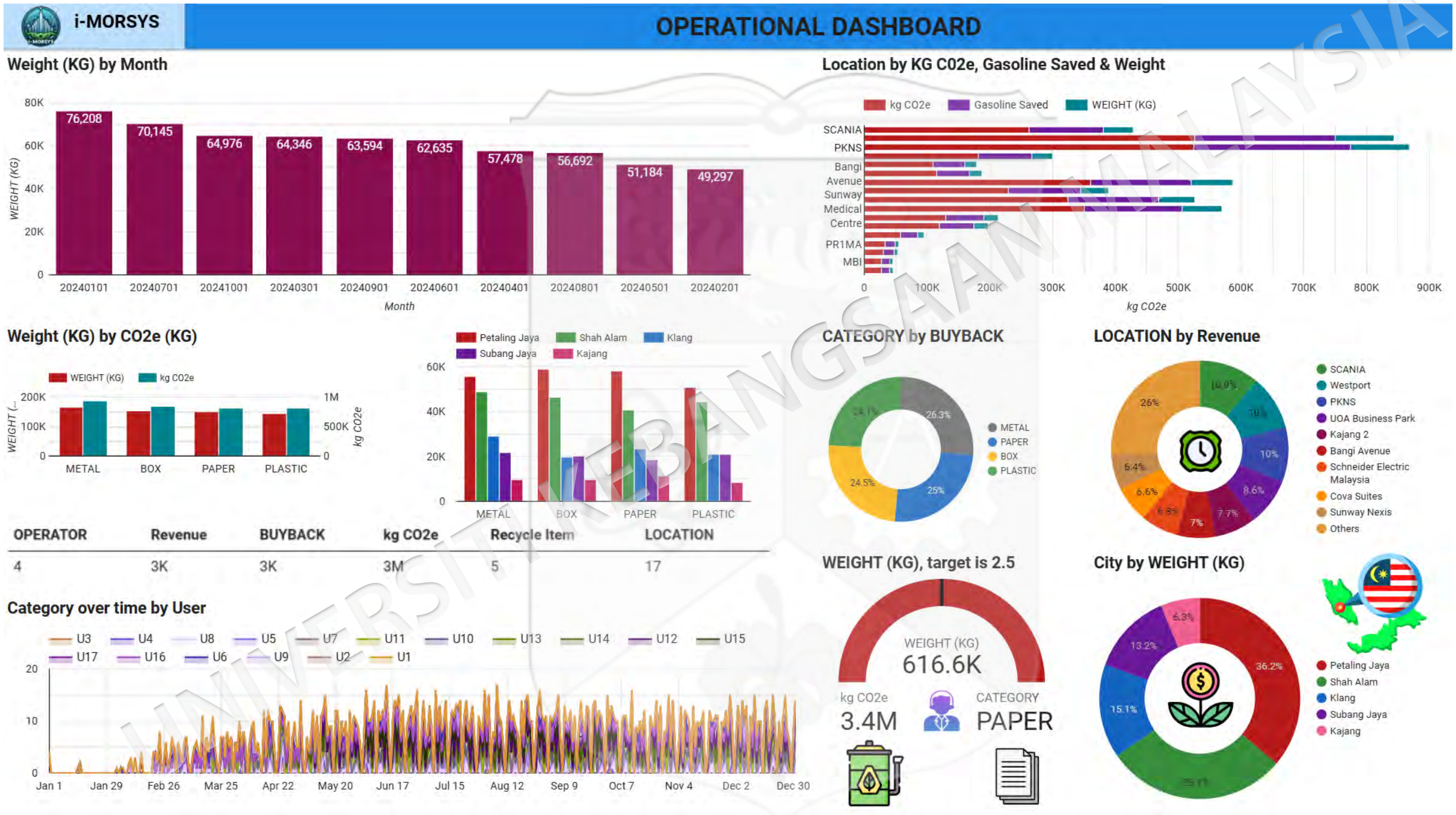

Figure 5.4 Looker studio implementation of the i-MORSYS operational dashboard

The Looker Studio implementation mock-up as shown in Figure 5.4 above takes a different visual approach in accordance with its platform-specific DDB in Figure 5.2.

Figure 5.4a presents the Weight Tracking Section, which displays monthly weight trends through bar charts and compares weight by material type, as well as bar charts that highlight location-specific metrics including CO2e, gasoline saved, and weight measurements. This is in line with the requirement specified in the DDB under visualization technique "use bar charts for temporal and categorical comparisons and line chart for trend visualization".

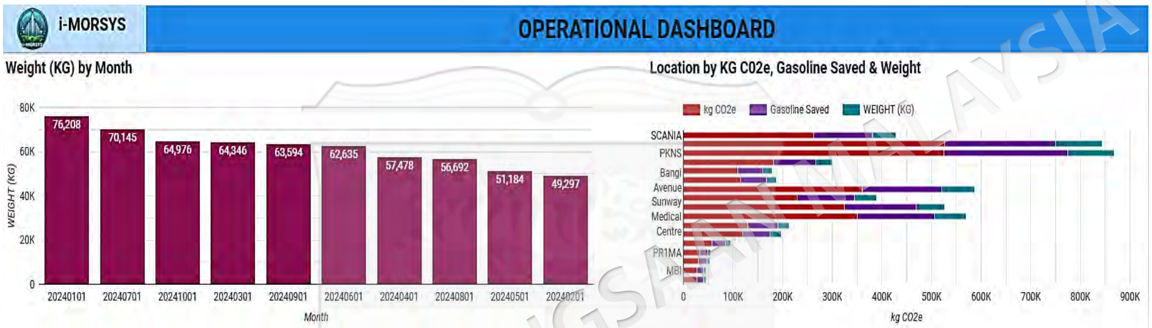

Figure 5.4a Weight tracking and location by Kg CO2e section

Figure 5.4b illustrates the Category Analysis section, which presents material categories by buyback value through pie charts and provides location-based revenue breakdowns. This also matched the DDB's requirement which suggested the use of pie chart, line chart and bar chart to enhance visualization and clarity.

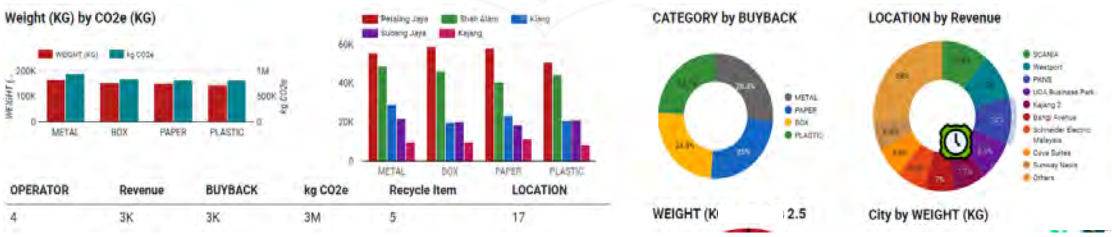

Figure 5.4b Category analysis section

Figure 5.4c depicts the Performance Metrics and User Activity Tracking, displaying key metrics like total weight (616.6K kg) and CO2e savings (3.4M) through gauge-style visualizations, alongside detailed user activity trends.

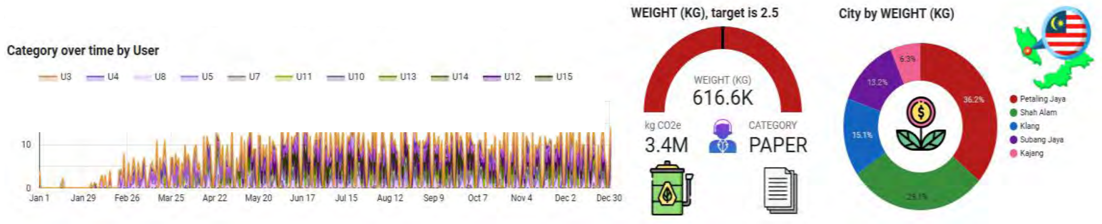

Figure 5.4c Performance metrics and user activity tracking section

d. Comparative analysis of the operational dashboards mock-up

While both operational dashboard mock-ups are based on the same core requirements from the IDDM framework, they demonstrate differences in visual approach and emphasis, demonstrating how the IDDM methodology can guide dashboard development while allowing for platform-specific adaptations and designer interpretation. Table 5.5 presents a comparison of key elements across the two dashboards:

Table 5.5 Comparison of operational dashboard mock-ups

Dashboard Elements	**Tableau Implementation**	**Looker Studio Implementation**
Layout Structure	Three distinct horizontal sections with hierarchical organization.	Grid-based layout with themed quadrants for different analysis types.
Primary Visualization Types	Donut charts for status, line charts for trends, bar charts for comparisons.	Bar charts for temporal analysis, pie charts for proportions, gauge charts for key metrics.
Color Scheme	Blue and teal with accent colors for material types.	Multi-colored with distinct color coding for locations and materials.
Data Presentation Approach	Status-focused with emphasis on completion rates and targets.	Analysis-focused with emphasis on comparisons across dimensions.
Navigation Model	Left-side panel with Overview, Operation, and Report options.	Integrated navigation within visualization contexts.
Performance Metrics Display	Prominent donut charts showing percentage completion.	Gauge charts and numerical indicators showing absolute values.
Temporal Representation	Daily performance line chart showing fluctuations.	Monthly bar charts showing trends over longer periods.

This comparison illustrates how the same methodological guidance can result in different yet effective mock-up implementations based on platform capabilities and designer interpretation. Both mock-ups complied with the core requirements specified in the DDB, though they take different approaches to visualization and layout.

e. Alignment with IG principles

Both implementations of the Operational Dashboard mock-up incorporate the IG principles introduced in Chapter 4, though they manifest these principles in different ways. Table 5.6 summarizes how key IG principles are implemented across both platforms:

Table 5.6 Alignment with information governance principles in operational dashboard

IG Principle	Tableau Implementation	Looker Studio Implementation
Effectiveness	Clear status indicators (80.01%, 88.08%) providing immediate operational visibility.	Comprehensive metrics (616.6K kg weight, 3.4M CO2e) supporting operational decisions
Transparency	Detailed location status table showing waiting times and completion status.	Multi-dimensional comparisons allowing cross-referencing of metrics.
Accountability	Operator performance tracking (34.74%) with attribution.	Operator and location-based performance metrics with clear attribution.
Quality	Timestamp indicators showing data currency (Last update: 3 December 2024, 9:35).	Detailed breakdown of metrics with supporting context for interpretation
Integrity	Consistent visualization approach across metrics with supporting historical context.	Standardized representation of metrics across different visualization types.
Compliance	Structured data presentation supporting regulatory reporting requirements.	Comprehensive metrics supporting sustainability reporting obligations.
Security	Role-based navigation structure supporting appropriate information access.	Category-level filtering enabling role-appropriate data views.
Availability	Multi-device compatible layout ensuring access across contexts.	Data-dense presentation maximizing information availability.

This alignment illustrates how the IDDM framework embeds IG principles into the design process in a way that remains consistent across different implementation platforms. Rather than being constrained by tool-specific limitations, each dashboard demonstrates how governance considerations can be meaningfully adapted within distinct visual and structural contexts.

f. Testing and improvement considerations

While the Testing, Evaluation, and Continuous Improvement elements of the IDDM Canvas are not directly visible in the mock-up implementations, they played a crucial role in guiding the development process and establishing a foundation for future dashboard enhancement. As Sarikaya et al. (2019) emphasize, these elements are essential for ensuring that dashboards remain effective and relevant over time, even if they are not explicitly visible in the interface itself.

The Testing elements from the DDBs guided the verification of visual clarity, data accuracy, and representation consistency during the mock-up development. Though not directly visible in the final mock-ups, these testing specifications influenced design decisions related to data visualization clarity and labeling comprehensiveness. According to Ellis & Dix (2006), effective visualization testing should be embedded throughout the design process rather than treated as a separate phase, which is reflected in how testing considerations shaped the visual implementations.

The Evaluation specifications in the DDBs established frameworks for gathering user feedback and assessing dashboard effectiveness, creating a foundation for future improvements. While not explicitly visible in the mock-ups, these evaluation frameworks influenced the inclusion of features like timestamps (Tableau implementation) and comprehensive metric displays (Looker Studio implementation) that support ongoing performance assessment. As noted by Few (2013), evaluation criteria should be inherently linked to dashboard purpose, which is reflected in how each implementation emphasizes metrics relevant to its primary users.

The Continuous Improvement elements guided the inclusion of feedback mechanisms and adaptable structures that can evolve with changing user needs. Though not directly implemented as interactive features in the mock-ups, these considerations influenced the modular design approaches that would facilitate future updates. Drawing from Burnett et al. (2004), who advocate for iterative, feedback-supported refinement in end-user programming to enhance dependability, the structured and expandable layouts in both dashboard implementations reflect similar mechanisms of progressive refinement.

These “invisible” elements of the IDDM Canvas demonstrate the methodology's comprehensive approach to dashboard development, extending beyond visual design to include mechanisms for continuous refinement and long-term adaptability. As emphasized by Tory and Möller (2005), visualization methodologies must not only satisfy immediate usability and design requirements, but also account for sustainability over time by accommodating real-world usage contexts and evolving user needs.

5.3.3 Application Scenario 2: i-MORSYS Analytics Dashboard Development

The second application scenario demonstrates the development of the i-MORSYS Analytical Dashboard. This dashboard aims to provide in-depth analysis of recycling trends, performance metrics, and sustainability indicators over time for decision-makers at waste management companies, local councils, and state government levels.

a. IDDM canvas application for analytical dashboard

Similar to the Operational Dashboard, the IDDM Canvas was applied to develop two distinct DDBs for the Analytical Dashboard, each tailored for a specific visualization platform. The first DDB was developed to guide the implementation of the Analytical Dashboard in Tableau. Figure 5.5 presents this completed canvas.

The filled IDDM Canvas depicted in Figure 5.5 served as the DDB, ensuring that all essential components were addressed in the design process. Each section of the canvas was meticulously written to meet the specific needs of decision-makers at waste management companies, local councils, and state government levels.

The second DDB was developed to guide the implementation of the Analytical Dashboard in Looker Studio, with adjustments to accommodate the platform's specific capabilities. Figure 5.6 presents this completed canvas.

Although each DDB includes slight adjustments to align with the specific capabilities of its respective platform, both remain grounded in the core principles of the IDDM. This suggests that the IDDM has the potential to offer consistent design guidance while maintaining the flexibility to adapt to platform-specific requirements.

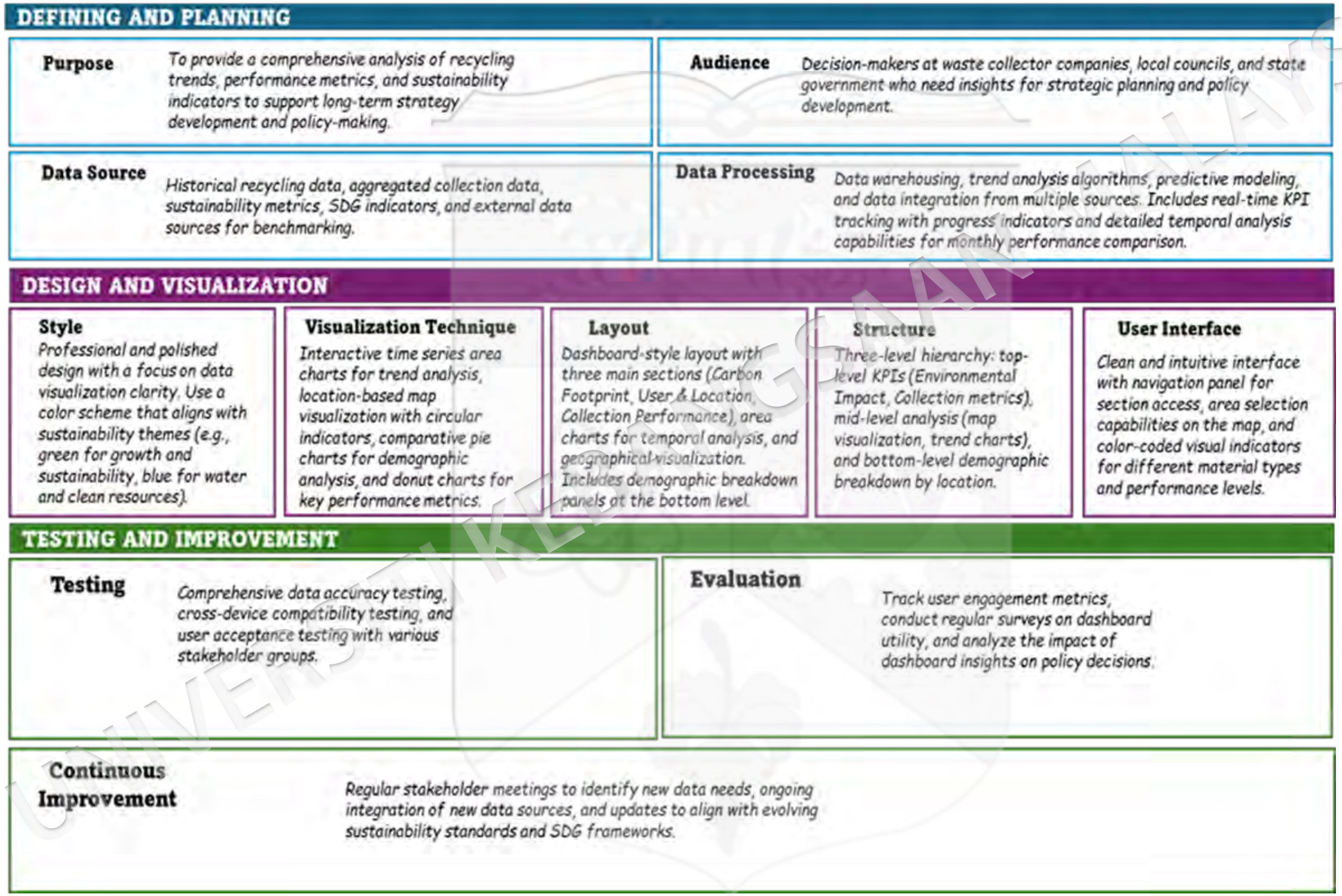

Figure 5.5 The filled IDDM canvas (DDB) for the i-MORSYS analytical dashboard – Tableau implementation

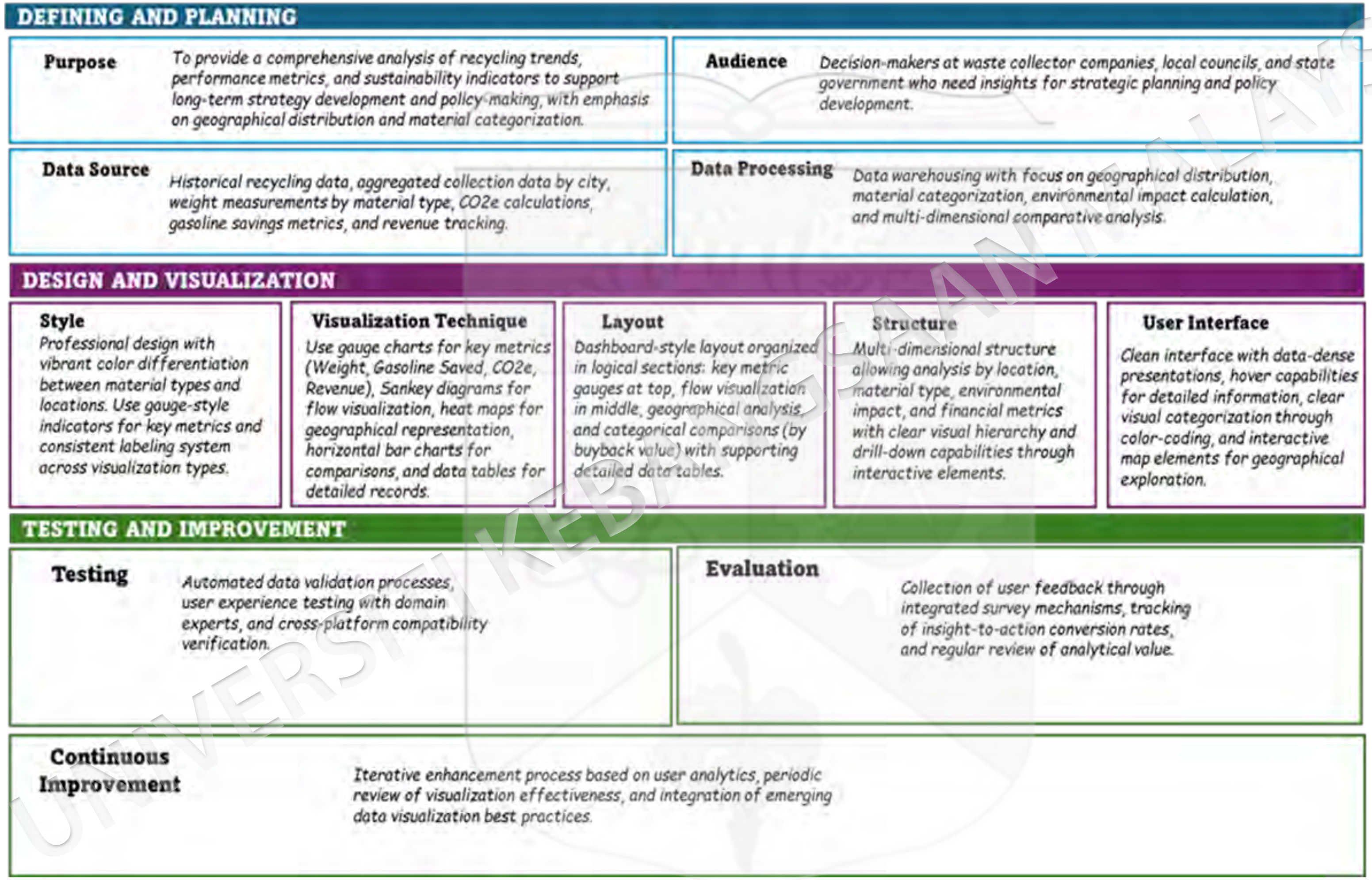

Figure 5.6 The filled IDDM canvas (DDB) for the i-MORSYS analytical dashboard – Looker Studio implementation

b. Key design decisions

Based on the DDBs, several key design decisions were made for each implementation. These decisions reflect how the IDDM canvas guided the dashboard designers' choices while accommodating platform-specific capabilities. To clearly illustrate the differences and similarities in design decisions across platforms, Table 5.7 presents a side-by-side comparison of key design elements.

Table 5.7 Key design decisions for analytical dashboard implementations

Design Element	Tableau Implementation	Looker Studio Implementation
Purpose and Audience Focus	Comprehensive analysis of recycling trends with emphasis on sustainability indicators to support long-term strategy development and policy-making.	Comprehensive analysis of recycling trends with emphasis on geographical distribution and material categorization for strategic planning.
Data Sources and Processing	Historical recycling data, aggregated collection data, sustainability metrics, SDG indicators, and external data sources for benchmarking.	Historical recycling data, weight measurements by material type, CO2e calculations, gasoline savings metrics, and revenue tracking.
Visualization Techniques	Interactive time series area charts, location-based map visualization, circular indicators, comparative pie charts, and donut charts for key performance metrics.	Gauge charts for key metrics, Sankey diagrams for flow visualization, heat maps for geographical representation, horizontal bar charts for comparisons, and data tables.
Layout and Structure	Three-level hierarchy with top-level KPIs, mid-level analysis, and bottom-level demographic breakdown by location.	Dashboard-style layout organized by key metric gauges at top, flow visualization in middle, geographical analysis, and categorical comparisons with supporting detailed data tables.
User Interface	Clean and intuitive interface with navigation panel for section access, area selection capabilities on map, and color-coded indicators.	Clean interface with data-dense presentations, hover capabilities for detailed information, and interactive map elements for geographical exploration.

This comparative analysis illustrates how the IDDM effectively facilitated design decisions, while remaining responsive to platform-specific constraints and capabilities.

c. Implementation in Tableau and Looker Studio

Using the respective DDBs, two independent designers created mock-up versions of the i-MORSYS Analytical Dashboard. Each used their preferred platform - one chose Tableau, the other Looker Studio. Figure 5.7 shows the Tableau implementation based on the DDB in Figure 5.7.

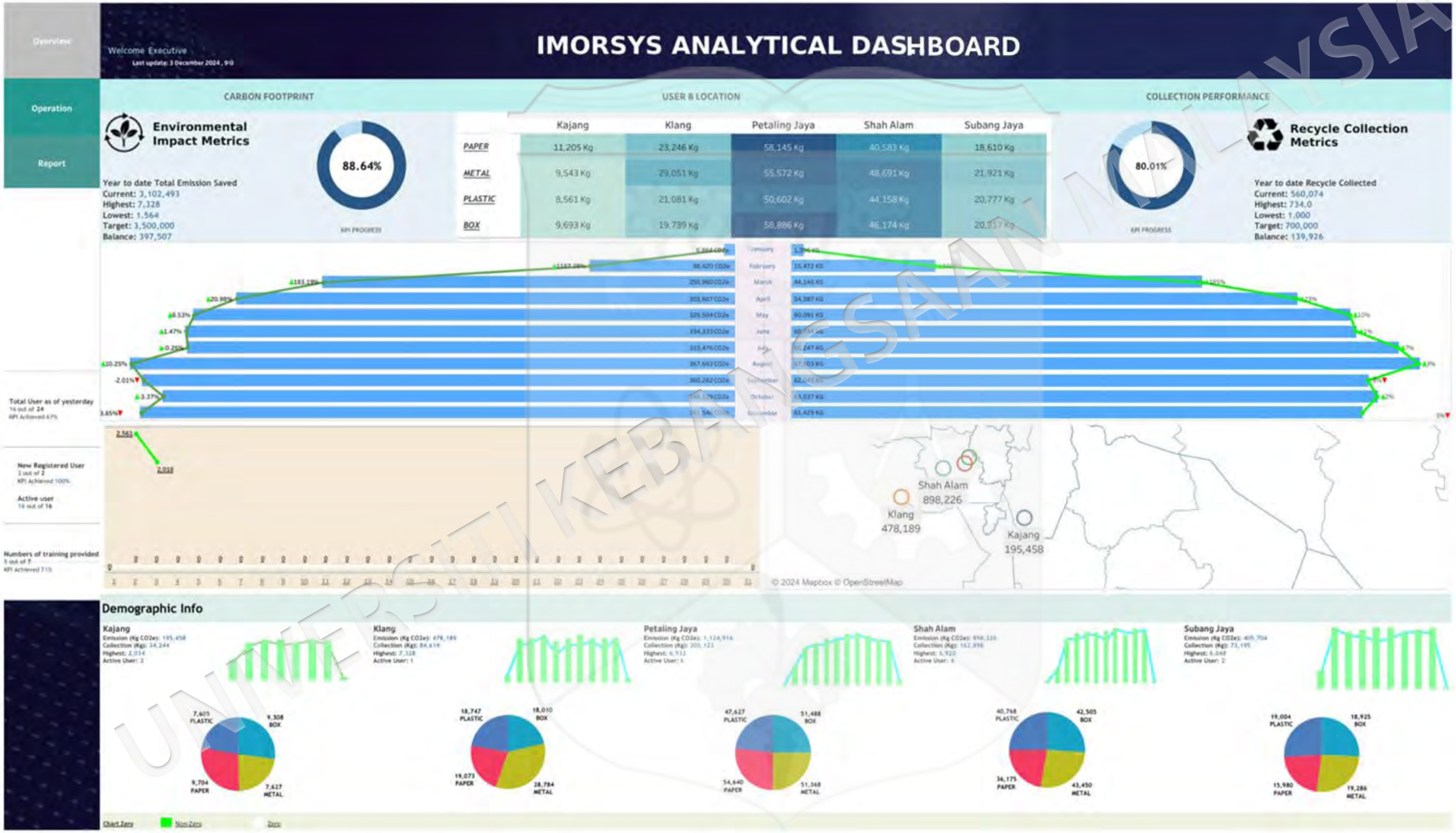

Figure 5.7 Tableau implementation of the i-MORSYS analytical mock-up dashboard

The Tableau implementation adopts the multi-section layout as specified in the DDB. To enhance clarity, each major section is presented individually, accompanied by a brief explanation.

As illustrated in Figure 5.7a, the Environmental Impact Metrics section embodies the top-level KPI layer as defined in the IDDM Canvas structure. The use of a donut chart to display 88.64% progress toward the annual emission-saving target directly aligns with the "Visualization Technique" component, which recommends the use of donut charts for key performance indicators. Supporting values such as highest, lowest, and target benchmarks are provided in line with the "Data Source" and "Style" components, ensuring both transparency and visual clarity. The visual layout further reflects the "User Interface" guidance from the canvas, offering a clean and intuitive display.

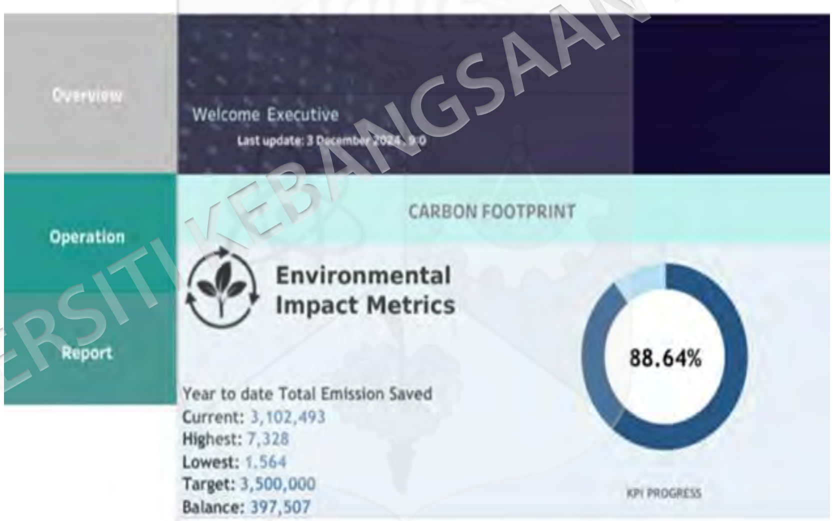

Figure 5.7a Environmental impact metrics section

Figure 5.7b shows the User and Location section, featuring a matrix display of recycling volumes by material type across different locations, enabling strategic comparison of regional performance.

This component aligns with the Structure element in the IDDM Canvas, which includes a mid-level analytical layer for location and category breakdowns. It also reflects the Layout specification, which outlines separate sections for key performance areas, and supports the User Interface element by presenting data in a clear, tabular format for easy interpretation.

USER & LOCATION

	Kajang	Klang	Petaling Jaya	Shah Alam	Subang Jaya
PAPER	11,205 Kg	23,246 Kg	58,145 Kg	40,583 Kg	18,610 Kg
METAL	9,543 Kg	29,051 Kg	55,572 Kg	48,691 Kg	21,921 Kg
PLASTIC	8,561 Kg	21,081 Kg	50,602 Kg	44,158 Kg	20,777 Kg
BOX	9,693 Kg	19,739 Kg	58,886 Kg	46,174 Kg	20,317 Kg

Figure 5.7b User and location section

Figure 5.7c illustrates the Collection Performance section, which presents the current recycling collection metrics, showing 80.01% progress toward the annual target. Supporting values such as current, highest, lowest, and target figures are also displayed for contextual reference. This section corresponds to the Structure element in the IDDM Canvas, representing a top-level KPI layer focused on operational performance. The use of a donut chart to visualize progress reflects the Visualization Technique component, while the inclusion of benchmark values supports the Data Processing and Layout elements, which emphasize clear metric presentation and contextual performance tracking.

Figure 5.7c Collection performance section

Figure 5.7d presents the Demographic Information section, located at the bottom of the dashboard. It provides a detailed breakdown of recycling patterns by location, using pie charts to visualize material composition and accompanying indicators for CO2e emissions, collection volumes, and user activity.

Figure 5.7d Demographic information section

This section reflects the Structure element in the IDDM Canvas, which includes demographic-level breakdowns by location, and aligns with the Layout, Visualization Technique, and User Interface components that emphasize clear, location-specific insights through intuitive visual formats.

In summary, the Tableau mock-up illustrates how the IDDM framework can be applied to structure an analytical dashboard that supports strategic decision-making. While the visual output was shaped by the designer's interpretation and platform capabilities, the overall layout, visualization types, and data presentation remained consistent with the elements outlined in the DDB. This implementation reflects the practicality of using the IDDM Canvas as a guiding blueprint for dashboard development.

The second implementation of the i-MORSYS Analytical Dashboard was developed using Looker Studio, guided by the platform-specific DDB presented in Figure 5.6. This version adopts a layout and visualization approach tailored to the capabilities of Looker Studio, while remaining aligned with the core design elements specified in the IDDM Canvas.

Figure 5.8 presents the completed mock-up using Looker Studio Platform, which integrates multiple visualization techniques, including gauge indicators, Sankey diagrams, geographical heat maps, bar charts, and data tables to deliver strategic insights across environmental, financial, and operational dimensions. The dashboard is organized into logical sections reflecting the DDB structure: key metrics at the top, flow and location-based analysis in the middle, and category-level breakdowns at the bottom.

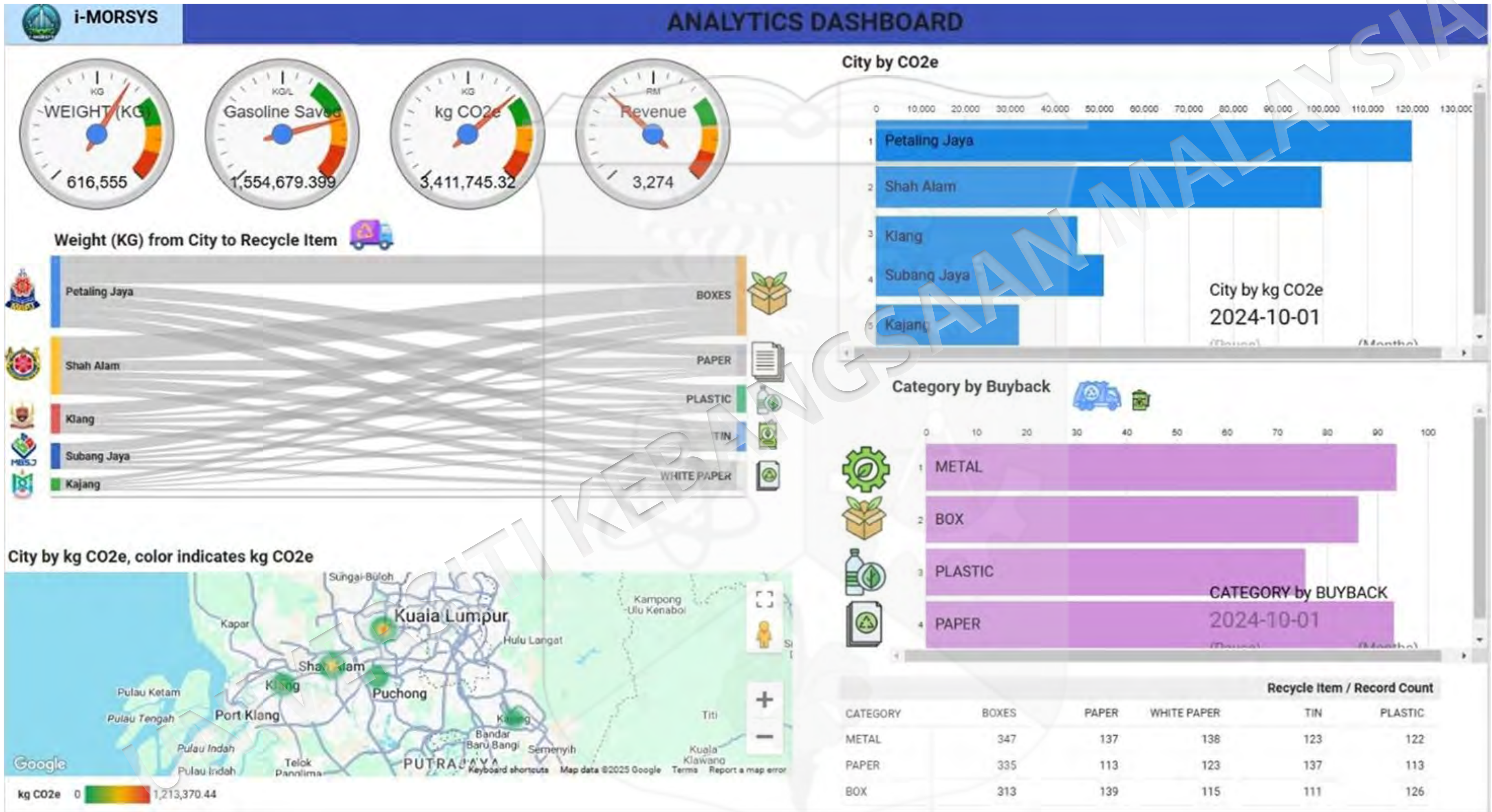

Figure 5.8 Looker Studio implementation of the i-MORSYS analytical mock-up dashboard

The overall layout of the Looker Studio mock-up dashboard showcased in Figure 5.8 reflects a design strategy that prioritizes modular organization, allowing users to explore insights across multiple dimensions from high-level KPIs to detailed comparative analyses. While the visual style differs from the Tableau implementation, the dashboard remains grounded in the DDB specifications, with each section purposefully aligned to fulfill specific analytical objectives. The following figures highlight the key sections of the dashboard, as segmented according to the DDB structure.

Figure 5.8a below presents the Key Performance Metrics section, where four gauge-style indicators are used to display Weight (kg), Gasoline Saved, CO_2e, and Revenue. These visual elements are strategically placed at the top of the dashboard to provide an at-a-glance summary of core sustainability and financial indicators. This section directly corresponds to the Layout element in the DDB, which specifies “key metric gauges at top,” and also reflects the Visualization Technique component, which recommends “gauge charts for key metrics.” The use of vibrant colors and clear metric labelling aligns with the Style and User Interface elements, ensuring quick interpretability and strong visual hierarchy.

Figure 5.8a Key performance metrics section

Figure 5.8b illustrates the Geographical Flow Analysis section, which integrates a Sankey diagram and a heat map to present spatial and categorical insights. The Sankey diagram visualizes the flow of recyclable materials from five source cities to designated recycling categories such as paper, plastic, and box, effectively capturing the relationship between origin and material type. Positioned alongside this, the heat map depicts the distribution of CO_2e impact across geographic locations, with varying intensity levels indicating the environmental footprint contributed by each area. This section reflects the Visualization Technique element in the DDB, which specifies the use of Sankey diagrams for flow representation and heat maps for geographic analysis. It also aligns with the Structure component by supporting multi-dimensional breakdowns based on location and material type, while the overall visual design supports the User Interface specification, emphasizing clarity and intuitive spatial interpretation.

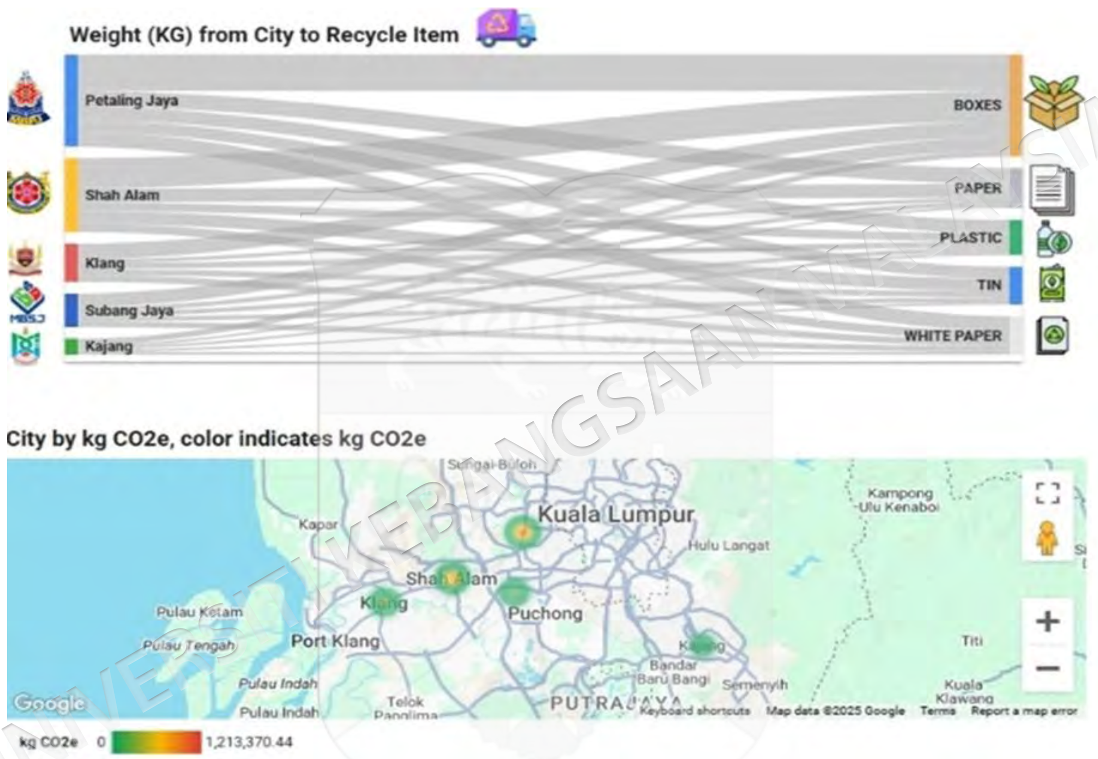

Figure 5.8b Geographical flow analysis section

Figure 5.8c presents the Comparative Performance section, which highlights ranked comparisons across cities and material categories. Horizontal bar charts are used to display the relative CO_2e contributions by city, enabling quick identification of high-impact areas. In parallel, a second set of bar charts visualizes buyback values by material category, offering insight into the economic aspect of recycling efforts. These visualizations are supported by a detailed data table that lists record counts by material type, providing additional granularity for reference and validation. This section aligns with the Visualization Technique component of the DDB, which outlines the use of horizontal bar charts for comparative analysis and data tables for detailed record display. It also reflects the Layout and Structure elements, which emphasize logically segmented views that support category-based evaluation and ranking, as well as the User Interface specification that promotes data-dense yet accessible visual formats.

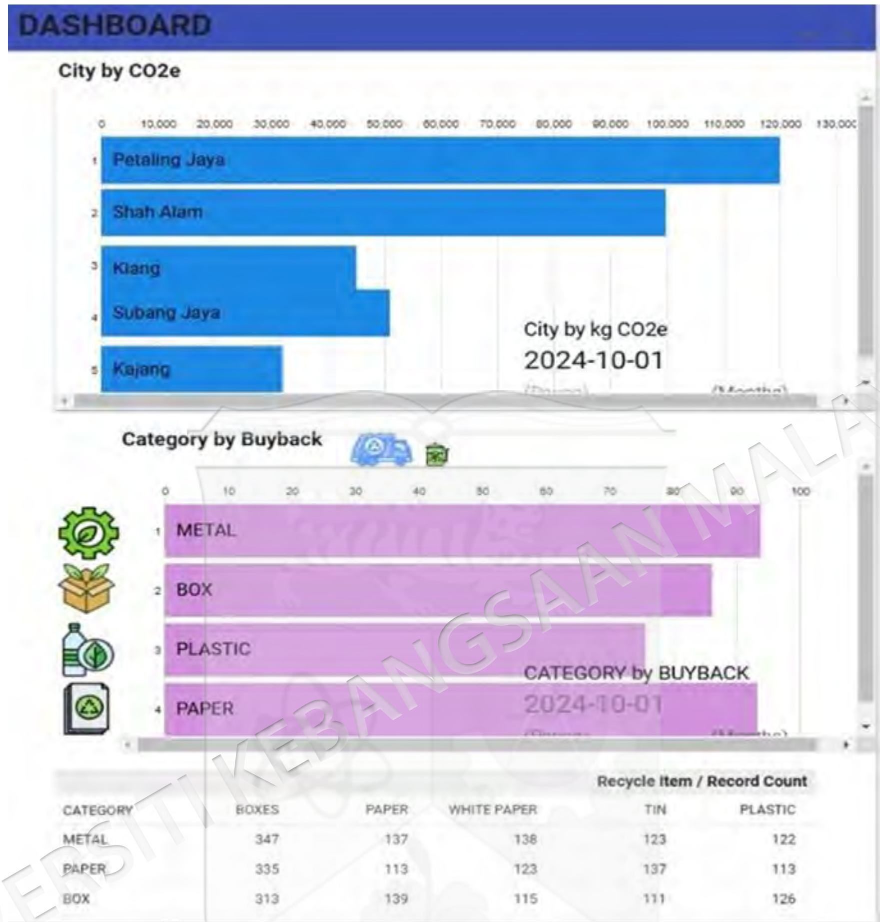

Figure 5.8c Comparative performance section

In summary, the Looker Studio implementation demonstrates how the IDDM Canvas can guide the development of an analytical dashboard that is both data-rich and visually structured. Despite differences in visual style compared to the Tableau version, this implementation remains consistent with the DDB specifications, incorporating platform-appropriate visualization techniques, layout structure, and user interface considerations. Each section of the dashboard - from key metrics to flow analysis and comparative breakdowns - reflects deliberate design choices informed by the IDDM framework.

d. Comparative analysis of the analytical dashboards mock-up

Similar to Operational Dashboard mock-up which have been discussed extensively in the 5.3.2, the two implementations of the Analytical Dashboard mock-ups also demonstrated differences in visual approach and emphasis, further demonstrating the flexibility of the IDDM framework. Table 5.8 below summarizes a comparison of key elements across the two mock-up implementations:

Table 5.8 Comparison of analytical dashboard mock-ups

Dashboard Elements	Tableau Implementation	Looker Studio Implementation
Layout Structure	Hierarchical layout with top–mid–bottom sections	Quadrant-style layout grouped by function
Primary Visualization Types	Donut charts, area charts, geographic markers	Gauge charts, Sankey diagrams, heat maps, bar charts
Color Scheme	Blue-teal gradient emphasizing temporal flow	Categorical color coding based on data types
Data Presentation Approach	Status and trend-oriented with KPI focus	Relationship-driven with multidimensional comparisons
Navigation Model	Sidebar with linear section flow	Content-based organization with modular visual hierarchy
Performance Metrics Display	Donut charts showing progress (%) + values	Gauge charts with target threshold ranges
Geographical Representation	Location markers with volume indicators	Heat map based on CO_2e intensity by area

This comparison reinforces the adaptability of the IDDM methodology in supporting consistent dashboard development across different visualization platforms. While each implementation reflects distinct layout structures and visual styles, both remain aligned with the design intent outlined in their respective DDBs, demonstrating how the framework accommodates platform-specific strengths without compromising core design coherence.

e. Alignment with IG principles

Both versions of the Analytical Dashboard demonstrate how IG principles can be operationalized through platform-specific design decisions. While the visual strategies and layout structures differ between Tableau and Looker Studio, the core governance considerations embedded in the IDDM Canvas remain evident. Table 5.9 summarizes the alignment of each implementation with the eight IG principles, highlighting how each platform interprets and reflects these principles through its interface, structure, and data presentation.

Table 5.9 Alignment with information governance principles in analytical dashboard

IG Principle	Tableau Implementation	Looker Studio Implementation
Effectiveness	Percentage-based progress indicators (e.g., 88.64%) used to track KPI achievements and environmental impact.	Gauge charts present absolute values with visual thresholds to convey performance at a glance.
Transparency	Material and location breakdowns presented in structured tables and segmented visualizations.	Sankey diagrams and bar charts visualize flow and distribution patterns across locations and materials.
Accountability	Regional collection metrics allow attribution of outcomes to specific cities and material types.	Ranking and comparison charts highlight performance by location and material category.
Quality	Standardized layout, consistent labeling, and updated values ensure accuracy and clarity.	Visual hierarchy, contextual coloring, and clean formatting support data reliability.
Integrity	Structured KPI layers and formatting reinforce data consistency across dashboard sections.	Uniform use of color, icons, and metric formatting across sections maintains presentation integrity.
Compliance	CO_2e and gasoline savings included to support environmental reporting and alignment with SDG targets.	Environmental indicators integrated in top-level KPIs to support sustainability tracking.
Security	Layout supports logical sectioning that could accommodate role-based access if implemented.	Section-based organization enables potential role-specific visibility and filtering.
Availability	Multi-layered data views (top–mid–bottom) provide access to both summary and detailed information.	Data-dense design with multiple access points (charts, tables, maps) supports user accessibility.

Table 5.9 highlights how both platforms interpret the IG principles based on their own strengths. Tableau leans more towards structured data clarity, while Looker Studio offers a more relationship-focused presentation. Despite these differences, both implementations show consistent efforts to embed governance principles such as

transparency, quality, and accessibility within the dashboard design, underscoring the practical utility of the IDDM framework.

f. Testing and improvement considerations

Similar to the Operational Dashboard, the elements of Testing, Evaluation, and Continuous Improvement embedded in the DDBs for the Analytical Dashboard played a significant role in shaping the design approach. Although these components are not explicitly represented in the mock-up interfaces, they formed an important foundation during the dashboard development process and offer a framework for future enhancement.

The testing considerations primarily focused on ensuring the quality and reliability of the visualizations. As emphasized by Sedlmair et al. (2012), analytical visualizations, particularly those dealing with real-world, exploratory tasks , demand rigorous validation processes to ensure accurate interpretation of complex and often ill-defined data relationships. In line with this, the Tableau version emphasized precise metric labeling and clean data progression across charts, while the Looker Studio implementation focused on consistent visual scaling and automated validation of calculated indicators.

Evaluation aspects outlined in the DDBs also shaped how performance metrics were structured and prioritized. As demonstrated by Albo et al. (2016), effective composite indicator visualizations must strike a balance between technical accuracy and interpretability to support stakeholder understanding and decision-making. Both versions of the Analytical Dashboard reflect this balance by structuring environmental and collection-related metrics in a format that enables strategic insight generation across stakeholder groups.

Meanwhile, the Continuous Improvement dimension was reflected in the use of scalable structures and modular layouts. Building on Shneiderman (1996)Visual Information-Seeking Mantra, “overview first, zoom and filter, then details-on-demand”, both implementations were designed with a progressive refinement approach. The Tableau dashboard enabled hierarchical exploration through layered sections, while the

Looker Studio version offered multi-dimensional navigation using diverse visualization formats. This structure supports the idea that user needs evolve over time, and dashboards must be designed to accommodate ongoing refinement and expanding information contexts.

Although not explicitly represented in the final dashboard interfaces, these components reflect the IDDM framework's commitment to long-term adaptability and sustainable use. This approach aligns with Munzner (2009) nested model, which highlights the need for visualization systems to evolve in response to increasing data complexity and shifting user requirements.

g. Conclusion

This demonstration phase applied the IDDM framework to the development of two mock-up dashboards for the i-MORSYS system, one operational and one analytical each implemented across two visualization platforms: Tableau and Looker Studio. These application scenarios revealed how the IDDM Canvas can function as a practical and adaptable design blueprint, guiding dashboard development while allowing for platform-specific flexibility.

The Operational Dashboard focused on real-time monitoring needs for field operators and collection teams, while the Analytical Dashboard provided decision-makers with strategic insights into long-term recycling performance and sustainability metrics. Despite differences in layout, visualization style, and platform capabilities, both dashboard types remained structurally aligned with their respective DDBs and adhered to the principles embedded in the IDDM.

Overall, the demonstration showcased the framework's ability to translate design intent into functional visual structures, tailored to different user needs and technical environments. However, to assess its effectiveness more critically, the next section presents a formal evaluation of the IDDM. This evaluation draws on feedback from the dashboard designers and a domain expert to identify strengths, limitations, and opportunities for further refinement of the IDDM.

5.4 EVALUATION OF THE IDDM

The evaluation phase in DSRM represents a critical component in assessing the usability, completeness, and practical value of the IDDM framework as an artefact developed for guiding dashboard design following its demonstration through mock-up development.

While the previous sections established the feasibility of applying the IDDM Canvas in guiding dashboard implementation across different platforms, this section focuses on how the framework performs from the perspective of those directly involved in the design and its intended domain of use.

To guide this evaluation process, an interview guide was developed based on best practices in qualitative research (Kallio et al. 2016). The interview guide serves as a structured tool to ensure consistency across interviews while allowing flexibility to explore participants' responses in depth. It includes questions covering key aspects of the IDDM's performance and utility, aligning with evaluation criteria for design science artifacts (Venable et al. 2016). The use of an interview guide is crucial in semi-structured interviews as it helps maintain focus on the research objectives while allowing for the exploration of unexpected insights (Longhurst 2003).

5.4.1 Evaluation Methodology

A qualitative research approach using semi-structured interviews was adopted to ensure a rigorous and comprehensive evaluation of the IDDM. This method allows for in-depth exploration of participants’ experiences and perceptions, providing rich, detailed data about the IDDM's application in practice (Kallio et al. 2016). Semi-structured interviews offer a balance between consistency across interviews and the flexibility to investigate deeper into individual responses, making them particularly suitable for evaluating complex processes like dashboard design (Longhurst 2003).

The evaluation involved two categories of participants: dashboard designers and a domain expert. These individuals were selected based on their direct involvement in the demonstration phase and their professional expertise in dashboard development.

An interview guide was developed containing open-ended questions focused on evaluating the IDDM's usability, effectiveness, completeness, and design impact. The guide also included questions about challenges, limitations, and potential improvements to ensure a well-rounded assessment. Semi-structured interviews were conducted with the selected participants and subsequently recorded and transcribed to ensure accurate data capture.

All interviews were carried out through Microsoft Teams, which provided a practical and flexible platform for conducting remote sessions. One advantage of using this platform is its automatic transcription feature, which helped capture detailed records of the conversation in real time. However, as the auto-generated transcripts were occasionally inaccurate, they were carefully reviewed and refined by the researcher. Once cleaned up, the transcripts were returned to each respondent for checking and confirmation, ensuring the information was both accurate and ethically verified.

Prior to the interviews, all participants received the full set of interview questions by email. They were given ample time to read and prepare their responses. This early engagement allowed the sessions to run more smoothly and helped respondents provide clearer and more reflective answers, making the interviews more focused and productive.

Once the interviews were completed and transcripts verified, the interview data were analysed using thematic analysis as described by Braun and Clarke (2006), supported by recent empirical applications of reflexive thematic analysis (Pearson et al. 2025) and ongoing methodological reflections in qualitative research (Morriss 2024). The analysis followed Braun and Clarke's six-phase framework, comprising (1) familiarisation with the data, (2) initial coding, (3) theme searching, (4) theme review, (5) theme definition and naming, and (6) final reporting, as illustrated in Figure 5.9 below:

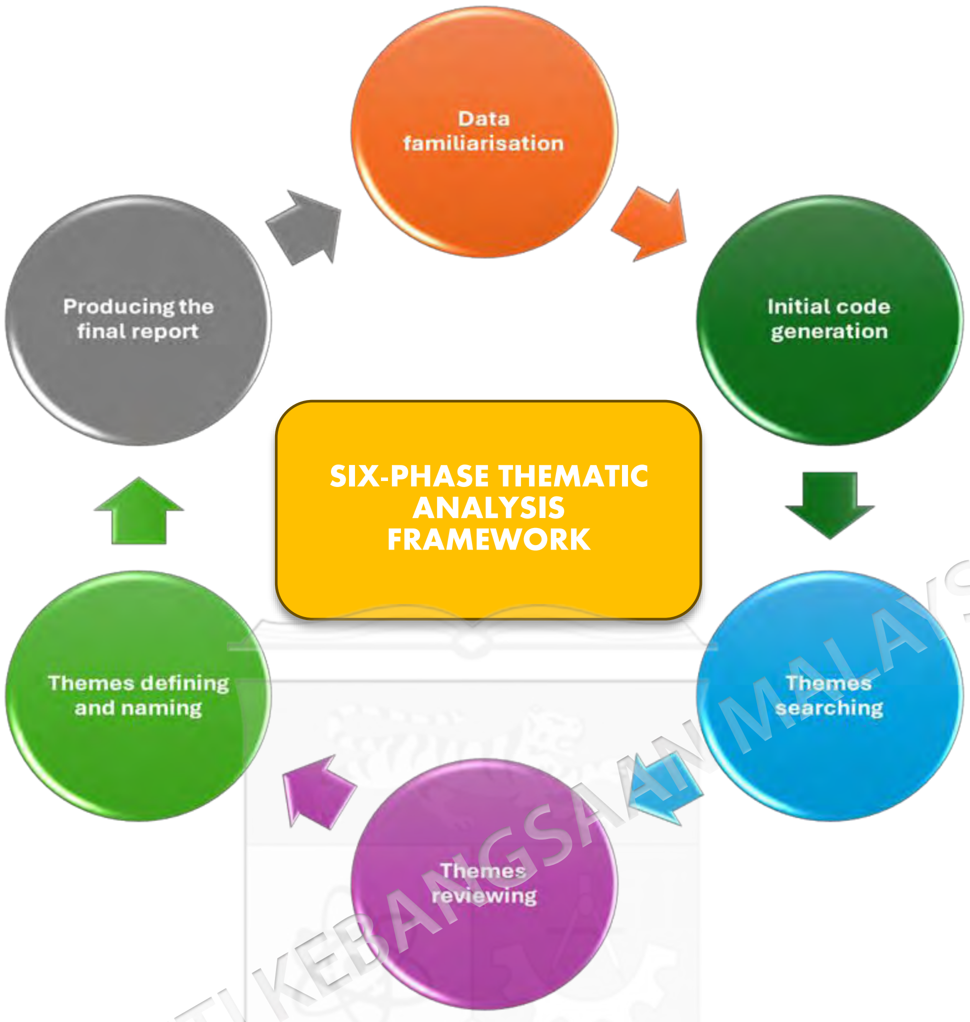

Figure 5.9 Braun and Clarke's (2006) six-phase thematic analysis framework

The structured yet flexible nature of the approach proved effective in identifying recurring patterns within participants' responses, allowing these to be translated into meaningful themes that highlight both the strengths and limitations of the IDDM framework. Through systematic coding and theme development, the analysis enabled comprehensive interpretation across the dataset, offering insights grounded in actual user experience.

To improve the analytical rigor and streamline the evaluation process, this study utilised AI-assisted thematic analysis via ChatGPT to help identify and organise key themes from the interview data. This method reflects recent shifts in qualitative research, where generative AI is increasingly explored as a tool to complement, not replace, traditional human-led analysis (Naeem et al. 2025; Perkins & Roe 2024). Comparative studies have reported encouraging results, with AI-generated themes showing 71% consistency with human coding in inductive analysis (Prescott et al. 2024). That said, this study remains fully aware of the limitations of AI tools, including their probabilistic nature and potential for inconsistency (Prescott et al. 2024). As such, all AI outputs were subjected to critical review and refinement by the researcher to safeguard analytical integrity. This blended approach added both depth and efficiency, while reinforcing the central role of human interpretation in unpacking the nuanced experiences of participants engaging with the IDDM framework.

Methodologically, the evaluation aligns with contemporary practices in assessing design frameworks within information systems research (Baskerville et al. 2018). By combining semi-structured interviews with thematic analysis, this evaluation aims to provide a nuanced understanding of the IDDM's effectiveness and potential areas for improvement.

While only three individuals were involved in the evaluation sessions, each participant was carefully chosen based on their direct engagement with the IDDM Canvas, either as a dashboard developer or a domain expert familiar with the smart waste management context. This kind of purposive selection is widely accepted in DSR, particularly in formative or refinement-oriented evaluations, where the aim is to learn from those with firsthand experience rather than to generalize statistically to larger populations (Palinkas et al. 2015; Robinson 2014). This approach aligns with the pragmatic and context-sensitive nature of DSR evaluations (Hevner et al. 2004), emphasizing learning and artifact improvement over broad generalizability.

In line with that, the approach taken here is intentionally interpretive and exploratory. Rather than proving effectiveness at scale, the goal is to gather situated, experience-driven feedback that can help refine the method and ensure its relevance in practice (Gregor & Hevner 2013; Iivari 2007). This aligns with the evaluation stage within DSRM, where artefacts are iteratively improved through practical exposure and reflection (Sonnenberg & vom Brocke 2012).

Despite the small sample size, the responses collected were rich in insight and offered grounded feedback related to usability, structure, and domain alignment.

Thematic patterns emerged naturally from their reflections, supporting the analytical approach adopted (Braun & Clarke 2006). In the context of DSR, this kind of depth-over-breadth engagement is often preferred during early artefact validation (Baskerville et al. 2018) . The overall methodology adopted in this evaluation is summarised in Table 5.10.

Table 5.10 Summary of IDDM evaluation methodology

Aspect	Description
Methodology	Qualitative research using semi-structured interviews enhanced with AI-assisted thematic analysis to obtain in-depth insights into the application and perceived utility of the IDDM framework.
Participant Selection	Two dashboard designers and one waste management expert participated in the evaluation. The dashboard designers were selected based on their direct involvement in developing the mock-up dashboards using the IDDM Canvas. The waste management expert was chosen due to their relevant experience in information systems and their domain expertise in waste management, which provided a complementary perspective on dashboard applicability.
Data Collection Method	Semi-structured interviews guided by open-ended interview questions aligned to core evaluation dimensions.
Interview Focus	Evaluation of the IDDM's usability, effectiveness, completeness, impact on dashboard design, as well as identification of implementation challenges, limitations, and areas for improvement.
Data Capture	All interviews were audio-recorded with consent and subsequently transcribed verbatim for analysis.
Analysis Method	Hybrid approach combining traditional thematic analysis with AI-assisted analysis using ChatGPT, conducted using the six-phase process proposed by Braun and Clarke (2006), allowing for the identification and interpretation of recurring themes in participant responses while ensuring rigorous human validation of all AI-generated insights.

With the evaluation methodology outlined, the following subsections provide further detail on the design of the evaluation process. This includes an overview of the selected respondents, the structure of the interview guide used, and the approach taken to analyse the qualitative data collected.

a. Respondent profiles

To ensure the evaluation of the IDDM reflected both technical and domain-specific perspectives, three respondents were purposively selected based on their direct involvement in the demonstration phase and their relevant expertise. This combination of roles was intended to provide a holistic view of the IDDM's usability, relevance, and applicability across different stages of dashboard design.

The first two respondents were dashboard designers who independently developed the mock-up dashboards using the IDDM Canvas as their primary design guide. Each selected their preferred visualisation platform, Tableau and Looker Studio respectively based on their technical expertise and familiarity. The first designer (DD1) had prior experience in developing dashboards specifically for waste management reporting, while the second designer (DD2) had worked on a wide range of dashboard projects across various domains. Their feedback was grounded in hands-on experience using the IDDM throughout the mock-up development process, making their insights particularly relevant for assessing the framework's usability, structural completeness, and practical design support.

The third respondent was a domain expert in waste management, with extensive operational and strategic experience in sustainability-driven initiatives. He holds a professional certification as a Green Project Manager (GPM) and has been actively involved in various recycling programmes and environmental projects at the municipal and state levels. His inclusion in the evaluation enabled the integration of domain-specific perspectives, particularly regarding the dashboards' practical utility, alignment with real-world reporting requirements, and relevance to decision-making within waste management organisations.

An overview of the respondents' roles and professional backgrounds is summarised in Table 5.11.

Table 5.11 Respondent profiles

Respondent Code	**Role**	**Experience**	**Background**
DD1	Dashboard Designer (Tableau)	9 years	Data visualisation specialist with strong expertise in Tableau. Developed the Operational and Analytical Dashboards using the IDDM Canvas.
DD2	Dashboard Designer (Looker Studio)	8 years	Business intelligence analyst skilled in Looker Studio. Responsible for implementing both dashboard mock-ups guided by the IDDM Canvas.

to be continued…

…continuation

WME	Waste Management Expert	12 years	Expert in waste management and recycling systems. Experienced in sustainability metrics and dashboard use for performance monitoring and reporting

These selected respondents collectively provided a balanced and contextually grounded basis for evaluating the primary artefact of this study, the IDDM. Their diverse backgrounds, ranging from platform-specific dashboard development to domain-level expertise in sustainability and waste management, ensured that the evaluation captured both technical implementation perspectives and end-user expectations. The next subsection outlines the structure of the interview guide used to elicit detailed feedback on the IDDM's performance across key evaluation dimensions.

b. Interview guide and question design

The interview guide was designed to evaluate the IDDM across seven core dimensions: usability, effectiveness, completeness, impact, challenges and limitations, potential improvements, and overall assessment. These dimensions were not drawn from a single theoretical model but were synthesised based on established evaluation practices in DSR, usability studies, and artefact-based methodology refinement, particularly in the context of dashboard design.

The usability dimension was grounded in the classical definition by Nielsen (1993), which emphasises learnability, efficiency, and satisfaction in system use. Complementary perspectives from Hornbæk (2006) and ISO 9241-11 (1998) framed usability as a multi-dimensional construct encompassing ease of understanding, user-friendliness, and goal-oriented effectiveness. These dimensions are particularly relevant when evaluating methodological artefacts like the IDDM, where clarity and flow influence design adoption.

To assess the completeness of the method, evaluation criteria from ontology assessment literature were adopted. As suggested by Brank et al. (2009), completeness refers to structural coverage and conceptual soundness—adapted here to evaluate whether the IDDM adequately addresses all relevant aspects of dashboard design without redundancy or omission.

The impact dimension was operationalised through the lens of perceived usefulness and adoption potential, as discussed in the Technology Acceptance Model (TAM) by Davis (1989) . This was supplemented by pragmatic quality concepts from Moody (2003) and design adoption frameworks such as Osterwalder (2004), which highlight the importance of clarity, simplicity, and value delivery in artefact usage.

The remaining dimensions, challenges, potential improvements, and overall assessment were included to capture reflections from actual users following the demonstration phase. These were formulated as open-ended prompts to surface unanticipated issues, user frustrations, and suggestions for enhancing the method. This approach also aligns with the iterative refinement logic proposed in artefact-centred frameworks such as the DSRM and Action Design Research (ADR), where continuous feedback informs successive improvements (Hevner et al. 2004; Sein et al. 2011).

All questions were open-ended, allowing for detailed, reflective responses grounded in the participants' direct experience with the IDDM during the dashboard design process. The structure of the interview guide for the two dashboard designers, including the evaluation dimensions, focus areas, sample questions, and supporting literature, is summarised in Table 5.12.

Table 5.12 Interview guide structure for dashboard designers

Dimension	Focus Area	Sample Interview Questions	Supporting Literature
Usability	Ease of understanding, user-friendliness, and logical flow	How easy was it to understand and apply the IDDM Canvas in your dashboard design process?	Nielsen (1993); Hornbæk (2006); ISO 9241-11 (1998)
Effectiveness	Support in decision-making, relevance to design goals	To what extent did the IDDM help address the specific needs of your target audience?	ISO 9241-11 (1998); Prat et al. (2015)
Completeness	Structural coverage and relevance of all design elements	Were there any aspects of dashboard design that you felt were not adequately addressed by the IDDM?	Brank et al. (2009)

to be continued…

…continuation

Impact	Perceived usefulness, influence on practice, adoption potential	How do you think the IDDM could impact the broader field of dashboard design?	Davis (1989); Moody (2003); Osterwalder (2004)
Challenges & Limitations	Difficulties or constraints during use	What challenges did you encounter while using the IDDM?	Venable et al. (2016); Sein et al. (2011) *(contextual)*
Potential Improvements	Suggestions for refining structure or usability	What additions or modifications would you suggest to improve the IDDM?	Sein et al. (2011); Peffers et al. (2007) *(iterative refinement logic)*
Overall Assessment	General evaluation of value and recommendation potential	On a scale of 1–10, how would you rate the overall usefulness of the IDDM in your dashboard design process?	Davis (1989); Rogers (1995) *(for adoption lens)*

In addition to the dashboard designers, one domain expert was also interviewed to provide a practitioner-oriented evaluation of the dashboards. Unlike the designers, the evaluation did not focus on the IDDM framework itself but rather on the dashboards produced using the method.

To complement the technical evaluation, this line of questioning explored the relevance, interpretability, and real-world utility of the dashboards in supporting operational and strategic decision-making within the waste management context. These elements reflect core principles of interaction design, particularly the importance of usability, information clarity, and stakeholder-centred outcomes in interactive systems (Sharp et al. 2019). Particular attention was given to how well the dashboards aligned with industry-standard metrics and supported sustainability reporting dimensions commonly associated with IG and regulatory compliance (Khatri & Brown 2010). The structure of this guide is presented in Table 5.13.

Table 5.13 Interview guide structure for waste management expert

Focus Area	**Sample Interview Questions**	**Supporting Literature**
Dashboard Relevance and Utility	How well do these dashboards reflect the actual information needs of waste management operations? Which features are most useful for strategic or operational decision-making?	Sharp et al. (2019); Tufte (2001)

to be continued…

…continuation

Domain-Specific Metrics	Are the indicators and KPIs used in the dashboards relevant to current reporting and regulatory practices? Are there any critical metrics that are missing?	Khatri & Brown (2010); Few (2006)
Interpretability and Clarity	Are the visualisations clear and easy to interpret for different stakeholders (e.g., managers, operators, policymakers)?	Few (2006); Tufte (2001)
Adoption and Integration	How feasible would it be to adopt dashboards like these in actual waste management workflows? What challenges might arise in implementation?	Davis (1989); Rogers (1995)
Sustainability and Compliance	Do the dashboards support sustainability tracking and compliance reporting (e.g., CO_2e savings, recycling targets)?	Khatri & Brown (2010)
Overall Assessment	Would you recommend a dashboard like this to other organisations in the industry? Why or why not?	Davis (1989); Rogers (1995)

The inclusion of both dashboard designers and a domain expert in the evaluation ensured that the IDDM was assessed from multiple angles, covering both technical implementation and practical utility in the target domain. With the interview guides structured to reflect these distinct perspectives, the next step involved analysing the collected data to identify recurring patterns, themes, and insights. The following subsection outlines the thematic analysis process used to interpret the interview responses.

c. Data analysis process

To analyse the interview data collected from both dashboard designers and the domain expert, a thematic analysis approach was employed. This method was selected for its flexibility and rigor in exploring patterns of meaning across varied participant experiences. Thematic analysis is particularly well-suited for DSR, where understanding how an artefact is interpreted, applied, and improved upon is essential.

All interview sessions were audio-recorded with participant consent and transcribed verbatim to ensure accuracy. Complete interview transcripts are provided as appendices to maintain transparency and enable verification of the analysis:

Dashboard Designer 1 (DD1) - Appendix A; Dashboard Designer 2 (DD2) - Appendix B; and Waste Management Expert (WME) - Appendix C. The thematic analysis presented in the following sections is grounded in this complete dataset.

As mentioned briefly in 5.4.1, the analysis followed the six-phase process proposed by Braun and Clarke (2006), a widely recognised approach in qualitative research for enabling both inductive and deductive theme development. Although the interview questions were designed around predefined evaluation dimensions, such as usability, effectiveness, completeness, and impact, the actual analysis remained open to emergent patterns across and within respondent groups. To ensure transparency and methodological traceability, Table 5.14 outlines each phase of the thematic analysis along with its practical application in the context of this study.

Table 5.14 Six phases of thematic analysis by Braun and Clarke (2006)

Phase	Description (Braun & Clarke, 2006)	Application in This Study
1. Familiarisation	Reading and re-reading the data to become deeply familiar with the content, noting initial observations.	Interview transcripts were read multiple times. Notes were taken to document early reflections related to IDDM usage and dashboard outcomes.
2. Generating Initial Codes	Systematically identifying and tagging interesting features across the dataset.	Manual open coding was conducted across all transcripts. Segments reflecting usability, challenges, or governance alignment were labelled using short phrases.
3. Searching for Themes	Organising codes into potential themes by clustering similar ideas or concepts.	Related codes were grouped under tentative themes such as “Ease of Use”, “Coverage Gaps”, or “Real-World Relevance”. Themes were cross-checked against research aims.
4. Reviewing Themes	Checking the validity of themes against the coded data and the entire dataset.	Themes were refined to remove overlaps and merged where appropriate. Irrelevant or weak themes were discarded to improve clarity and coherence.
5. Defining and Naming Themes	Clearly defining what each theme represents and how it contributes to the overall understanding of the data.	Final themes were named based on their conceptual significance, and definitions were developed to guide the writing of analytical narratives.
6. Producing the Report	Writing up the analysis with illustrative quotes and linking findings to research questions and literature.	Thematic narratives were organised according to the predefined evaluation dimensions (e.g., usability, effectiveness, completeness), with selected respondent quotes.

This structured approach ensured that the insights derived from participants were not only grounded in empirical data, but also systematically aligned with the study's overarching evaluation objectives. The following subsections present the findings of this analysis, beginning with reflections on the usability of the IDDM framework.

5.4.2 Evaluation Findings

The next process in the DSRM involves evaluating the developed artifact to determine its effectiveness and relevance in real-world contexts. In this study, the evaluation of the IDDM framework was conducted through semi-structured interviews with three participants who had hands-on experience using the methodology during the demonstration phase. Using the six-step thematic analysis approach by Braun and Clarke (2006), the interview transcripts were analysed systematically. From this process, several key themes were identified, offering deeper insight into the framework's practical strengths, areas that require refinement, and suggestions for further enhancement.

a. Theme 1: Framework usability and learning experience

The first key theme that surfaced from the analysis centres on the overall usability of the IDDM Canvas, particularly in terms of how users experienced and learned to use the tool. Both dashboard designers described the framework as intuitive and practical once they got the hang of it, although they did face a slight learning curve at the start. This observation is consistent with Nielsen's (1993) usability heuristics, which highlight *learnability* as a core aspect of effective system design. Table 5.15 summarises participants' feedback on their initial impressions, learning curve, and overall perception of the IDDM Canvas. The following discussion elaborates on these points, drawing directly from their reflections.

Table 5.15 Framework usability assessment by respondents

Respondent	Initial Experience	Learning Curve	Overall Usability Rating
DD1	*"Initially felt like too many sections... lot of paperwork"*	*"Easy to use after I understood the structure."*	*"Very user friendly... like following a checklist"*
DD2	*"At first seems quite... like a lot"*	*"There were a couple of sections that I had to revisit"*	*"Presently intuitive... logical flow guiding step by step"*
WME	*N/A - Evaluated dashboard outputs only*	N/A	*"Dashboards are highly effective in delivering relevant data"*

One of the strongest themes from the interviews was the usability and structured nature of the IDDM Canvas. DD1 reflected on the experience, stating: *"Actually, it was easy to use after I understood the structure. The IDDM Canvas is practical and clear. The 12 sections gave me a full map, from defining the purpose, all the way to planning for continuous improvement."*

This view was echoed by DD2, who noted: *"I found the IDDM Canvas presently intuitive because the way it was made is easy to digest. At first, it felt like a logical flow guiding me step by step."*

Both designers appreciated the structured layout of the framework. DD1 likened it to "*following a checklist*," while DD2 highlighted how *"breaking down the design process into distinct stages made it less overwhelming."* This kind of structured guidance appeared to instill confidence, particularly when navigating complex design decisions, aligning with Sedlmair et al. (2012), who stress the value of systematic support in visualization design.

Still, initial impressions weren't without challenge. DD1 admitted: *"Initially, I felt like there were too many sections. It felt like a lot of paperwork before any real work began. But once I linked each section to my actual workflow in Tableau, it made more sense."*

This reflects that while the framework is comprehensive, users may require clearer onboarding or contextual examples to map the Canvas to their specific tools or work patterns. This is consistent with Tory and Möller (2005) argument that methodological frameworks should maintain a degree of flexibility to accommodate diverse user needs.

While the first theme highlighted how users interacted with the structure and usability of the IDDM Canvas, a second, equally important theme emerged, one that speaks to the shift in mindset and approach fostered by the framework.

b. Theme 2: Enhanced design thinking and user-centricity

Another prominent insight from the interviews was how the IDDM Canvas encouraged designers to think more critically and empathetically throughout the dashboard development process. Across all interviews, participants described how the framework prompted them to engage more deeply with user needs and to structure their design decisions around practical outcomes. This shift towards more reflective and user-aware thinking reflects key principles of user-centered design as outlined by Sharp et al. (2019), and also resonates with the dashboard design best practices emphasized by Few 2012). Table 5.16 below summarizes how the IDDM Canvas influenced design thinking and user-centric approaches among the participants:

Table 5.16 Impact of IDDM on design approach

Design Aspect	**Before IDDM**	**With IDDM**	**Reported Benefits**
Planning Approach	*"Jump straight into visuals" (DD1)*	*"Think first... saved a lot of rework" (DD1)*	Reduced rework, better alignment
User Consideration	*"Ad-hoc approaches" (DD2)*	*"Define who would be using... what their key questions were" (DD2)*	More tailored, user-centric designs
Design Philosophy	*"Just building a dashboard" (DD2)*	*"Designing a solution" (DD2)*	Solution-oriented thinking
Decision Documentation	*"Something I never used to do" (DD1)*	*"Document my decisions... why I used line charts" (DD1)*	Better rationale, improved communication

The impact of the IDDM Canvas on participants' design mindset is clearly illustrated in Table 5.16, which compares their design approaches before and after applying the framework. The shift is not only procedural but also philosophical, with designers demonstrating more structured, user-focused, and solution-oriented thinking.

DD2 articulated this transformation clearly: *"The IDDM's strong emphasis on user analysis and task identification really pushed us to think from the users' perspective. The Canvas prompted us to clearly define who would be using the dashboard, what their key questions were, and what actions they needed to take based on the information."*

This shift towards user-centric thinking was not just conceptual, it directly influenced the decisions made during dashboard development. It supports the argument made by Yigitbasioglu and Velcu (2012), who highlight the importance of deeply understanding user needs in dashboard design.

DD1 also shared a concrete example of this shift in practice: *"The Audience section helped me differentiate views, for example, between local council staff and operations managers. Normally, I go straight into visuals, but IDDM made me think first. That saved a lot of rework later."*

The benefit of reducing unnecessary rework through early-stage planning was consistently mentioned, underscoring the value of incorporating user analysis upfront, an approach also emphasized by Janes et al. (2013) in their work on dashboard planning.

Beyond task-level improvements, the IDDM Canvas appeared to reshape the entire design mindset. As DD2 noted: *"It felt less like just building a dashboard and more like designing a solution."* This represents a clear shift from viewing dashboard development as a purely technical exercise to one rooted in problem-solving and human-centred design, aligning well with Buchanan (1992) foundational views on design thinking.

This user-focused orientation was also validated from an external viewpoint. The waste management expert (WME), who evaluated the dashboard outputs rather than using the Canvas directly, observed: *"The dashboards are highly effective in delivering the relevant data and visual insights tailored to my organization's needs... This lead approach, I think ensures that both the frontline staff and the relevant decision makers have the information that they need at their respective levels."*

While the previous theme focused on how the IDDM Canvas enhanced design thinking and brought user-centricity to the forefront, participants also pointed out areas where the framework could be strengthened. This brings us to the third theme, which addresses the balance between the framework's comprehensive structure and certain practical gaps that surfaced during real-world application.

c. Theme 3: Comprehensive coverage with implementation gaps

Overall, participants agreed that the IDDM framework provided a strong foundation for dashboard design. However, they also highlighted several areas where additional support or refinement could improve their usability and effectiveness. This theme captures both the sense of completeness and the need for more practical implementation aids, especially when translating Canvas into actual dashboard development. Table 5.17 summarizes how participants assessed the framework's coverage, what gaps were identified, and what improvements they suggested:

Table 5.17 Framework completeness assessment

Framework Element	**Coverage Assessment**	**Identified Gaps**	**Suggested Improvements**
Core Design Elements	*"Covered everything I need"* (DD1)	None identified	None suggested
Iterative Design	*"Implicitly encourages"* (DD2)	*"More explicit guidance... on iterative design process"* (DD2)	Add a dedicated section on iteration
Information Governance	*"Touched upon"* (DD2)	*"More of a reminder... rather than deep dive"* (DD2)	Expand with practical implementation strategies
User Onboarding	Not covered	*"Many users don't know how to use filters"* (DD1)	Include training/onboarding section
Domain-Specific Metrics	Partially covered	*"Vehicle tracking... fuel usage"* (WME)	Add industry-specific templates

DD1 acknowledged the framework's broad scope, stating: *"The 12 sections covered everything I need. From setting goals, choosing direct data, planning layout up to dashboard review."* This perception of completeness reflects the structured and methodical nature of the framework, aligning with the dashboard design process described by Sarikaya et al. (2019).

Still, DD2 pointed out areas where more clarity could be helpful, particularly around iteration and feedback cycles. DD2 shared: *“While the IDDM was quite comprehensive, I felt that perhaps a bit more explicit guidance, especially on the iterative design process and user feedback loops could have been beneficial.”* This sentiment highlights the importance of flexible, feedback-driven refinement in dashboard design, as emphasised by Sedlmair et al. (2012).

The IG component, though present, was viewed as lacking in actionable depth. As DD2 put it: *“IG was touched upon within the Canvas, prompting consideration for data quality, security, and compliance. However, I felt it was more of a reminder to consider these aspects rather than a deep dive into practical implementation strategies.”* This points to a need for operational-level guidance, reinforcing Khatri and Brown’s (2010)argument on the importance of translating IG principles into practice.

From the domain expert’s perspective, WME identified a further enhancement opportunity: *“To make the dashboard more useful, I think there are a few key metrics that we could add, things like vehicle tracking and fleet efficiency, which would include fuel usage, the truck idle time and optimization of routes.”* Such suggestions underline the value of tailoring dashboard design to specific industry needs, in line with Maheshwari et al. (2021)who argue for the inclusion of domain-specific indicators to increase dashboard relevance and impact.

While participants generally viewed the IDDM Canvas as comprehensive and structured, their feedback also pointed to several practical issues that emerged during real-world implementation. These hands-on experiences form the basis of the fourth theme, which focuses on the operational challenges encountered when applying the framework in practice.

d. Theme 4: Practical implementation challenges

The evaluation revealed several technical and procedural hurdles faced by participants when implementing the IDDM Canvas. These insights offer a grounded view into the types of real-world frictions that may arise, not necessarily due to flaws in the framework itself, but due to external factors such as platform constraints, time pressures, or interpretational ambiguity. Many of these challenges reflect well-documented issues in the dashboard development literature (Burnett et al. 2004; Roberts et al. 2017) . Table 5.18 categorizes the main implementation challenges alongside their impacts and the mitigation strategies used by participants:

Table 5.18 Implementation challenges and mitigation strategies

Challenge Type	Specific Issues	Impact on Implementation	Mitigation Approach Used
Time Investment	*"Initial effort required to thoroughly complete each section"* (DD2)	*"Temptation to rush through"* (DD2)	*"Investing time upfront ultimately saved time"* (DD2)
Platform Limitations	*"Gauge charts... aren't natively supported"* (DD1)	Had to use alternative visualizations	*"Use KPI cards and line charts instead"* (DD1)
Framework Interpretation	*"Evaluation and Continuous Improvement... quite confusing"* (DD1)	Initial misunderstanding of scope	*"Realised they can be handled externally"* (DD1)
Data Preprocessing	*"CSV... had to preprocess using Python"* (DD1)	Additional technical steps required	Adapted workflow to include preprocessing

One of the most commonly cited issues was the time required to properly engage with each section of the Canvas, especially during the early planning stages. As DD2 explained: *"The main challenge wasn't necessarily with the methodology itself, but rather with the initial effort required to thoroughly complete each section of the Canvas. It takes time and focused effort to really dig deep into user needs and define clear objectives."* This reflects a common tension in design projects between the desire for rapid development and the need for thoughtful, user-informed planning, an issue similarly observed by (Jooste et al. 2013) .

Platform constraints also presented challenges. Working with Tableau, DD1 noted: *"Tableau is powerful but has some limitations. For example, gauge charts or dynamic tooltips aren't natively supported. So I had to use KPI cards and line charts instead."* DD2 added that "*The visualization capabilities of the specific platform we were using did influence some of our choices, although the IDDM helped us to first identify the ideal visualization and then see how closely we could achieve it within the platform's constraints."* These reflections align with the framework proposed by Bach et al. (2014), which emphasizes the importance of flexible design methodologies that adapt to technological constraints while preserving the core intent of temporal data visualizations.

Interpretation of certain framework elements also required clarification during implementation. DD1 shared: *"At first I thought I had to build those metrics inside the dashboard. Later I realised they can be handled externally, like monthly reviews or feedback forms from the client side."* This highlights a key distinction between what needs to be embedded in the dashboard design versus what can be managed post-deployment, a distinction similarly emphasized by Ellis and Dix (2006).

Although several implementation challenges were noted, participants maintained that the IDDM framework remained valuable overall. Its adaptability across different project settings emerged as a key strength. The following theme explores this aspect in more detail.

e. Theme 5: Framework flexibility and adaptability

Even with the earlier limitations and challenges, all participants consistently highlighted the IDDM framework's flexibility as one of its strongest qualities. This adaptability, whether in terms of project scale, dashboard type, or industry application, is an essential characteristic for any methodological tool. Moody (2003) argues that evaluation frameworks for visual systems must be able to accommodate real-world diversity in use cases, and the feedback gathered here strongly supports that perspective. Table 5.19 below shows how participants assessed the framework's flexibility across various dimensions:

Table 5.19 Framework flexibility assessment

Flexibility Dimension	Evidence from Evaluation	Application Examples
Project Complexity	*"Focus on 5-6 core sections... or apply all 12 sections"* (DD1)	Simple dashboards vs. complex multi-stakeholder systems
Dashboard Types	*"Operational dashboard... analytical dashboard"* (DD2)	Successfully applied to both dashboard categories

to be continued…

…continuation

Platform Independence	Tableau (DD1) and Looker Studio (DD2) implementations	Framework adapted to different technical environments
Timeline Adaptability	*"Worked well even with tight timelines"* (DD1)	Scalable based on project constraints

DD1 expressed strong confidence in the framework's flexibility, stating: *"Very, very flexible. For this project, it worked well even with tight timelines and mixed data quality. I can see it being applied to both simple and complex dashboards. For simpler use cases, you can focus on 5 to 6 core sections. For more complex projects, you can apply all 12 sections in detail."* This kind of scalability reflects the principles of adaptive methodology proposed by Sein et al. (2011) in their work on Action Design Research.

DD2 supported this view, highlighting the clarity and modular nature of the framework: *"The dashboard clearly separates two sets of information... IDDM is quite clear in guiding the design process. It makes the steps easier to follow."* The ability to apply the same methodology across different dashboard types further supports Prat et al. (2015) argument for evaluation frameworks that can flex based on complexity.

From the end-user perspective, the WME observed how the dashboards, developed using IDDM, were suitable for a wide range of stakeholders: *"The modularity and ability to present complex data in a digestible format makes them adaptable for various scales from, for instance, from municipalities for the usage of benchmarking the performance or for privately operators to see or to make or generate the reports as evidence of their task completed."* This reinforces the framework's cross-sector relevance, bridging both public and private operational needs.

In addition to highlighting the framework's flexibility, participants also offered concrete suggestions for enhancing the IDDM Canvas. These recommendations reflect thoughtful engagement with the methodology and reveal opportunities for refining IDDM Canvas's usability, inclusivity, and long-term sustainability.

f. Theme 6: Recommendations for enhancement

Beyond evaluating its current strengths and limitations, participants actively proposed several enhancements to improve the IDDM framework. These suggestions not only demonstrate the depth of their engagement but also align with contemporary issues discussed in dashboard design literature (Brath & Peters 2004; Palpanas et al. 2007). Table 5.20 summarises the key recommendations offered, grouped by enhancement category:

Table 5.20 Enhancement recommendations summary

Enhancement Category	**Specific Recommendations**	**Justification**	**Supporting Literature**
Guidance and Examples	*"Template pack... from different industries"* (DD1)	Help first-time users	Sedlmair et al. (2012)
User Onboarding	*"Add user guides or training tips"* (DD1)	Many users unfamiliar with features	Convertino et al. (2004)
Accessibility	*"Accessibility considerations... ensuring dashboards usable by everyone"* (DD2)	Inclusive design needed	Alper et al. (2010)
Technology Integration	*"Advanced technologies such as generative AI"* (WME)	Enhance interaction capabilities	Kirk (2016)
Lifecycle Planning	*"Dashboard's lifecycle and maintenance plan"* (DD2)	Long-term sustainability	North & Macal (2007)

Among the most frequently mentioned suggestions was the need for clearer guidance and real-world examples. DD2 recommended: *"I think having more explicit guidance or examples for different project scales and types of dashboards would be beneficial, like a version of the Canvas tailored for smaller or less complex projects."* Echoing this, DD1 proposed: *"A template pack, showing real examples from different industries would help guide first-time users."* These suggestions align with March & Smith (1995) emphasis on making design methodologies more accessible through applied exemplars.

The importance of user onboarding was also stressed, particularly by DD1, who noted: *“Many users don't know how to use Tableau filters or interactive elements. While IDDM covers functionality and improvement, I think it would be helpful to include a section that reminds developers to add user guides or training tips.”* Similarly, DD2 highlighted the value of including *“sections about design and user feedback integration.”* This reinforces findings from Yigitbasioglu & Velcu (2012) and Brooke (1995) who highlight the role of training and support in successful dashboard adoption.

Accessibility also surfaced as a crucial area for improvement. DD2 recommended: *“A section or prompts specifically addressing accessibility considerations would be a great addition, ensuring dashboards are usable by everyone.”* This was supported by the WME’s detailed feedback: *“Accessibility enhancements to cater for widely demographic, especially for those who have certain disabilities... through adding certain features such as larger text, the options to have larger text, high contrast visuals, and screen reader compatibility.”* These points reflect a broader push for inclusive data visualization practices, as outlined by Marriott et al. (2021).

From a technical standpoint, the WME proposed a forward-looking enhancement: *“I think that while the current dashboard provides very strong foundational metrics and visualization, I think it could benefit more from integration of more advanced technologies such as generative AI since this would allow users to interact with the dashboard using natural language queries.”* This aligns with emerging directions in conversational analytics and intelligent dashboards discussed by Setlur et al. (2016).

The previous theme outlined several enhancement opportunities for the IDDM Canvas, reflecting participants’ thoughtful engagement with the framework. To conclude the evaluation, the final theme synthesizes participants’ overall impressions and their perspectives on the framework’s future use and adoption.

g. Theme 7: Overall assessment and adoption potential

The final theme captures participants' overall evaluation of the IDDM framework, including their likelihood of continued use and recommendation to others. Feedback was overwhelmingly positive, with each participant providing a rating and elaborating on the key strengths they experienced. Table 5.21 summarises the overall assessment ratings and accompanying justifications:

Table 5.21 Overall assessment and adoption likelihood

Respondent	Rating	Key Strengths Identified	Recommendation Likelihood
DD1	8/10	*"Gave structure, made work more user-focused, helped prevent mistakes"*	*"Yes... especially for multiple stakeholders"*
DD2	8.5/10	*"Valuable structure and user-centric approach... improved quality"*	*"Definitely recommend... for structured approach"*
WME	9/10	*"Well aligned with industry requirements... metrics coverage"*	*"Absolutely. Without hesitation"*

DD1 rated the framework "8 out of 10," stating: *"It gave me structure, made my work more user-focused, and helped prevent mistakes I usually only catch at the end. From defining the goal to planning updates, IDDM kept me in control."*

Similarly, DD2 gave a rating of "8.5," commenting: *"It provided a valuable structure and a user-centric approach that significantly improved the quality and purposefulness of the dashboard we developed."* These high satisfaction ratings reflect the effectiveness of the IDDM Canvas as a design artifact, aligning with the evaluation principles proposed by Venable et al. (2016).

From the end-user standpoint, the WME awarded the highest rating – "9 out of 10", explaining: *"I would confidently rate the dashboards 9 out of 10. I think that they are well aligned with the current industry requirements in terms of metrics coverage, the interface functionality and the reporting capacity."* This form of external validation from a domain expert is critical in assessing the practical relevance of the framework, as emphasised by Hevner et al. (2004).

All three participants indicated a strong willingness to recommend the framework. DD1 noted: *"I would recommend it especially to those building dashboards for multiple stakeholders or public use. It helps clarify user needs early, structure the thinking process, and avoid rework."* DD2 reinforced this by saying: *"I would definitely recommend the IDDM to other dashboard designers, especially those who are looking for a more structured and user-focused approach."*

The WME's endorsement from an industry lens was particularly emphatic: *"Yes, absolutely. Without hesitation. I think that the dashboards have a strong potential to support organizations in achieving efficiency and for regulatory compliance as well as environmental stewardship."* This industry validation supports the framework's relevance to real-world applications, as emphasized by Gregor and Hevner (2013) in their discussion of positioning DSR contributions.

5.4.3 Discussion of Evaluation Findings

The thematic analysis confirms that the IDDM framework effectively fulfils its primary objective, to offer structured, user-centric guidance for dashboard development while remaining adaptable to diverse implementation scenarios. The evaluation highlights both the framework's strengths and actionable areas for further refinement.

One of the most significant contributions is the framework's emphasis on structured design thinking and user-centricity. By encouraging designers to consider user needs, organizational context, and IG principles before delving into technical implementation, the IDDM addresses a common shortfall in dashboard projects, namely, the tendency to prioritize features over relevance (Few 2010; Yigitbasioglu & Velcu 2012).

Although certain implementation gaps were identified, such as the need for clearer support around iterative design and operationalising IG principles, these should not be seen as weaknesses. Instead, they offer valuable insights for the framework's future development. Such evolution aligns with the iterative principle of DSR (Peffers et al. 2007), where real-world application is used to inform continuous improvement.

The framework's flexibility across different dashboard types, platforms, and project scopes further validates its generalisability, an important criterion for any methodological contribution Baskerville et al. (2018). Its modular design allows it to function both as a full-scale framework for complex, multi-stakeholder systems and as a simplified guide for smaller, focused projects.

Enhancement suggestions, particularly around accessibility, user onboarding, and integration of emerging technologies, reflect the framework's responsiveness to shifting technological and user expectations. These insights mirror broader discussions in the information systems field about inclusive and adaptive design (Marriott et al. 2021), further reinforcing the framework's long-term relevance.

To consolidate the evaluation, Table 5.22 maps key findings to established DSR evaluation criteria, demonstrating how the IDDM framework performs across functionality, completeness, usability, and generality dimensions.

Table 5.22 Evaluation findings mapped to DSR criteria

DSR Evaluation Criteria	Evidence from IDDM Evaluation	Implications
Functionality (Prat et al. 2015)	Successfully guided development of two dashboard types	Framework achieves intended purpose
Completeness (March & Smith 1995)	Covers all major design aspects with minor gaps identified	Comprehensive with room for enhancement
Consistency (Hevner et al. 2004)	Both designers achieved quality outcomes using different platforms	Internal consistency demonstrated
Usability (Nielsen 1993)	Initial learning curve followed by effective application	Acceptable usability with documentation needs
Fit with Organization (J. Venable et al. 2016)	High ratings from domain expert (9/10)	Strong alignment with industry needs
Generality (Gregor & Hevner 2013)	Successful application across dashboard types and platforms	Demonstrates broad applicability

Taken together, the findings discussed above provide a comprehensive understanding of how the IDDM framework performs in real-world scenarios. To synthesise these insights, the following section summarises the overall evaluation outcomes and highlights their broader implications.

5.4.4 Summary of Evaluation

The evaluation of the IDDM framework through semi- structured interviews with dashboard designers and a domain expert provides strong evidence of its effectiveness, usability, and practical value. Thematic analysis revealed seven key themes that collectively paint a picture of a framework that successfully guides dashboard development while maintaining the flexibility required for diverse implementation contexts.

The overwhelmingly positive assessments, combined with constructive suggestions for improvement, suggest that the IDDM Canvas framework represents a meaningful methodological contribution to the field of dashboard design. High ratings (averaging 8.5 out of 10) and strong endorsements from both designers and a domain expert indicate that the IDDM Canvas effectively addresses real-world needs within the dashboard development community.

Moreover, the evaluation highlights the importance of ongoing refinement grounded in user feedback and evolving industry requirements. Participants' recommendations point to actionable areas for enhancement, offering a practical roadmap for strengthening the framework's future applicability and reach.

In conclusion, the evaluation provides initial evidence supporting the IDDM framework as a potentially effective and scalable methodology for guiding dashboard development, particularly in complex domains such as smart waste management. While certain aspects may benefit from further refinement and broader validation, the current iteration of the framework demonstrates practical relevance and offers a structured pathway from theoretical design principles to real-world application. This positions the IDDM as a promising methodological contribution with potential value for both academic exploration and industry implementation.

5.5 SUMMARY

This chapter has presented the demonstration and evaluation of the IDDM Canvas in real-world dashboard development settings, validating its practical value as a structured design methodology. It fulfilled two key objectives: first, to demonstrate the framework's applicability across different dashboard types and visualization platforms; and second, to evaluate its usability, design support, and overall impact through qualitative feedback.

The demonstration phase applied the IDDM Canvas to develop mock-up dashboards for the i-MORSYS system, a conceptual smart waste management solution focusing on recycling initiative monitoring. Two types of dashboards were developed: operational dashboards for real-time monitoring by on-ground teams, and analytical dashboards for strategic decision-making by higher-level stakeholders. Each dashboard type was implemented using two separate platforms (Tableau and Looker Studio), with design work carried out by independent professional designers. This setup not only highlighted the framework's platform independence, but also its flexibility to guide diverse design interpretations while maintaining structural coherence.

Throughout the development process, the IDDM Canvas served as a Dashboard Design Blueprint (DDB), guiding each designer through key aspects such as defining objectives, identifying target users, processing data, selecting appropriate visualizations, and planning for iteration and improvement. Despite some stylistic and structural variations due to platform differences, all mock-up dashboards remained consistent with their DDBs and successfully integrated the IG principles embedded within the IDDM framework.

The evaluation phase involved semi-structured interviews with the two dashboard designers and a waste management domain expert. To enhance analytical rigor and efficiency, the evaluation employed AI-assisted thematic analysis using ChatGPT, with all AI-generated insights subjected to rigorous human validation to ensure analytical integrity. This hybrid analytical approach revealed seven key themes: (1) framework usability and learning experience, (2) improved design thinking and user-centred mindset, (3) comprehensive structure with some implementation gaps, (4) practical challenges during application, (5) adaptability and flexibility of the framework, (6) suggestions for enhancement, and (7) overall assessment and adoption potential.

Overall feedback from participants was highly positive. The IDDM Canvas received user ratings between 8 and 9 out of 10, and all participants expressed confidence in recommending the method to others. They particularly valued the framework's clarity, structured flow, and emphasis on user needs, noting that it helped reduce trial-and-error during design and encouraged more thoughtful planning. While some limitations were noted such as the need for clearer guidance on iterative processes, more practical strategies for applying governance principles, accessibility considerations, and platform-specific examples, these were framed as opportunities to improve an already solid foundation. The modular nature of the Canvas was seen as a strength, allowing it to be scaled and adapted to different project scopes.

In summary, the demonstration and evaluation have shown that the IDDM Canvas is a viable and effective methodology for guiding dashboard design, particularly in complex domains such as smart waste management. It bridges the gap between theoretical design principles and practical implementation, offering a balanced approach that supports both structure and flexibility. These outcomes position the IDDM Canvas as a meaningful contribution to the field of dashboard design and provide a strong foundation for its future refinement and broader adoption.

The findings presented in this chapter, combined with the framework development detailed in Chapter 4, provide compelling evidence of the IDDM Canvas's theoretical soundness and practical utility. Having successfully demonstrated and evaluated the framework through real-world application, the research now turns to synthesizing the broader achievements and contributions of this study. Chapter 6 will consolidate the research outcomes, articulate the theoretical and practical contributions to knowledge, discuss the implications for both academia and industry, and outline directions for future research that can build upon the foundation established by this work.

CHAPTER VI

RESEARCH ACHIEVEMENT, CONTRIBUTION, AND FUTURE WORK

6.1 INTRODUCTION

This final chapter concludes the research by reflecting on the core achievements, consolidating the theoretical and practical contributions, and outlining possible directions for future work. The journey began by identifying a critical gap in the literature, specifically, the absence of a standardized and structured method that could guide the design of information dashboards across domains. While dashboards have become increasingly vital in supporting data-driven decision-making, the development process remains fragmented and ad hoc, with little integration of IG or formal ontological grounding.

In response to this gap, the study adopted the DSRM proposed by Peffers et al. (2007) as its core methodology. Through iterative cycles of problem analysis, artefact development, demonstration, and evaluation, the research progressively led to the formulation of the IDDM Canvas. The IDDM is an ontologically grounded and practically oriented artefact developed to bridge the disconnect between theoretical design principles and the real-world complexities of dashboard implementation.

This chapter begins by revisiting the research objectives and outlining how each one has been addressed throughout the study. It then presents the research contributions through the lens of the DSR Knowledge Contribution Framework, as introduced by Gregor and Hevner (2013) and later refined by Gregor and Zwikael (2024). This is followed by an in-depth discussion of the primary artefact, the IDDM, together with several supporting sub-artefacts that were developed during the research process. The chapter concludes with key reflections and proposes several future research directions that could build upon the foundations established in this study.

6.2 RESEARCH ACHIEVEMENTS

The achievements of this study are best reflected through the systematic fulfillment of each research objective outlined in Chapter 1. These objectives guided the entire research process, from the initial literature analysis to the development and validation of the proposed method. This section outlines how each research objective was achieved, emphasising the key outcomes that contributed to advancements in the field of information dashboard design.

6.2.1 Achievement of Research Objective 1

The first objective was to examine existing information dashboard design methods and identify their limitations with respect to standardization, ontological structuring, and support for IG considerations. This was addressed through a comprehensive narrative literature review, as presented in Chapter 2, which examined thirteen recent studies covering various dashboard applications. The review explored eight core dimensions: application domain, standard methodology, key phases, design principles, best practices, key features, modelling tools, and design outcomes.

The analysis uncovered several critical gaps. Firstly, there was no evidence of a universally adopted method - studies applied a range of approaches, including iterative design models (Conrow et al. 2023; Kokoç & Altun 2019) and DSR frameworks (Pestana et al. 2020; Pamuk & Schumann 2024). Secondly, while recurring themes were found across design principles and practices, no unified or holistic design method was proposed. Thirdly, none of the reviewed studies explicitly integrated IG principles as a design foundation. In addition, the use of ontological structuring was entirely absent. Finally, no prior works focused on the specific domain of smart waste management.

These findings confirmed that a methodological gap exists in dashboard design research. The absence of a structured, governance-aware, and ontologically grounded design method validated the need for this study and set the direction for developing the IDDM framework.

6.2.2 Achievement of Research Objective 2

The second objective aimed to develop a standardized, domain-independent, ontology-based and governance-aware IDDM that effectively guides the design and implementation of information dashboards. This process, detailed in Chapter 4, was carried out using the DSRM and involved several structured phases.

The research began by identifying twelve key building blocks commonly referenced in dashboard design literature. These were grouped into three main categories: defining and planning (Purpose, Audience, Data Source, Data Processing), design and visualisation (Style, Visualisation Technique, Layout, Structure, User Interface), and testing and improvement (Testing, Evaluation, Continuous Improvement).

In contrast to existing methods, this study embedded IG as a foundational element. Eight IG principles: Quality, Security, Compliance, Integrity, Availability, Transparency, Accountability, and Effectiveness were integrated into the method to promote a more structured and responsible design process.

To formalise these elements, the IDDO was developed using the UOA. This process was underpinned by the UFO, which provided the philosophical and semantic foundation for modelling the key concepts and their relationships. By grounding the ontology in UFO, the IDDO benefits from a well-established upper ontology that ensures ontological clarity, consistency, and interoperability. The model was then structured using OntoUML, which allowed for the expression of complex semantic structures in a precise and visually communicable format. This formal representation not only enabled syntactical validation, but also enhanced the transparency, reusability, and rigour of the dashboard design framework.

Building on the ontology, the research then translated the IDDO into a visual, practitioner-friendly tool- the IDDM Canvas. Inspired by the transformation of the BMO into the BMC (Osterwalder et al., 2010), the IDDM Canvas offers a structured layout for applying the method in real-world design settings.

6.2.3 Achievement of Research Objective 3

The third objective involved demonstrating and validating the proposed ontology-based and governance-aware IDDM using smart waste management as the application domain. In this study, the focus was specifically placed on the recycling domain, which represents an important branch within the broader scope of smart waste management. This focus aligns with global priorities such as the Sustainable Development Goals (SDGs) and the circular economy agenda, both of which emphasise the importance of reducing waste, recovering resources, and promoting environmental sustainability. Rather than focusing on waste collection or disposal, which are typically operational in nature, recycling was selected due to its strategic relevance and its increasing role in driving system-level transformation across waste ecosystems.

The demonstration was carried out through the design of dashboards for the i-MORSYS a conceptual solution developed to support more efficient and informed recycling operations. Two dashboards, one operational and one analytical, were developed by independent designers using Tableau and Looker Studio. These platforms were selected to test the method's flexibility and tool independence. The use of multiple platforms confirmed that the IDDM is adaptable across different technological environments.

To assess the effectiveness of the framework, a qualitative evaluation was conducted through semi-structured interviews involving dashboard designers and a domain expert in waste management. Thematic analysis of the interview transcripts revealed seven key themes that reflect the practical impact of the IDDM. These themes include usability and ease of learning, the enhancement of design thinking and user centricity, comprehensive coverage with some areas for improvement, practical challenges in real-world application, flexibility and adaptability of the framework, recommendations for refinement, and the overall potential for adoption.

In addition to confirming the practical value of the IDDM, the evaluation process also highlighted opportunities for future development. These include the need for more detailed guidance in supporting iterative design processes, clearer strategies for embedding IG principles into design activities, greater consideration for accessibility features, and the potential integration of emerging technologies such as artificial intelligence and natural language interaction. There was also a call for the development of industry-specific templates to further streamline adoption across different sectors.

Overall, the evaluation yielded strong positive feedback, with participants expressing high levels of satisfaction and confidence in the method's relevance and applicability. The average rating of 8.5 out of 10 further reinforced the robustness of the IDDM, positioning it as a valuable tool for addressing the complex design challenges faced within the recycling domain and beyond.

In summary, the successful fulfilment of all three research objectives demonstrates a coherent progression from identifying the research gap to developing and validating a method that addresses both theoretical and practical needs. Table 6.1 below consolidates these achievements for clarity.

Table 6.1 Summary of research objectives and achievements

Research Objective	Focus	Achievement
RO1	To examine existing information dashboard design methods and identify their limitations with respect to standardization, ontological structuring, and support for information governance considerations.	Addressed through a comprehensive narrative literature review of thirteen recent studies on dashboard design. Revealed critical gaps, including the absence of a standardized method, lack of IG integration, no ontological approach, and no application in smart waste management.
RO2	To develop a standardized, domain-independent, ontology-based and governance-aware IDDM that effectively guides the design and implementation of information dashboards.	Achieved through the synthesis of twelve building blocks, integration of eight IG principles, ontological formalization via the IDDO using UFO and OntoUML, and transformation into the IDDM Canvas. Ensured both conceptual rigour and practical usability.
RO3	To demonstrate and validate the proposed ontology-based and governance-aware IDDM using smart waste management as the application domain.	Demonstrated using i-MORSYS dashboards on Tableau and Looker Studio. Evaluation with dashboard designers and a domain expert confirmed utility, adaptability, and surfaced future enhancement areas. Average satisfaction rating: 8.5/10.

The successful achievement of all three research objectives provides a solid foundation for positioning this study within the broader context of DSR From identifying the lack of a unified method, to developing the ontologically grounded

IDDM Canvas, and validating its practical value through demonstration and evaluation, each phase contributed meaningfully to both academic insight and practical relevance. The next section builds on this by discussing the contributions of the study through the lens of the Design Science Research Knowledge Contribution Framework. This includes a closer look at the key artefacts developed throughout the research process, particularly the IDDM Canvas and its supporting ontology, to show how they extend existing knowledge in information dashboard design from both conceptual and methodological perspectives.

6.3 RESEARCH CONTRIBUTION

In this final chapter of the study, it is essential to clarify the specific knowledge contributions made by the artefacts developed throughout the research. These contributions are examined through the lens of established DSR frameworks. Specifically, the discussion draws on the widely recognised model by Gregor and Hevner (2013) and the more recent refinement introduced by Gregor and Zwikael (2024), which together provide a structured basis for classifying design knowledge in terms of both contribution type and abstraction level.

Adopting these frameworks enables a systematic and transparent positioning of the research artefacts, distinguishing between abstract design knowledge, prescriptive methods, and instantiated solutions. This approach ensures that the contributions of the study are not merely described, but are situated within an established theoretical context, thereby enhancing their interpretability and rigor. In the context of this research, such positioning is particularly important given the development of multiple interrelated artefacts that collectively contribute to the advancement of information dashboard design.

Accordingly, the following section provides an overview of the artefacts developed in this study, serving as an entry point for the subsequent discussion of their individual roles, relationships, and knowledge contributions.

6.3.1 Overview of Artefacts Developed

This section provides a comprehensive overview of the main artefact and supporting sub-artefacts produced throughout the course of this research. These artefacts collectively represent the tangible outputs of the DSR process and serve as the foundation for evaluating this study's knowledge contribution. The artefacts span from abstract theoretical constructs to practical instantiations, aligned with the layered nature of DSR outputs.

a. Main artefact: Information Dashboard Design Method (IDDM)

The central contribution of this research is the IDDM, a methodological framework designed to guide the development of effective, user-centred, and governance-aware dashboards. The IDDM offers a structured yet flexible approach that addresses key shortcomings observed in existing dashboard design practices, particularly the absence of standardisation and the lack of alignment with IG principles.

The IDDM functions as a comprehensive design methodology that bridges theoretical foundations and practical needs, offering prescriptive guidance for dashboard practitioners. Its conceptual development is rooted in formal ontological structures (via IDDO) and further operationalised through the IDDM Canvas. What distinguishes the IDDM from earlier approaches is its integration of user needs (Purpose and Audience), systematic governance considerations, and emphasis on reusability across different domains and dashboard types.

b. Sub-artefact 1: Information Dashboard Design Ontology (IDDO)

Serving as the theoretical backbone of the IDDM, the IDDO provides a rigorous semantic structure that defines the core building blocks and relationships within dashboard design. Formalised using OntoUML and grounded in the UFO, the IDDO establishes a consistent conceptual foundation for dashboard design knowledge.

The IDDO introduces a set of twelve reusable and conceptually distinct dashboard components, while embedding governance principles as quality-related ontological constructs. This integration facilitates governance-aware design at the modelling level, providing a robust theoretical lens through which dashboards can be conceptualised and evaluated. As a result, the IDDO promotes clarity, consistency, and interoperability—three pillars often missing in ad hoc dashboard practices.

c. Sub-artefact 2: IDDM canvas with embedded guidelines

The IDDM Canvas transforms abstract ontological knowledge into a practical tool that can be directly used by designers. Its layout, inspired by Osterwalder's BMC, is visually structured to guide users through the key phases of dashboard design, ranging from identifying purpose and audience to determining visualisation choices and governance strategies.

By embedding IG principles into directive statements within the canvas rather than isolating them as separate elements, the tool ensures that governance considerations are seamlessly integrated throughout the design process. This design choice lowers the barrier to adoption for practitioners, particularly those unfamiliar with governance frameworks or ontology-driven design.

d. Sub-artefact 3: Dashboard Design Blueprints (DDBs)

The DDBs are comprehensive design specifications generated using the IDDM Canvas. They represent structured design outputs that demonstrate how the canvas can be applied across different implementation scenarios. Four blueprints were created during the demonstration phase, each aligned with a different dashboard type or platform (Tableau and Looker Studio).

These artefacts serve as reusable templates for practitioners, reduce onboarding time for new users of the framework, and validate the completeness of the IDDM methodology. Their variation in form and context illustrates the flexibility of the approach and its potential applicability across diverse use cases.

e. Sub-artefact 4: i-MORSYS dashboard mock-ups

The i-MORSYS dashboard mock-ups represent the final instantiation of the methodology, positioned at Level 1 in the DSR abstraction hierarchy. These dashboards were developed based on the design blueprints and serve to demonstrate the practical viability of the IDDM in the context of smart waste management.

By developing both operational and analytical dashboards tailored to the needs of local authorities and stakeholders, the mock-ups demonstrate the framework's ability to address multi-stakeholder requirements while supporting both strategic and real-time decision-making. The cross-platform development further validates the technology-agnostic nature of the IDDM.

f. Sub-artefact 5: Unified Ontological Approach (UOA)

The UOA is a customised ontology development method created to support the structured construction of the IDDO. Synthesising best practices from existing ontology development methodologies (e.g., Ontology Development 101, Methontology, NeOn), the UOA offers a lightweight and accessible process for developing practical ontologies.

The UOA represents a methodological contribution aimed at ontology engineers and practitioners seeking to operationalise formal knowledge structures in applied domains. Its application in this research ensured the clarity, consistency, and extensibility of the IDDO.

g. Other research contributions

Beyond the core artefacts described above, this study offers several additional contributions that further enrich the knowledge base. Firstly, the synthesis of IG principles specifically tailored for dashboard design fills an important theoretical gap. By systematically analysing existing governance frameworks and contextualising them within the dashboard domain, the research identifies eight relevant principles, laying the groundwork for future governance-aware design methodologies.

Secondly, the methodology used to extract and consolidate common dashboard design elements from literature represents a reusable meta-framework. This analytical strategy, identifying shared patterns and converting them into formalised building blocks, could be replicated in other fragmented research areas to unify dispersed practices into coherent design frameworks.

Thirdly, the evaluation framework, comprising seven themes derived from qualitative analysis, provides a replicable model for assessing dashboard methodologies. The thematic categories- usability, design thinking enhancement, coverage, challenges, flexibility, suggested improvements, and overall impact - offer a holistic lens for evaluating both technical and contextual aspects of design artefacts.

Finally, the application of the research in the smart waste management domain contributes valuable domain-specific insights, particularly in relation to environmental monitoring, cross-stakeholder coordination, and the integration of operational and strategic decision-making. While smart waste management serves as the application domain for demonstration, the insights derived may be transferable to other sustainability-oriented contexts.

6.3.2 Tree Metaphor: A Consolidated View of the Research Foundation and Artefact Outputs

To better understand the interconnected nature of the research contributions, this study adopts a tree metaphor, depicted in Figure 6.1, which visually represents the evolutionary growth and layered structure of the artefacts developed. This metaphor captures not only the hierarchical relationships among the contributions but also their organic integration, grounded in established theoretical foundations and culminating in practical instantiations.

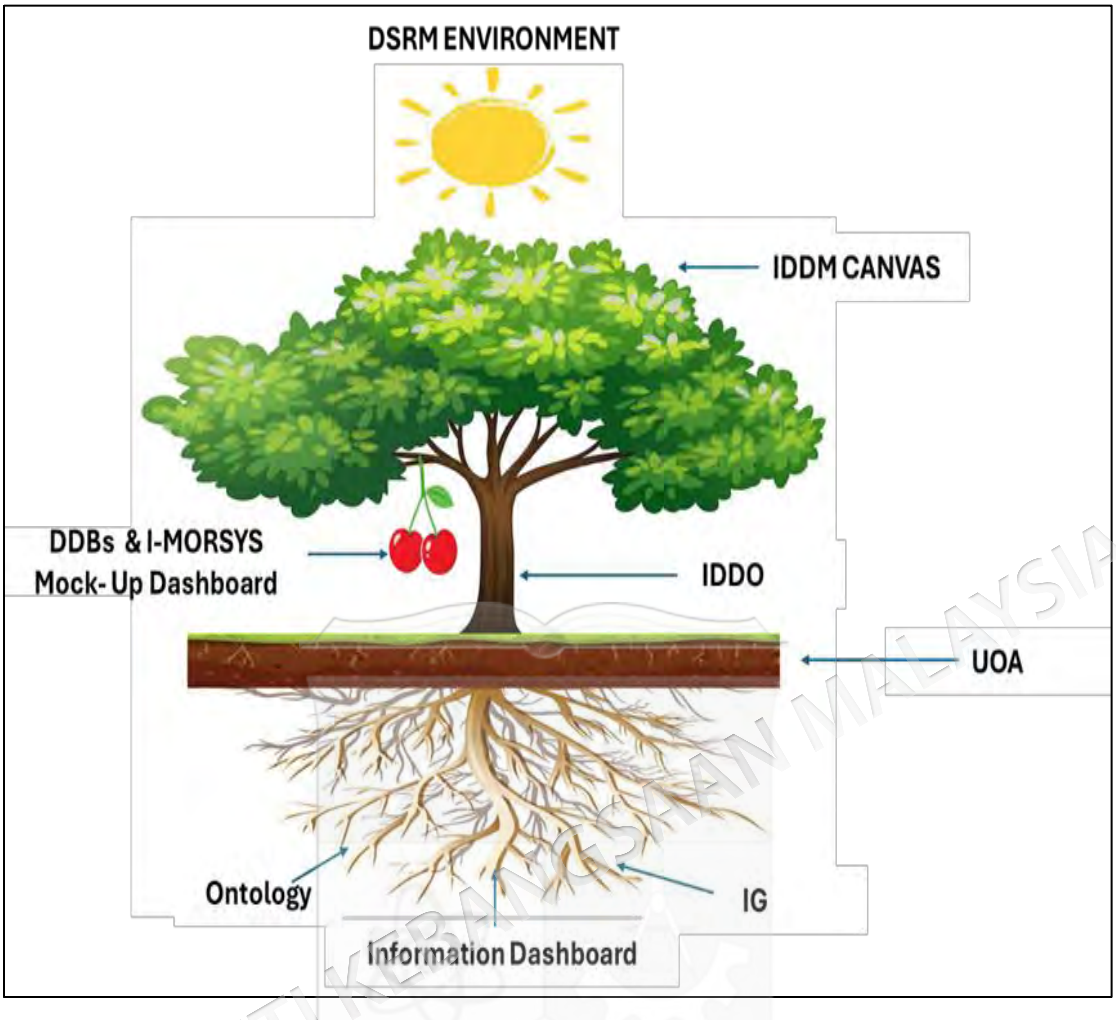

Figure 6.1 Tree metaphor illustrating the layered research contributions within the DSRM

At the foundation of the tree, three roots represent the core building blocks of this research: Dashboard Design principles derived from existing literature, Ontology as a formal knowledge structuring approach, and IG as the governance foundation. These roots anchor the study in established bodies of knowledge and provide the conceptual grounding upon which the research is built. Within this context, ontology and IG also function as the kernel theories of the study, shaping both the structure and orientation of the proposed solution.

Embedded within the soil above the roots is the UOA. The UOA functions as the methodological grounding layer from which the core artefacts emerge. It represents a systematic synthesis of existing ontology development methods, adapted to support the structured development of dashboard design knowledge. This grounding layer ensures that the subsequent artefacts are developed in a consistent, rigorous, and methodologically sound manner.

Rising from this foundation is the trunk of the tree, represented by the IDDO. The IDDO serves as the central structural artefact of the research, formally capturing the key concepts, relationships, and constraints involved in dashboard design. Developed using the UOA and grounded in the UFO, the IDDO provides the theoretical backbone that supports the transformation of abstract design knowledge into a structured and reusable form.

Extending outward from the trunk is the canopy, represented by the IDDM Canvas. The canvas translates the formal ontological structures into a practical and accessible design tool. Inspired by the transformation of the BMO into the BMC, the IDDM Canvas operationalizes the IDDO by enabling practitioners to systematically apply ontological and governance-aware design knowledge in real-world dashboard development contexts.

The tree ultimately bears fruit in the form of two concrete instantiations: the DDBs and the i-MORSYS mock-up dashboards. These artefacts demonstrate the practical applicability of the IDDM Canvas, showing how the method can guide the design and implementation of functional, governance-aware dashboards. In this research, smart waste management is employed as the application domain for demonstration and validation, rather than as the foundational basis of the contribution, thereby evidencing the domain-independent nature of the proposed design method.

Encompassing the entire tree is the sun, representing the DSRM environment. The DSRM provides the overarching research framework within which all artefacts were designed, demonstrated, evaluated, and refined. Just as the sun sustains the growth of a tree, the DSRM ensures methodological rigour, iterative refinement, and alignment with established research standards throughout the study.

Overall, the tree metaphor encapsulates the full research journey, from foundational theories and methodological grounding to practical instantiation, highlighting how each artefact builds upon and reinforces the others within a coherent design science framework. Building on this integrated view, the following section positions these research contributions within established DSR Knowledge Contribution Frameworks to clarify their theoretical and practical significance.

6.3.3 Design Science Research Knowledge Contribution Framework

To systematically position the knowledge contributions of this study, two established DSR frameworks are adopted: the DSR Knowledge Contribution Matrix by Gregor and Hevner (2013), and the Abstraction Levels of Design Knowledge by Gregor and Zwikael (2024). These frameworks provide complementary perspectives that collectively capture both the nature of the knowledge produced and the theoretical depth of the contributions made from this study.

a. Overview of the DSR knowledge contribution matrix

As depicted in Figure 6.2, the first lens of knowledge contribution adopted in this study is the DSR Knowledge Contribution Matrix, adapted from Gregor and Hevner (2013). This model classifies DSR contributions along two critical dimensions:

1. The maturity of the solution being applied (vertical axis) – ranging from low (novel or experimental solutions) to high (established and validated solutions).
2. The maturity of the application domain or problem context (horizontal axis) – ranging from low (new, unstructured, or underexplored domains) to high (well-known and well-studied domains).

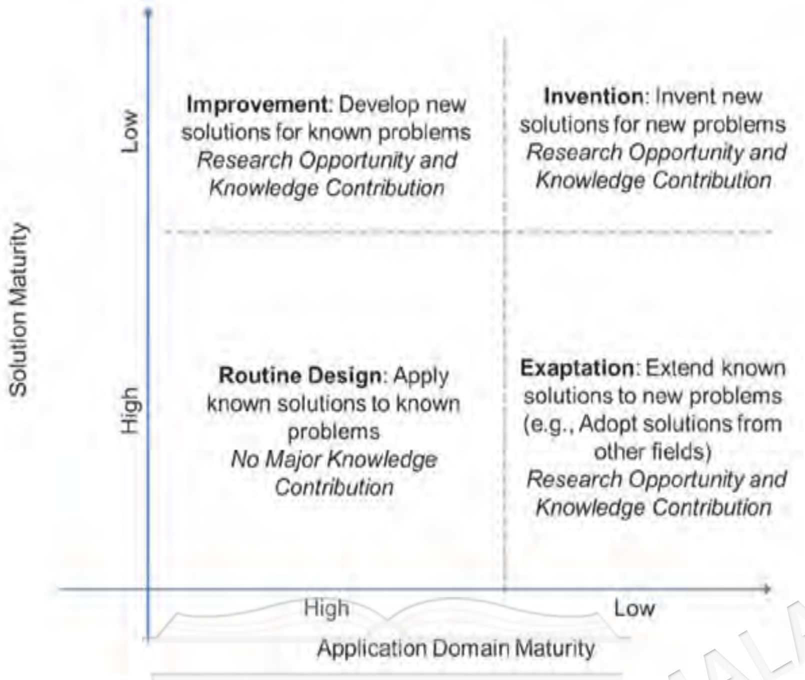

Figure 6.2 DSR contribution types based on solution and domain maturity

Source: Adapted from Gregor & Hevner (2013)

To further clarify the characteristics of each contribution type, Table 6.2 summarises the four quadrants and the nature of knowledge produced in each zone.

Table 6.2 Summary of DSR knowledge contribution quadrants

Quadrant	Solution Maturity	Domain Maturity	Contribution Type	Description	Typical Knowledge Contribution
Q1 - Invention	Low	Low	Novel solution for novel problem	Ground-up innovation to address new challenges	New models, constructs, or design theories
Q2 - Improvement	Low	High	Novel solution for known problem	Enhance or optimise solutions in familiar contexts	Refined methods, better performance or usability
Q3- Exaptation	High	Low	Known solution for novel problem	Apply known solutions in new or emerging domains	Cross-domain adaptation, contextual innovation
Q4- Routine Design	High	High	Known solution for known problem	Standard implementation with minimal novelty	Operational artefacts, no significant theoretical contribution

The matrix outlined in Table 6.2 provides a strategic lens for understanding how different types of research contribute to the body of knowledge in DSR. Each quadrant represents a distinct form of design knowledge, defined not only by the novelty of the artefact itself but also by the novelty of the context in which it is applied.

Among these, Invention (Quadrant 1) is often associated with high-impact research, as it introduces entirely new constructs or theories to solve previously unaddressed problems. These contributions demand both creative insight and theoretical grounding, making them significant from an academic perspective.

Improvement (Quadrant 2), while working within known domains, contributes through the enhancement of existing processes, models, or tools. Many design artefacts fall into this category, especially when the focus is on refining usability, efficiency, or scalability within an established field.

On the other hand, Exaptation (Quadrant 3) offers value by repurposing existing solutions to address problems in new contexts. This approach highlights the adaptability of design knowledge and is often seen in interdisciplinary or emerging fields, where established models are transferred into unfamiliar territories.

Finally, Routine Design (Quadrant 4) involves the straightforward application of well-known solutions to well-understood problems. While often relevant in operational contexts, such contributions typically lack theoretical novelty and are therefore not the focus of scholarly DSR.

b. Positioning of artefacts in the DSR knowledge contribution matrix

Having established the conceptual basis of the DSR Knowledge Contribution Matrix, this subsection positions the artefacts developed in this study within the framework.

Figure 6.3 visualizes the positioning of the artefacts within the DSR Knowledge Contribution Matrix introduced by Gregor and Hevner (2013). The model classifies the artefacts based on the maturity of the application domain (horizontal axis) and the maturity of the solution space (vertical axis), resulting in four distinct quadrants.

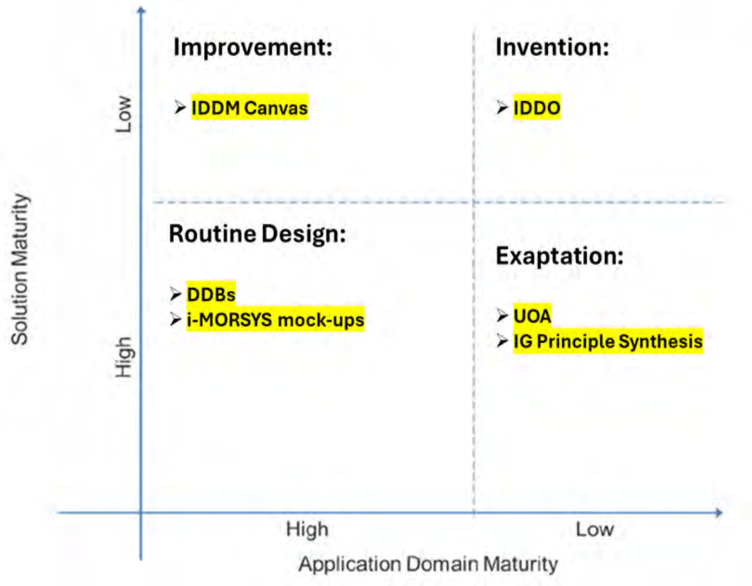

Figure 6.3 Positioning of artefacts in the DSR knowledge contribution matrix

Source: Adapted from Gregor & Hevner (2013)

To further elaborate on the rationale behind each positioning, Table 6.3 summarises the quadrant assignment for each artefact along with a brief justification.

Table 6.3 Artefact positioning within the DSR knowledge contribution matrix

Artefact	Quadrant	Quadrant Description	Justification
IDDO	Quadrant 1 – Invention	New solution for a new problem	Addresses a novel theoretical gap by introducing a formal ontology grounded in UFO and IG principles as foundational governance, applicable across domains.
IDDM Canvas	Quadrant 2 – Improvement	Improved solution for a known problem	Enhances existing dashboard design approaches by embedding IG and transforming abstract theory into a practical visual tool.
DDBs	Quadrant 4 – Routine Design	Known solution for a known problem	Serves as design templates for dashboard planning; applies existing methodology in familiar contexts without theoretical innovation.
i-MORSYS Mock-ups	Quadrant 4 – Routine Design	Known solution for a known problem	Platform-based instantiations of IDDM artefacts demonstrating operational feasibility in a mature domain.

to be continued…

…continuation

UOA	Quadrant 3 – Exaptation	Known solution applied to a new problem (adapted from other fields)	Adapts and synthesises existing ontology development methods into a new lightweight approach tailored for dashboard ontology development.
IG Principle Synthesis	Quadrant 3 – Exaptation	Known solution applied to a new problem (adapted from other fields)	Extracts and recontextualises IG principles into dashboard design, drawing from existing frameworks in broader governance literature.

As illustrated in the table above, the artefacts developed in this research are distributed across all four quadrants of the DSR Knowledge Contribution Matrix. This distribution demonstrates the study's contribution not only in introducing novel theoretical constructs but also in adapting existing knowledge and validating implementations in a mature application domain.

To complement this quadrant-based perspective, the following subsection introduces the abstraction-based framework proposed by Gregor and Zwikael (2024), which provides an overview of design science contributions based on theoretical generalisability and levels of design knowledge.

c. Overview of levels of design knowledge abstraction

Complementing the quadrant-based view introduced earlier, the second analytical lens adopted in this study is the Levels of Design Knowledge model developed by Gregor and Zwikael (2024). While the previous framework categorizes contributions based on the maturity of problems and solutions, this model offers a vertical classification of design science outputs according to the theoretical abstraction and generalisability of the knowledge they produce.

As illustrated in Figure 6.4, the model organizes design knowledge into three hierarchical levels, each reflecting a different degree of abstraction and applicability.

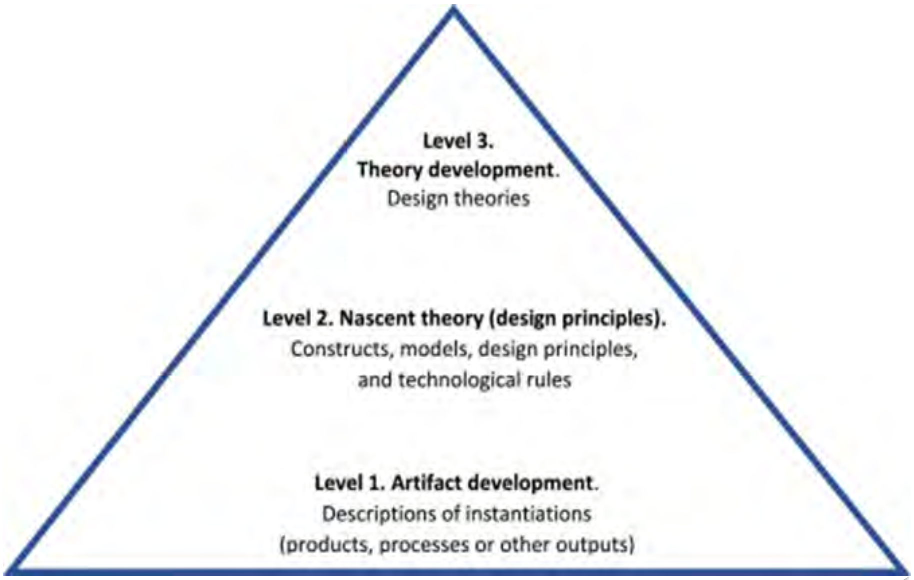

Figure 6.4 Levels of design knowledge

Source: Adapted from Gregor & Zwikael (2024)

As shown in Figure 6.4 above, the levels are defined as follows:

At the base of the hierarchy is Level 1: Situated Implementation, which refers to artefacts designed for a specific, contextualised problem. These contributions demonstrate feasibility and utility in real world settings but are typically limited in terms of generalisability. Examples include system prototypes, mock-ups, and dashboards tailored for a particular domain or user group.

Moving upward, Level 2: Nascent Design Theory captures design artefacts that reflect more structured and reusable design knowledge. These are often expressed through methods, models, or frameworks that can be applied across similar domains. While not fully generalised, they offer prescriptive guidance to practitioners and serve as a bridge between abstract theory and operational practice.

At the highest level is Level 3: Abstract Design Theory, which encompasses formal and generalisable artefacts such as ontologies, meta models, or mid-range theories. These contributions are domain-independent and form the conceptual foundation upon which future artefacts, models, or methods can be built. Their value lies in their potential to influence both theoretical discourse and methodological practice across multiple research contexts.

These three levels are not mutually exclusive. In fact, impactful DSR often contributes across multiple levels simultaneously, grounding abstract theory in practice while also deriving new theory from real-world implementation. The artefacts developed in this study exhibit such characteristics, as discussed in the following sections.

To support understanding of the distinctions between each level, Table 6.4 below presents a synthesised summary of their defining attributes and typical artefact examples.

Table 6.4 Levels of design knowledge and typical contributions

Level	Nature of Contribution	Description	Typical Artefacts
Level 3	Abstract Design Theory	Highly generalisable theoretical constructs with domain independent applicability	Ontologies, meta models, mid range theories
Level 2	Nascent Design Theory	Structured design methods and models reusable across similar contexts	Frameworks, processes, design guidelines
Level 1	Situated Implementation	Artefacts built for specific real world applications	Prototypes, dashboards, domain specific mock ups

d. Positioning of artefacts in the levels of design knowledge abstraction

Having introduced the abstraction-based framework, this subsection positions the artefacts developed in this study within the Levels of Design Knowledge model proposed by Gregor and Zwikael (2024).

Figure 6.5 visualises the positioning of the artefacts across the three abstraction levels, reflecting their conceptual depth and degree of generalisability.

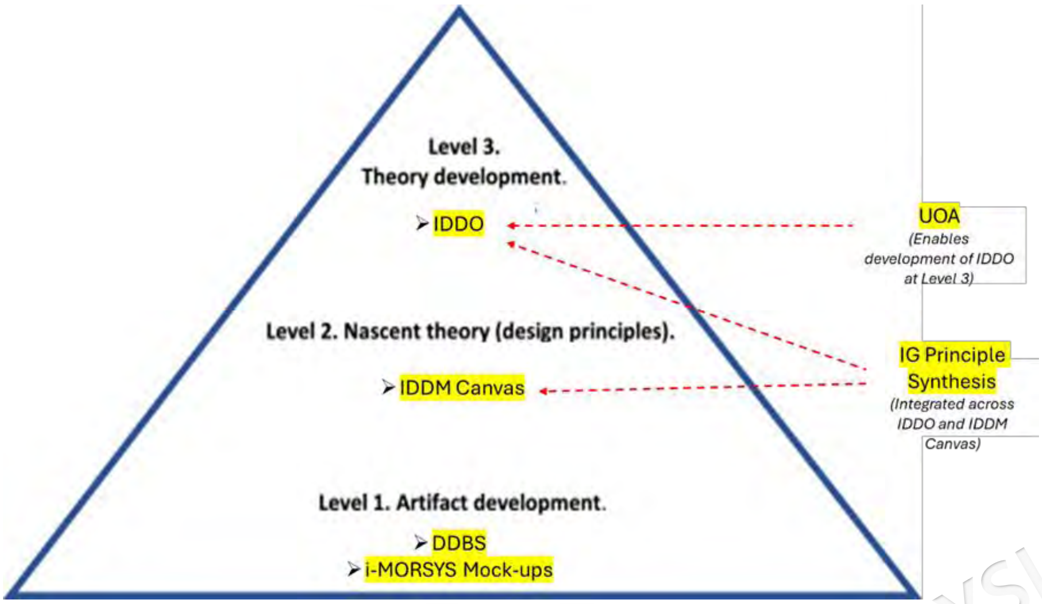

Figure 6.5 Artefact positioning in levels of design knowledge

Source: Adapted from Gregor & Zwikael (2024)

As shown in Figure 6.5, the core artefacts developed in this study are distributed across all three levels. The IDDO is positioned at Level 3 (Abstract Design Theory), reflecting its role as a domain-independent, formal ontology that provides foundational design knowledge. The IDDM Canvas is positioned at Level 2 (Nascent Design Theory), as it operationalises the ontology into a reusable method and structured design tool. The DDBs and i-MORSYS mock-up dashboards are positioned at Level 1 (Situated Implementation), representing concrete instantiations tailored to specific contexts..

Notably, two supporting components—the UOA and IG Principle Synthesis—are positioned outside the abstraction hierarchy. These elements do not constitute direct artefacts within the three-level model but act as enablers of theoretical development and cross-cutting inputs. The UOA facilitated the structured development of the IDDO at Level 3, while the IG Principle Synthesis informed both the ontological and methodological artefacts by embedding governance considerations throughout the design process.

To further elaborate on this positioning, Table 6.5 summarises the abstraction level assigned to each artefact along with a brief justification.

Table 6.5 Artefact positioning within levels of design knowledge

Artefact	Level	Level Description	Justification
IDDO	Level 3 – Abstract Design Theory	Generalisable theoretical artefacts applicable across domains	Provides a formal ontology for dashboard design grounded in foundational ontology, reusable and extensible beyond specific contexts.
IDDM Canvas	Level 2 – Nascent Design Theory	Structured methods, models, or frameworks with moderate generalisability	Operationalizes the IDDO through a structured process and tool, reusable across domains but tailored to dashboard-specific practices.
DDBs	Level 1 – Situated Implementation	Instantiations tailored to specific contexts	Completed canvases derived from IDDM, customised for actual projects and user needs.
i-MORSYS Mock-ups	Level 1 – Situated Implementation	Instantiations tailored to specific contexts	Mock-up dashboards implemented using platform-specific visualisation tools; validate method in real-world setting.
UOA	Methodological Enabler	Supports Level 3 artefact development	While not fitting neatly into the three levels, it enables the creation of Level 3 artefacts through adapted ontology engineering.
IG Principle Synthesis	Meta-level Theoretical Input	Supports theoretical grounding across levels	Provides a theoretical lens integrated into IDDO and IDDM; informs governance-awareness in dashboard design.

As summarised in Table 6.5, the artefacts developed throughout this study collectively span the full spectrum of design knowledge, ranging from abstract design theory to situated implementation. In addition to their direct classification within the three abstraction levels, the research also introduced auxiliary contributions—namely the UOA and the IG Principle Synthesis—which serve as critical enablers for artefact construction and theoretical integration.

The dual positioning across both the quadrant model (Gregor & Hevner, 2013) and the abstraction hierarchy (Gregor & Zwikael, 2024) reinforces the completeness and multidimensionality of the research contribution. It demonstrates alignment with the core objectives of DSR as articulated by Hevner et al. (2004) and further elaborated by Venable et al. (2016), which advocate for contributions that are simultaneously innovative, rigorous, and practically useful.

While the preceding sections positioned the artefacts within established DSR contribution frameworks based on problem–solution maturity and levels of abstraction, it is also important to situate the core artefact of this study within broader design theory perspectives in information systems. Accordingly, the next section examines the theoretical positioning of the IDDM in relation to prevailing schools of thought on design theory in DSR.

6.3.4 Positioning the IDDM within Design Theory Perspectives

As briefly discussed in Chapter 3 (see Figure 3.6), this study has acknowledged the ongoing debate in the DSR community regarding the role of theory in artefact development. Apart from articulating the specific knowledge contributions of this study, it is also important to position the developed artefacts, particularly the IDDM Canvas and the IDDO within the broader discourse of design theory in the field of information systems. According to Fisher et al. (2010), three distinct schools of thought exist regarding the necessity of theoretical grounding in artefact development. Scholars such as March and Smith (1995) and Hevner et al. (2004) emphasize artefact creation and utility, often without requiring a strong theoretical foundation. Meanwhile, Goldkuhl (2004) and Venable (2006a; 2006b) represent a more pragmatic stance, where theory is used only if it supports practical problem-solving.

This study, however, adopts a more theory-driven approach. It is aligned with what Walls et al. (1992), Gregor (2006), and Gregor and Jones (2007) define as the Kernel Theory Fundamentalist perspective. This view posits that design artefacts should be grounded in well-established kernel theories to ensure both rigour and relevance. This ontological approach to grounding DSR artifacts aligns with recent developments in artifact ontology, as demonstrated by Weigand et al. (2021), who provide a comprehensive ontological analysis of artifacts in DSR, emphasizing the importance of formal ontological foundations for understanding the nature and classification of technical artifacts. In line with this orientation, the development of the IDDO was grounded in the UFO to ensure conceptual clarity, semantic consistency, and ontological rigour. This formal ontological foundation provides a structured way to represent the key elements and relationships involved in dashboard design.

Complementing this, the eight IG principles were embedded within the design logic, not as decorative or supplementary considerations, but as governance foundations that shape decision-making, reinforce accountability, and ensure alignment with organisational policies and compliance standards.

The core artefact in this study is the IDDM Canvas, which serves as the practical implementation of the IDDO. Designed as a reusable and theory-informed framework, Canvas provides structured guidance for dashboard design across various domains. This layered approach, from ontological formalism to governance integration and practical application, reflects a clear alignment with the Kernel Theory Fundamentalist school of thought. As articulated by Walls et al. (1992) and Gregor and Jones (2007), this perspective insists that artefacts be grounded in well-established theoretical foundations. In line with that tradition, the IDDM Canvas embodies a design theory that is both conceptually rigorous and practically applicable.

This theoretical orientation is further illustrated in Figure 6.6, which positions the IDDO and the IDDM Canvas within the broader landscape of design theory perspectives. Adapted from the work of Fisher et al. (2010), the figure highlights the Kernel Theory Fundamentalist quadrant as the most representative of this study's approach, where artefacts are not only informed by practical needs but are also systematically grounded in robust theoretical foundations, particularly the UFO and IG principles.

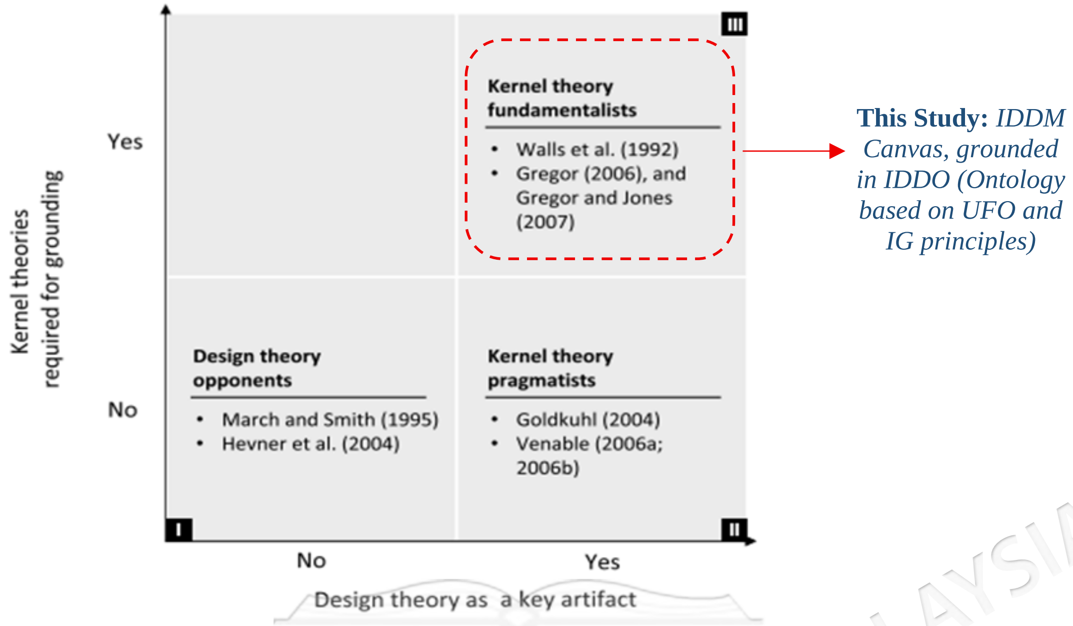

Figure 6.6 Positioning of this study's artefact (IDDM Canvas, grounded in IDDO) within the design theory schools

Source: Adapted from Fisher et al. 2010

Taken together, the preceding sections have positioned the artefacts developed in this study across multiple dimensions of DSR. The contributions have been systematically classified in terms of problem–solution maturity and levels of design knowledge abstraction, and further situated within the broader design theory discourse in information systems. This positioning demonstrates that the proposed IDDM is not only methodologically and practically grounded, but also theoretically anchored within a well-established kernel theory perspective. Building on this synthesis, the next section concludes the chapter by consolidating the overall research achievements and highlighting the key contributions and implications of the study.

6.4 CONCLUSION

This research addresses the need for a unified and standardised methodology to guide the design of information dashboards, an area where practices have often been inconsistent, fragmented, and lacking formal guidance. Although dashboards are widely used across sectors, many existing approaches remain under-theorised and fail to support systematic development or the integration of governance principles.

A key achievement of this research is the development of a design methodology that bridges the gap between theoretical rigour and practical relevance. By anchoring the method on ontological foundations and translating them into practitioner-oriented tools, the study offers a structured yet accessible approach to dashboard design that caters to both academic expectations and real-world application.

The theoretical strength of this framework lies in its formal ontology - the IDDO, constructed using OntoUML and grounded in the UFO. This ontological structure provides clear definitions of dashboard components and their semantic relationships, enabling conceptual clarity, design consistency, and knowledge reusability. The integration of IG principles within this ontology also addresses a notable gap by embedding governance considerations into the foundation of the design process.

In practice, the IDDO was operationalised through the development of the IDDM supported by the IDDM Canvas. This visual tool transforms complex conceptual models into practical design templates. It enables practitioners to systematically structure dashboard elements while embedding governance considerations as actionable design prompts. The IDDM was successfully applied to develop dashboards across two platforms, Tableau and Looker Studio, demonstrating platform independence and practical relevance.

The framework's practical value was validated through evaluations with domain experts and dashboard designers. The results highlighted the IDDM's effectiveness in supporting structured thinking, ensuring design completeness, and promoting governance-aware outcomes. The i-MORSYS mock-ups developed for the smart waste management domain illustrate the framework's potential for addressing domain-specific needs in sustainability and environmental monitoring.

6.5 FUTURE WORK

Building on the insights gained from this research, several practical directions can be explored to further enhance the IDDM framework. Some of these were informed by feedback gathered during the semi-structured interviews with dashboard practitioners and domain experts.

First, although the current version of the IDDM includes a Continuous Improvement section, its support for iterative design could be made more robust. Future refinement may include agile-aligned workflows or modular templates that better accommodate projects requiring rapid prototyping and frequent iteration.

Another promising direction involves the operationalization of IG principles. While these principles are conceptually integrated into the framework, practitioners would benefit from more concrete, actionable guidance, particularly in applying governance elements such as compliance, data quality, and security in real-world settings.

Improving the framework's accessibility dimension is also an important consideration. As dashboards become increasingly mainstream, embedding inclusive design guidelines will help ensure that solutions remain usable and meaningful to a wider range of users, including those with varying abilities or access needs.

To support broader adoption, domain-specific adaptations of the IDDM could be developed. These might take the form of template libraries, curated design patterns, or customised visual examples that are tailored to specific industries or organizational settings.

A natural progression for this research is the development of digital tools to support the IDDM's application. An interactive version of the canvas, integrated with contextual prompts, collaborative functionality, and platform-specific support, could significantly improve usability and lower the barrier to adoption.

Additionally, future studies should expand the demonstration of the IDDM framework beyond the smart waste management domain. Applying it in other sectors such as healthcare, education, public services, or financial analytics would not only test its adaptability but also offer opportunities for refinement based on sector-specific requirements.

In tandem with these efforts, the growing integration of AI into design workflows opens up new possibilities for automation. With further formalization, the

IDDM Canvas could serve as a structured input for generative AI systems, enabling automatic generation of dashboard prototypes based on completed canvas components. This would streamline the design process while preserving alignment with best practices and governance considerations. Such a capability would not only accelerate the prototyping process but could also position the IDDM as a foundational input for AI-assisted dashboard generation tools in the future.

6.6 SUMMARY

This final chapter has brought together the key elements of the research, tracing how each objective was progressively addressed and how the contributions align with the broader goals of DSR. From the early identification of a clear gap in the lack of standardized methods for dashboard design, the study progressed through the development of ontologically grounded artefacts and culminated in a practical methodology that was demonstrated and evaluated in a real-world domain.

The contributions presented span across different levels of abstraction, ranging from conceptual foundations to domain-specific implementations, highlighting the multi-layered nature of design science work. Each artefact developed in this study was positioned within established knowledge contribution models, enabling a clearer understanding of how they advance both theory and practice.

Beyond literature analysis and modelling, the insights gathered through semi-structured interviews with practitioners and domain experts played a key role in shaping the final framework. This combination of theoretical development and applied validation has helped reinforce the practical relevance and usability of the IDDM.

Although demonstrated in the context of smart waste management, the IDDM's underlying structure is adaptable, offering potential for use in other domains. Its flexible design and emphasis on governance-aware, user-centred principles make it suitable for broader applications where structured dashboard design is critical.

In summary, this research contributes a structured, conceptually sound, and practically relevant methodology for designing information dashboards. While it does not claim to provide a universal solution, it offers a well-founded starting point for future exploration, extension, and adaptation, responding to the growing need for effective, trustworthy, and meaningful data visualization in diverse organizational settings. Its layered architecture ensures flexibility for evolving technologies and emerging governance expectations.

With this, the research concludes with the hope that the IDDM will serve as both a practical guide and a foundation for future innovation in dashboard design.

REFERENCES

Abdul Malak, H. 2022. Top 9 information governance tips for 2022. Association of Intelligent Information Management, August 30. https://info.aiim.org/aiim-blog/top-information-governance-best-practices [5 February 2024].

Abdul Rehman, A. & Alharthi, K. 2016. An introduction to research paradigms. *International Journal of Educational Investigations* 3(8): 51–59.

Abdul Sattar, Mohammad Nazir Ahmad, Ely Salwana Mat Surin & Ahmad Kamil Mahmood. 2021. An improved methodology for collaborative construction of reusable, localized, and shareable ontology. *IEEE Access* 9: 17463–17484.

Abduldaem, A. & Gravell, A. 2019. Principles for the design and development of dashboard: Literature review. *Proceedings of the INTCESS 2019- 6th International Conference on Education and Social Sciences*, hlm. 1307–1316.

Abdullah, N., Al-wesabi, O. A., Mohammed, B. A., Al-Mekhlafi, Z. G., Alazmi, M., Alsaffar, M., Baklizi, M. & Sumari, P. 2022. IoT-based waste management system in formal and informal public areas in Mecca. *International Journal of Environmental Research and Public Health* 19(20): 13066.

Ahadi Haji Mohd Nasir, Ely Salwana Mat Surin & Mohammad Nazir Ahmad. 2024a. Towards unified information dashboard design - Common principles, practices, and challenges. *Procedia Computer Science* 234: 1586–1592.

Ahadi Haji Mohd Nasir, Ely Salwana Mat Surin & Mohammad Nazir Ahmad. 2023. Unifying information dashboard design: Exploring shared principles, practices and challenges. *Proceedings of the 29th International Sustainable Development Research Society Conference (ISDRS)*, hlm. 1-13.

Ahadi Haji Mohd Nasir, Ely Salwana Mat Surin & Mohammad Nazir Ahmad. 2025a. Integrating information governance as the foundation for information dashboard design ontology. *Journal of Information Technology Education: Innovations in Practice* 24: 001.

Ahadi Haji Mohd Nasir, Mohd Firdaus Sulaiman, Liew Kok Leong, Ely Salwana Mat Surin & Mohammad Nazir Ahmad. 2024b. An approach for developing an ontology: Learned from business model ontology design and development. *International Journal of Advanced Computer Science and Applications* 15(3): 539-554.

Ahadi Haji Mohd Nasir, Nik Habibullah Nik Mohd Nizam., Mohd Khairul Maswan Mohd Redzuan, & Mohammad Nazir Ahmad. 2025b. Developing an ontology-driven and governance-integrated method for information dashboard design.

International Journal of Advanced Computer Science and Applications 16(6): 448–462.

Ahn, J., Campos, F., Hays, M. & Digiacomo, D. 2019. Designing in context: Reaching beyond usability in learning analytics dashboard design. *Journal of Learning Analytics* 6(2): 70–85.

Albo, Y., Lanir, J., Bak, P. & Rafaeli, S. 2016. Off the radar: Comparative evaluation of radial visualization solutions for composite indicators. *IEEE Transactions on Visualization and Computer Graphics* 22(1): 569–578.

Alhamadi, M. 2020. Challenges, strategies and adaptations on interactive dashboards. *Proceedings of the 28th ACM Conference on User Modeling, Adaptation and Personalization*, pp. 368–371.

Alhamadi, M., Alghamdi, O., Clinch, S. & Vigo, M. 2022. Data quality, mismatched expectations, and moving requirements: The challenges of user-centred dashboard design. *ACM International Conference Proceeding Series*, pp. 1-14.

Ali, T., Irfan, M., Alwadie, A. S. & Glowacz, A. 2020. IoT-based smart waste bin monitoring and municipal solid waste management system for smart cities. *Arabian Journal for Science and Engineering* 45(12): 10185–10198.

Aliyu Ishaq, Shamsuddeen Jumande Mohammad, Al-Amin Danladi Bello, Surajo Abubakar Wada, Adejimi Adebayo & Zainab Toyin Jagun. 2023. Smart waste bin monitoring using IoT for sustainable biomedical waste management. *Environmental Science and Pollution Research* 2023.

Almasi, S., Bahaadinbeigy, K., Ahmadi, H., Sohrabei, S. & Rabiei, R. 2023. Usability evaluation of dashboards: A systematic literature review of tools. *BioMed Research International* 1: 9990933.

Alourani, A., Ashraf, M.U. & Aloraini, M. 2025. Smart waste management and classification system using advanced IoT and AI technologies. *PeerJ Computer Science* 11: 1-28

Alper, B., Riche, N. H., Ramos, G. & Czerwinski, M. 2010. Design study of linesets, a novel set visualization technique. *IEEE Transactions on Visualization and Computer Graphics* 17(12): 2259-2267.

Alturki, A., Gable, G. G. & Bandara, W. 2013. The design science research roadmap: in progress evaluation. *Proceedings of the Pasific Asia Conference on Information Systems*, pp. 1-16.

Ananthasuresh, G. K. 2015. Buckminster fuller and his fabulous designs. *Resonance* 20(2): 98-122.

ARMA International. n.d. The principles, ARMA International. https://www.arma.org/page/principles [13 September 2023].

Arp, R., Smith, B. & Spear, A. D. 2015. *Building Ontologies with Basic Formal Ontology*. Cambridge: The MIT Press.

Azman Mat Isa, Sabri Mohd Sharif, Rabiah Mohd Ali & Nordiana Mohd Nordin. 2019. Managing evidence of public accountability: an information governance perspective. International Journal of Innovation, Creativity and Change 10(7): 142-153.

Bach, B., Dragicevic, P., Archambault, D., Hurter, C. & Carpendale, S. 2014. A review of temporal data visualizations based on space-time cube operations. Paper presented at Eurographics Conference on Visualization, Swansea, Wales, United Kingdom. 25 June.

Bach, B., Freeman, E., Abdul-Rahman, A., Turkay, C., Khan, S., Fan, Y. & Chen, M. 2023. Dashboard design patterns. *IEEE Transactions on Visualization and Computer Graphics* 29(1): 342–352.

Baclawski, K., Kokar, M. K., Kogut, P. A., Hart, L., Smith, J., Letkowski, J. & Emery, P. 2002. Extending the Unified Modeling Language for ontology development. *Software and Systems Modeling* 1(2): 142–156.

Balletto, G., Milesi, A., Ladu, M. & Borruso, G. 2020. A dashboard for supporting slow tourism in green infrastructures. A methodological proposal in Sardinia (Italy). *Sustainability (Switzerland)* 12(9): 3579.

Barrass, M. 2021, October 18. Unified Foundational Ontology, Governance Foundation. https://governance.foundation/frameworks/ufo [8 May 2024].

Baskerville, R., Baiyere, A., Gregor, S., Hevner, A. & Rossi, M. 2018. Design science research contributions: Finding a balance between artifact and theory. *Journal of the Association for Information Systems* 19(5): 358-376.

Becker, J., Delfmann, P. & Knackstedt, R. 2007. Adaptive reference modeling: Integrating configurative and generic adaptation techniques for information models. *Physica-Verlag* 27–58.

Bozkurt, Y., Rossmann, A., Pervez, Z. & Ramzan, N. 2025. Development and evaluation of an urban data governance reference model based on design science research. *Government Information Quarterly* 42(2): 102025.

Brank, J., Grobelnik, M. & Mladenic, D. 2009. A survey of ontology evaluation techniques. https://www.researchgate.net/publication/228857266 [23 May 2024].

Brath, R. & Peters, M. 2004. Dashboard design :Why design is important. *DM Review Online*, 15 October.

Braun, V. & Clarke, V. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3(2): 77–101.

Brooke, J. 1995. SUS: A quick and dirty usability scale. https://www.researchgate.net/publication/228593520 [6 January 2024].

Buchanan, R. 1992. Wicked problems in design thinking. *Design Issues* 8(2): 5-21.

Burnett, M., Cook, C. & Rothermel, G. 2004. End-user software engineering. *Communications of the ACM* 47(9): 53-58.

Chen, Y. C. 2018. Effects of urbanization on municipal solid waste composition. *Waste Management* 79: 828–836.

Conrow, L., Fu, C., Huang, H., Andrienko, N., Andrienko, G. & Weibel, R. 2023. A conceptual framework for developing dashboards for big mobility data. *Cartography and Geographic Information Science* 50(5): 495-514.

Convertino, G., Neale, D. C., Hobby, L., Carroll, J. M. & Rosson, M. B. 2004. A laboratory method for studying activity awareness. *ACM International Conference Proceeding Series* 82: 313–322.

Corcho, O. 2006. Ontology based document annotation: Trends and open research problems. *International Journal of Metadata, Semantics and Ontologies* 1(1): 47–57.

Datta, R., Valavala, M. & Haris Uddin Sharif, M. 2019. Information governance: A Necessity in today's business environment. *International Journal of Computer Science and Mobile Computing* 8(8): 67–76.

Davis, F. D. 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly* 13(3): 319–339.

Deininger, M., Daly, S. R., Sienko, K. H. & Lee, J. C. 2017. Novice designers' use of prototypes in engineering design. *Design Studies* 51: 25–65

Department Of Statistics Malaysia (DOSM). 2021. Department of statistics Malaysia press release. https://www.dosm.gov.my/ [3 April 2024].

Dillon, J. 2023. An introduction to smart waste management, 5 April. https://www.superfy.com/introduction-smart-waste-management/ [25 May 2023].

Dobraja, I. & Kraak, M. J. 2020. Principles of dashboard adaptability to get insights into origin-destination data. *Journal of Location Based Services* 14(1): 28–48.

Dunston, P. S., Arns, L. L., Mcglothlin, J. D., Lasker, G. C. & Kushner, A. G. 2011. An immersive virtual reality mock-up for design review of hospital patient rooms. In. Wang, X. & Tsai, J. J.-H. (eds.) *Collaborative Design in Virtual Environments*, pp. 167–176. Netherlands: Springer.

Eckerson, W. 2010. *Performance Dashboards: Measuring, Monitoring, and Managing Your Business*. 2nd Edition. New York: John Wiley & Sons.

EDRM. 2011. How the Information Governance Reference Model (IGRM) complements ARMA International's Generally Accepted Recordkeeping Principles (GARP). https://edrm.net/wp-content/uploads/downloads/2011/12/ [25 May 2023].

EDRM. 2022. Information Governance Reference Model. Electronic Discovery Reference Model (EDRM). https://edrm.net/resources/frameworks-and-standards/information-governance-reference-model/ [4 February 2024].

EEA. 2021. Digital technologies will deliver more efficient waste management in Europe. https://www.eea.europa.eu/publications/digital-technologies-will-deliver-more/ [4 February 2024].

Elekes, M., Molnár, V. & Micskei, Z. 2023. Assessing the specification of modelling language semantics: A study on UML PSSM. *Software Quality Journal* 31(2): 575–617.

Ellis, G. & Dix, A. 2006. An explorative analysis of user evaluation studies in information visualisation. *Proceedings of the BELIV'06: BEyond time and errors - novel EvaLuation methods for Information Visualization*, pp. 1-7.

Elshehaly, M., Randell, R., Brehmer, M., Lynn, M. & Alvarado, N. 2020. QualDash: Adaptable generation of visualisation dashboard for healthcare quality improvement. *IEEE Transactions on Visualization and Computer Graphics* 27(2): 689–699.

Ernie Mazuin, Mohd Shahizan Othman & Rizal Yusof. 2018. Operational dashboard: Accelerator for shop floor workers. *International Journal of Engineering and Technology* 7(2): 4–6.

Fang, B., Yu, J., Chen, Z., Osman, A. I., Farghali, M., Ihara, I., Hamza, E. H., Rooney, D. W. & Yap, P. -S. 2023. Artificial intelligence for waste management in smart cities: a review. *Environmental Chemistry Letters 21*: 1959-1989.

Faridah Zulkipli, Zulkifli Mohd Nopiah, Noor Ezlin Ahmad Basri & Cheng Jack Kie. 2018. Dynamical integrated framework development of solid waste management in Malaysia. *International Journal of Engineering and Technology* 7(4):21-24.

Femi Aminu, E., Oyefolahan, I. O., Bashir Abdullahi, M. & Salaudeen, M. T. 2020. A review on ontology development methodologies for developing ontological knowledge representation systems for various domains. *International Journal of Information Engineering and Electronic Business* 12(2): 28–39.

Ferdian Suprata. 2019. Data storytelling with dashboard: Accelerating understanding through data visualization in financial technology company case study. Jurnal Metris 20(1): 1-10.

Fernandez Lopez, M., Gomez-Perez, A. & Juristo, N. 1997. Methontology: From ontological art towards ontological engineering. *Proceedings of the 1997 AAAI Spring Symposium*, pp. 33-40.

Fernandez Lopez, M., Gomez-Perez, A., Sierra, J. P. & Sierra, A. P. 1999. Building a Chemical ontology using methontology and the ontology design environment. *IEEE Intelligent Systems* 14(1): 37–45.

Fernández-Lépez, M., Suárez-Figueroa, M. C. & Gómez-Pérez, A. 2012. Ontology development by reuse. In. Suárez-Figueroa, M. C., Gómez-Pérez, A., Motta, E. & Gangemi, A. (eds.) *Ontology Engineering in a Networked World*, pp. 147–170. Heidelberg: Springer Berlin.

Fernández-López, M. & Gómez-Pérez, A. 2002. Overview and analysis of methodologies for building ontologies. *Knowledge Engineering Review* 17(2): 129-156.

Few, S. 2003. *Information Dashboard Design*. North Sebastopol: O'Reilly Media, Inc

Few, S. 2006. *Information Dashboard Design: The Effective Visual Communication of Data*. North Sebastopol: O'Reilly Media, Inc.

Few, S. 2010. Dashboard design for at-a-glance monitoring. www.perceptualedge.com [3 April 2023].

Few, S. 2012. Show *Me the Numbers Designing Tables and Graphs to Enlighten Data Visualization for Enlightening Communication*. Berkeley: Analytics Press.

Fischer, C., Winter, R. & Wortmann, F. 2010. Design theory. *Business & Information Systems Engineering* 2(6): 387–390.

Fonseca, C. M., Guizzardi, G., Almeida, J. P. A., Sales, T. P. & Porello, D. 2022. Incorporating types of types in ontology-driven conceptual modeling. *Proceedings of the Lecture Notes in Computer Science*, pp. 18–34.

Furqan Durrani, A. M., Rehman, A. U., Farooq, A., Meo, J. A. & Sadiq, M. T. 2019. An automated waste control management system (AWCMS) by using Arduino. Paper presented at 2019 International Conference on Engineering and Emerging Technologies (ICEET), Institute of Electrical and Electronics Engineers Inc, Lahore, Pakistan. 21-22 February.

Gallina, B. & Szatmári, Z. 2016. Ontology-based Identification of Commonalities and Variabilities among Safety Processes. *Proceedings of the Lecture Notes in Computer Science*, pp. 182-189.

Ghosh Mitra, S., Chandra, A. & Ramaprasad, A. 2024. The ontology of urban governance: A framework for pathways to sustainable urban transition. *Urban Science* 8(2): 38.

Ginting, G. & Damayanti Apnena, R. 2024. Smart waste management and recycling based on IoT using machine learning algorithm. *Journal of Applied Intelligent System* 9(2): 192-199

Goldkuhl, G. 2004. Design theories in information systems - a need for multi-grounding. *Journal of Information Technology Theory and Application* 6(2): 59-72.

Gregor, S. & Hevner, A. R. 2013. Positioning and presenting design science research for maximum impact. *MIS Quarterly* 37(2): 337-356.

Gregor, S. & Jones, D. 2007. The anatomy of a design theory. *Journal of the Association for Information Systems* 8(5): 312–335.

Gregor, S. & Zwikael, O. 2024. Design science research and the co-creation of project management knowledge. *International Journal of Project Management* 42(3): 102584.

Gregor, S. 2006. The nature of theory in information system. *MIS Quarterly* 30(3): 611-642

Gröger, C., Hillmann, M., Hahn, F., Mitschang, B. & Westkämper, E. 2013. The operational process dashboard for manufacturing. *Procedia CIRP* 7: 205–210.

Gruber, T. 2009. Ontology. In. Lin, L. & Ozsu, M. T. *Encyclopedia of Database Systems*, pp. 1963-1965. Reading: Addison Wesley.

Gruber, T. R. 1993. A translation approach to portable ontology specifications. *Knowledge Acquisition* 5(2): 199-220.

Gruber, T. R. 1995. Toward principles for the design of ontologies used for knowledge sharing. *International Journal of Human Computer Studies* 43: 907–928.

Guarino, N. 1997. Semantic matching: Formal ontological distinctions for information organization, extraction, and integration. *Proceedings of the Lecture Notes in Computer Science*, pp. 139–170.

Guarino, N. 1998. *Formal Ontology in Information Systems*. Amsterdem: IOS Press.

Guizzardi, G. & Guarino, N. 2023. Semantics, ontology and explanation. http://arxiv.org/abs/2304.11124 [3 July 2023].

Guizzardi, G. & Guarino, N. 2024. Explanation, semantics, and ontology. *Data & Knowledge Engineering* 153: 102325.

Guizzardi, G. 2005. *Ontological Foundations for Structural Conceptual Models*. Enschede: Universal Press.

Guizzardi, G., Benevides, A. B., Fonseca, C. M., Porello, D., Almeida, J. P. A. & Sales, T. P. 2022. UFO: Unified Foundational Ontology. *Applied Ontology* 17(1): 167–210.

Gupta, S. 2023, January 17. The 5 Stages of the Design Thinking Process (ELI5 Guide). Springboard. https://www.springboard.com/blog/design/design-thinking-process/ [19 March 2024].

Han, J., Kim, K. H., Rhee, W. & Cho, Y. H. 2021. Learning analytics dashboards for adaptive support in face-to-face collaborative argumentation. *Computers and Education* 163: 104041.

Henaien, A., Ben Elhadj, H. & Fourati, L.C. 2024. A sustainable smart IoT-based solid waste management system. *Future Generation Computer Systems* 157: 587–602

Hepp, M. 2008. Ontologies: State of the art, business potential, and grand challenges. In. Hepp, M., De Leenheer, P., de Moor, A. & Sure. Y. (eds.). *Ontology Management: Semantic Web, Semantic Web Services, and Business Applications*, pp.3-22. New York: Springer.

Hertzum, M. 2020. *Usability Testing: A Practitioner's Guide to Evaluating the User Experience, Synthesis Lectures on Human-Centered Informatics*. New Jersey: Morgan and Claypool Publishers.

Hevner, A. R., March, S. T., Park, J. & Ram, S. 2004. Design science in information systems research. *MIS Quarterly* 28(1): 75-105.

Hishamadie Ahmad, Mohammad Fairus Khalid, Kandan Rajendar, Mohd Nizam Mohd Mydin, Bukhary Ikhwan Ismail & Hong Ong. 2020. A unified dashboard for collaborative robot management system. *Proceedings of the IEEE Student Conference on Research and Development*, *SCOReD 2020*, hlm. 5–9.

Holdford, D. A., Pontinha, V. M. & Wagner, T. D. 2022. Using the business model canvas to guide doctor of pharmacy students in building business plans. *American Journal of Pharmaceutical Education* 86(3): 243–253.

Hoppe, T., Eisenmann, H., Viehl, A. & Brigmann, O. 2017. Shifting from data handling to knowledge engineering in aerospace industry. https://www.researchgate.net/publication/320444301 [3 April 2023].

Hornbæk, K. 2006. Current practice in measuring usability: Challenges to usability studies and research. *International Journal of Human Computer Studies* 64(2): 79–102.

Iivari, J. 2007. A paradigmatic analysis of information systems as a design science. *Scandinavian Journal of Information Systems* 19: 39-64.

InfoGov Basics. n.d. Information governance resources: Best practices. https://www.infogovbasics.com/best-practices/ [5 February 2024].

ISO 9241-11. 1998. ISO 9241-11. https://standards.iteh.ai/catalog/standards/sist/c4f936de-9ec3-4eae-91ee- [5 February 2024].

Janes, A, Silitti,A. & Succi, G. 2013. Effective dashboard design. *Cutter IT Journal* 26(1):17-24

Jarke, J. & Macgilchrist, F. 2021. Dashboard stories: How narratives told by predictive analytics reconfigure roles, risk and sociality in education. *Big Data and Society* 8(1): 205395172110255.

Jooste, C., Van Biljon, J. & Mentz, J. 2013. Usability evaluation guidelines for Business Intelligence applications. *ACM International Conference Proceeding Series*, pp. 331–340.

Kallio, H., Pietilä, A. M., Johnson, M. & Kangasniemi, M. 2016. Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing* 72(12): 2954-2965.

Kelly, C., Fawkes, J., Habermehl, R., de Ferreyro Monticelli, D. & Zimmerman, N. 2023. PLUME Dashboard: A free and open-source mobile air quality monitoring dashboard. *Environmental Modelling and Software* 160: 105600.

Khatri, V. & Brown, C. V. 2010. Designing data governance. *Communications of the ACM* 53(1): 148–152.

Kirk, A. 2016. *Data Visualization: A Handbook for Data Driven Design*. London: SAGE Publications.

Kivunja, C. & Kuyini, A. B. 2017. Understanding and applying research paradigms in educational contexts. International Journal of Higher Education 6(5): 26-41.

Knutas, A., Pourzolfaghar, Z. & Helfert, M. 2019. The role and impact of descriptive theories in creating knowledge in design science. *Communications in Computer and Information Science* 654: 90–108.

Kooper, M. N., Maes, R. & Lindgreen, E. E. O. R. 2011. On the governance of information: Introducing a new concept of governance to support the management of information. *International Journal of Information Management* 31(3): 195–200.

Kuechler, W., Vaishnavi, V. & Kuechler, B. 2008. On theory development in design science research: Anatomy of a research project. *European Journal of Information Systems* 17(SI): 489-504.

Kuznetsova, M., Frits, M. L., Dulgarian, S., Iannaccone, C., Mort, E., Bates, D. W. & Salmasian, H. 2021. An analysis of the structure and content of dashboards used to monitor patient safety in the inpatient setting. *JAMIA Open* 4(4): ooab096.

Lassila, O. & Mcguinness, D. 2001. The role of frame-based representation on the Semantic Web. https://www.researchgate.net/publication/229101030 [3 July 2023].

Latif, S., Chen, S. & Beck, F. 2021. A deeper understanding of visualization-text interplay in geographic data-driven stories. *Computer Graphics Forum* 40(3): 311–322.

Lavalle, A., Maté, A., Santos, M. Y., Guimarães, P., Trujillo, J. & Santos, A. 2025. A methodology for the systematic design of storytelling dashboards applied to Industry 4.0. *Data and Knowledge Engineering* 156: 102410.

Le, D. H. 2020. UFO: A tool for unifying biomedical ontologybased semantic similarity calculation, enrichment analysis and visualization. *PLoS ONE* 15(7): e0235670.

Lee, Y. H. B. 2020. Prototyping: The dual actions. *Cubic Journal* 3: 54–73.

Lei, X., Wu, P., Zhu, J. & Wang, J. 2022. Ontology-based information integration: A State of the art review in road asset management. *Archive of Computational Methods in Engineering* 29: 2601–2619.

Liehu, I., Hynninen, R. & Lähteinen, J. 2022. Utilizing digital technologies for waste management. https://www.researchgate.net/publication/357871569 [28 August 2023].

Liu, C., Peng, G. & Kong, S. 2022. Developing a framework of information governance addressing online health information quality. *Proceedings of the 21st European Conference on Research*, pp. 91-102.

Lomas, E. 2019. Information Governance and Cybersecurity: Framework for securing and managing information effectively and ethically. In. Chang, H. -C. & Hawamdeh, S. (eds.). *Cybersecurity for Information Professionals*, pp.109-130. London: CRC Press.

Longhurst, R. 2003. Semi-Structured interviews and focus groups. In.. Clifford, N., Cope, M. & Gillespie, T. (eds.). *Key Method in Geography*, pp. 117–132. London: SAGE Publications.

Maheshwari, D., Janssen, M. & Veenstra, A. F. Van. 2021. A multi-level framework for measuring and benchmarking public service organizations: Connecting stages-of-growth models and enterprise architecture. *Proceedings of the 5th International Conference on Theory and Practice of Electronic Governance*, pp. 73-80.

Malamed, C. 2015. *Visual Design Solutions*. New Jersey: Wiley.

Manik, S.L.C., Berawi, M.A., Gunawan & Sari, M. 2024. Smart waste management system for smart & sustainable city of Indonesia's new state capital: A literature review. *E3S Web of Conferences* 517: 1-6

March, S. T. & Smith, G. F. 1995. Design and natural science research on information technology. *Decision Support Systems* 15(4): 251–266.

Marriott, K., Lee, B., Research, M., Butler, M., Cutrell, E., Ellis, K., Goncu, C., Hearst, M., McCoy, K. & Szafir, D. A. 2021. Inclusive data visualization for people with disabilities: A call to action. *Interactions* 28(3): 47-51.

Martínez-Ortiz, I., Pérez-Colado, I., Rotaru, D. C., Freire, M. & Fernández-Manjón, B. 2019. From heterogeneous activities to unified analytics dashboards. *Proceedings of the IEEE Global Engineering Education Conference*, pp. 1108–1113.

Martins, N., Martins, S. & Brandão, D. 2022. Design principles in the development of dashboards for business management. In. Raposo, D., Neves, J. & Silva, J. (eds.) *Perspectives on Design II: Research, Education and Practice*, pp.353-365, Vol. 16. Cham: Springer Cham.

Masola, C., Borgo, S., Gangemi, A., Guarino, N., Oltramari, A. & Schneider, L. 2002. WonderWeb Deliverable D17. The WonderWeb Library of Foundational Ontologies and the DOLCE ontology. https://www.researchgate.net/publication/2547471 [3 July 2023].

Massa, L., Tucci, C. & Afuah, A. 2017. A critical assessment of business model research. *The Academy of Management Annals* 11(1): 73-104.

Matentzoglu, N., Goutte-Gattat, D., Tan, S. Z. K., Balhoff, J. P., Carbon, S., Caron, A. R., Duncan, W. D., et al. 2022. Ontology Development Kit: A toolkit for building, maintaining and standardizing biomedical ontologies. *Database* 2022: baac087.

Matheus, R., Janssen, M. & Maheshwari, D. 2020. Data science empowering the public: Data-driven dashboards for transparent and accountable decision-making in smart cities. *Government Information Quarterly* 37(3): 101284.

Maturi, S.M., Dhanikonda, S.R. & Giddaluru, S. 2025. Smart dustbins: Real-time monitoring and optimization for waste management in smart cities through IoT devices. *Engineering, Technology and Applied Science Research* 15(1): 19246–19252

MHLG. 2018. Malaysia Smart City framework. https://www.kpkt.gov.my/kpkt/resources/user_1/GALERI/PDF_PENERBITAN/FRAMEWORK/FRAMEWORK_SMART_CITY_EXECUTIVE_SUMMARY.pdf [14 November 2023].

MIDA. 2021. Waste to energy for a sustainable future. MIDA e-newsletter. https://www.mida.gov.my/waste-to-energy-for-a-sustainable-future/ [14 June 2022].

Mikalef, P., Boura, M., Lekakos, G. & Krogstie, J. 2020. The role of information governance in big data analytics driven innovation. *Information and Management* 57(7): 103361.

Mkhinini, M. M., Labbani-Narsis, O. & Nicolle, C. 2020. Combining UML and ontology: An exploratory survey. *Computer Science Review* 35: 100223.

Mohammad Omar Sabri. 2025. The embracement of design science research methodology in the development of digital transformation models. *WSEAS Transactions on Business and Economics* 22: 12–19.

Möller, F., Schoormann, T. & Strobel, G. 2022. Unveiling the cloak: Kernel Theory use in design science research. *Proceedings of the Forty-Third International Conference on Information Systems*, pp. 1-17.

Moody, D. L. 2003. The method evaluation model: A theoretical model for validating information systems design methods. *ECIS 2003 Proceedings*, pp. 1-18.

Morriss, L. 2024. Themes do not emerge. An editor's reflections on the use of Braun and Clarke's thematic analysis. *Qualitative Social Work* 23(6): 1234-1250.

Muhammad Afif Fathullah, Anusuyah Subbarao, Abdulaziz Ahmad & Saravanan Muthaiyah. 2025. Merging qualitative design methods with design science. *International Journal of Qualitative Methods* 24: 1-11

Muhammad Zar Zaid Harith, Mohammad Asif Hossain, Ismail Ahmedy, Mohd Yamani Idna Idris, Kok Soon Tey & Rafidah Md. Noor. 2020. Prototype development of iot based smart waste management system for smart city. *IOP Conference Series Materials Science and Engineering* 884(1): 012051.

Mukherjee, S. 2019. Information governance for the implementation of cloud computing: A review. *The IUP Journal of Information Technology* XV(3): 22-37.

Munzner, T. 2009. A nested model for visualization design and validation. *IEEE Trans Vis Comput Graph* 15(6): 921-928.

Munzner, T. 2014. *Visualization Analysis and Design*. New York: CRC Press.

Muriyatmoko, D., Tjahyanto, A., Harmini, T. & Iqbal, M.R. 2024.Design science research methodology of mobile apps development for students with cerebral palsy spastic and dyskinetic. *Procedia Computer Science* 234: 1578–1585.

Design science research methodology of mobile apps development for students with cerebral palsy spastic and dyskinetic. Procedia Computer Science 234: 1578–1585.

Nadj, M., Maedche, A. & Schieder, C. 2020. The effect of interactive analytical dashboard features on situation awareness and task performance. *Decision Support Systems* 135: 113322.

Naeem, M., Smith, T. & Thomas, L. 2025. Thematic analysis and artificial intelligence: A step-by-step process for using ChatGPT in thematic analysis. *International Journal of Qualitative Methods* 24: 1-18

Nickerson, R. C., Varshney, U. & Muntermann, J. 2013. A method for taxonomy development and its application in information systems. *European Journal of Information Systems* 22(3): 336–359.

Nie, W., De Vita, K. & Masood, T. 2023. An ontology for defining and characterizing demonstration environments. *Journal of Intelligent Manufacturing* 35(7): 1-21.

Nielsen, J. 1993. *Usability Engineering*. Massachusetts: Morgan Kaufmann Publishers.

Noran, O. 2016. Advancing research in enterprise architecture: An information systems paradigms approach. *ICEIS 2016 - Proceedings of the 18th International Conference on Enterprise Information Systems*, 2, pp. 539–548.

Nordiana Mohd Nordin, Azman Mat Isa, Ahmad Zam Hariro Samsudin & Abdul Rahman Ahmad. 2022. Information governance for enhancing the performance of higher education institutions. *Environment-Behaviour Proceedings Journal* 7(SI10): 135–139.

North, M. & Macal, C. 2007. *Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling*. New York: Oxford University Press.

Noy, N. F. & Mcguinness, D. L. 2001. Ontology development 101: A guide to creating your first ontology. www.unspsc.org [4 July 2023].

Nurulhuda Muhamad, Masnita Misiran, Nor Idayu Mahat, Malina Zulkifli, Zahayu Md Yusof, Mohd Nizam Saad & Azizul Rusmadi Abdul Rahman. 2024. Design and implementation of community dashboard analytics for Abidin Mosque Parish in Kedah, Malaysia. *ALAM CIPTA: International Journal on Sustainable Tropical Design Research and Practice* 17(2): 36-41.

Osterwalder, A. 2004. The business model ontology: A proposition in a design science research. PhD Thesis, University of Lausanne, Switzerland.

Osterwalder, A., Pigneur, Y., Clark, T. & Smith, A. 2010. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. New Jersey: John Wiley & Sons.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N. & Hoagwood, K. 2015. Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research* 42(5): 533–544.

Palpanas, T., Chowdhary, P., Mihaila, G. & Pinel, F. 2007. Integrated model-driven dashboard development. *Information Systems Frontiers* 9: 195–208.

Pamuk, M. & Schumann, M. 2024. Towards AI dashboards in financial services: Design and implementation of an AI development dashboard for credit assessment. *Machine Learning and Knowledge Extraction* 6(3): 1720–1761.

Pardini, K., Rodrigues, J. J. P. C., Diallo, O., Das, A. K., de Albuquerque, V. H. C. & Kozlov, S. A. 2020. A smart waste management solution geared towards citizens. *Sensors (Switzerland)* 20(8): 2380.

Parlar, S. 2019, November 20. Ontologies: In Detail- How to Develop an Ontology?, Analytics Vidhya. https://medium.com/analytics-vidhya/ontologies-in-detail-2916f9226133 [5 May 2023].

Pearson, H., Myall, M., Darlington, A.-S. & Gibson, F. 2025. 2025. The approach and application of analysing inductive and deductive datasets: a worked example using reflexive thematic analysis. *Qualitative Research in Psychology* 22(4): 842–886.

Peffers, K., Tuunanen, T., Rothenberger, M. A. & Chatterjee, S. 2007. A design science research methodology for information systems research. *Journal of Management Information Systems* 24(3): 45–77.

Pérez-Castillo, R. & Piattini, M. 2022. Design of classical-quantum systems with UML. *Computing* 104(11): 2375–2403.

Perkins, M. & Roe, J. 2024. The use of Generative AI in qualitative analysis: Inductive thematic analysis with ChatGPT. *Journal of Applied Learning and Teaching* 7(1): 390 -395.

Pestana, M., Pereira, R. & Moro, S. 2020. Improving health care management in hospitals through a productivity dashboard. *Journal of Medical Systems* 44(4): 87.

Pietranik, M. & Kozierkiewicz, A. 2023. Methods of managing the evolution of ontologies and their alignments. *Applied Intelligence* 53(17): 20382–20401.

Pittet, P., Cruz, C. & Nicolle, C. 2012. Guidelines for a dynamic Ontology: Integrating Tools of evolution and Versioning in Ontology. http://semanticweb.org/wiki/Main_Page [22 January 2023].

Poppe, J. A., Smorenburg, R. S., Goos, T. G., Taal, H. R., Reiss, I. K. M. & Simons, S. H. P. 2024. Development of a web-based oxygenation dashboard for preterm neonates: A quality improvement initiative. *Journal of Medical Systems* 48(1): 46.

Poveda-Villalón, M., Fernández-Izquierdo, A., Fernández-López, M. & García-Castro, R. 2022. LOT: An industrial oriented ontology engineering framework. *Engineering Applications of Artificial Intelligence* 111: 104755.

Prat, N., Comyn-Wattiau, I. & Akoka, J. 2015. A taxonomy of evaluation methods for information systems artifacts. *Journal of Management Information Systems* 32(3): 229–267.

Prescott, M. R., Yeager, S., Ham, L., Rivera Saldana, C. D., Serrano, V., Narez, J., Paltin, D., et al. 2024. Comparing the efficacy and efficiency of human and generative AI: Qualitative thematic analyses. *JMIR AI* 3: 1-9

Proença, D., Vieira, R. & Borbinha, J. 2016. A maturity model for information governance. *Proceedings of the Lecture Notes in Computer Science*, pp. 15–26.

Pulsipher, D. W. 2022. Information Governance Maturity Model. White Paper: Intel, pp. 1-7.

Rasmussen, N., Chen, C. Y. & Bansal, M. 2009. *Business Dashboards: A Visual Catalog for Design and Deployment*. New Jersey: John Wiley & Sons. Inc.

Real, R., Snider, C. & Goudswaard, M. 2022. Dimensions of prototyping knowledge: Characterising prototype evaluation methods and their contributions to design knowledge. *Design Computing and Cognition*: 703-721

Roberts, L. D., Howell, J. A. & Seaman, K. 2017. Give me a customizable dashboard: personalized learning analytics dashboards in higher education. *Technology, Knowledge and Learning* 22(3): 317–333.

Robinson, O. C. 2014. Sampling in interview-based qualitative research: A theoretical and practical guide. *Qualitative Research in Psychology* 11(1): 25–41.

Rösch, N., Tiberius, V. & Kraus, S. 2023. Design thinking for innovation: context factors, process, and outcomes. *European Journal of Innovation Management* 26(7): 160–176.

Rossi, F.S., Adams, M.C.B., Aarons, G. & McGovern, M.P. 2025. From glitter to gold: Recommendations for effective dashboards from design through sustainment. *Implementation Science* 20(1): 1-12.

Rouzbahani, F., Asadi, F., Rabiei, R., Moghaddasi, H. & Emami, H. 2020. Developing a model for national health information governance program in Iran. *Journal of Medicine and Life* 13(4): 510–516.

Rudnicki, R. 2016. Best practices of ontology development. http://www.w3.org/2001/sw/wiki/Tools [6 April 2023].

Salatino, A. A., Thanapalasingam, T., Mannocci, A., Birukou, A., Osborne, F. & Motta, E. 2020. The computer science ontology: A comprehensive automatically-generated taxonomy of research areas. *Data Intelligence* 2(3): 379–416.

Salvi, A., Gillenwater, L. A., Cockrum, B. P., Wiehe, S. E., Christian, K., Cayton, J., Bailey, T., et al. 2024. Development of a real-time dashboard for overdose touchpoints: User-centered design approach. *JMIR Human Factors* 11: e57239.

Samrose, S. & McDuf, D. 2021. Meetingcoach: An intelligent dashboard for supporting efective and inclusive meetings. *Conference on Human Factors in Computing Systems - Proceedings. Association for Computing Machinery*, pp. 1-14.

Sanz-Blasco, E., Gómez-Delgado, M., Clemente-Párraga, J. & Aguilera-Benavente, F. 2025. Development of a plugin-based prototype for spatial explicit application of fuzzy multicriteria evaluation. *Expert Systems with Applications* 276: 127199

Sarikaya, A., Correll, M., Bartram, L., Tory, M. & Fisher, D. 2019. What do we talk about when we talk about dashboards? *IEEE Transactions on Visualization and Computer Graphics* 25(1): 682–692.

Schneider, T. & Šimkus, M. 2020. Ontologies and data management: A brief survey. *Kunstliche Intelligenz* 34(3): 329–353.

Sedlmair, M., Meyer, M. & Munzner, T. 2012. Design study methodology: Reflections from the trenches and the stacks. *IEEE Transactions on Visualization and Computer Graphics* 18(12): 2431-2440

Sedrakyan, G., Mannens, E. & Verbert, K. 2019. Guiding the choice of learning dashboard visualizations: Linking dashboard design and data visualization concepts. *Journal of Visual Languages and Computing* 50: 19–38.

Sein, M. K., Henfridsson, O., Purao, S., Rossi, M. & Lindgren, R. 2011. Action design research. *MIS Quarterly: Management Information Systems* 35(1): 37–56.

Setlur, V., Battersby, S. E., Tory, M., Gossweiler, R. & Chang, A. X. 2016. Eviza: A natural language interface for visual analysis. *UIST 2016 - Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, pp. 365–377.

Sharp, H., Rogers, Y. & Preece, J. 2019. *Interaction Design: Beyond Human-Computer Interaction*. 5th Edition. Indiana: John Wiley & Sons.

Shneiderman, B. 1996. The eyes have it: A task by data type taxonomy for information visualizations. *Proceedings 1996 IEEE Symposium on Visual Languages*, pp. 336-343

Shultz, J. & Jha, R. 2021. Using virtual reality (Vr) mock-ups for evidence-based healthcare facility design decisions. *International Journal of Environmental Research and Public Health* 18(21): 11250.

Silver, M. S., Markus, M. L. & Beath, C. M. 1995. The information technology interaction model: A foundation for the MBA core course. *MIS Quarterly: Management Information Systems* 19(3): 361–387.

Simon, P. M. 2015. Ontology. In. *Encyclopedia Britannica*. https://www.britannica.com/topic/ontology-metaphysics [4 July 2023].

Snyder, C. 2003. *Paper Prototyping: The Fast and Easy Way to Design and Refine User Interface*. Massachusetts: Morgan Kaufmann Publishers.

Sonnenberg, C. & vom Brocke, J. 2012. Evaluations in the science of the artificial - Reconsidering the build-evaluate pattern in design science research. *Proceedings of the Lecture Notes in Computer Science*, pp. 381–397.

Spoladore, D., Pessot, E. & Trombetta, A. 2023. A novel agile ontology engineering methodology for supporting organizations in collaborative ontology development. *Computers in Industry* 151: 103979.

Stahlman, G., Yanovitzky, I. & Kim, M. 2025. Design, application, and actionability of US public health data dashboards: Scoping review. *Journal of Medical Internet Research* 27: e65283.

Stancin, K., Poscic, P. & Jaksic, D. 2020. Ontologies in education – state of the art. *Education and Information Technologies* 25(6): 5301–5320.

Staron, M. 2015. Dashboard development guide-How to build sustainable and useful dashboards to support software development and maintenance. https://core.ac.uk/download/pdf/43560952.pdf [9 April 2023].

Stein, M. 2022, September 7. What is data unification? - Joinr. https://joinr.com/data-unification-guide/ [19 May 2023].

Studer, R., Benjamins, V. R. & Fensel, D. 1998. Knowledge engineering: Principles and methods. *Data and Knowledge Engineering* 25(1–2): 161–197.

Suárez-Figueroa, M. C., Gómez-Pérez, A. & Fernández-López, M. 2015. The NeOn Methodology framework: A scenario-based methodology for ontology development. *Applied Ontology* 10(2): 107–145.

Syaiful Ahdan, Erliyan Redy Susanto & Nana Rachmana Syambas. 2019. Proposed design and modeling of smart energy dashboard system by implementing IoT (Internet of Things) based on mobile devices. Paper presented at 2019 IEEE

13th International Conference on Telecommunication Systems, Services, and Applications (TSSA), Bali Dynasty Resort, South Kuta, Bali. 3-4 October.

Szpilko, D., de la Torre Gallegos, A., Jimenez Naharro, F., Rzepka, A. & Remiszewska, A. 2023. Waste management in the Smart City: Current practices and future directions. *Resources* 12(10): 115.

Toreini, P., Langner, M., Maedche, A., Morana, S. & Vogel, T. 2022. Designing attentive information dashboards. *Journal of the Association for Information Systems* 23(2): 521–552.

Tory, M. & Möller, T. 2005. Evaluating visualizations: Do expert reviews work? *IEEE Computer Graphics and Applications* 25(5): 8-11

Tudorache, T. 2020. Ontology engineering: Current state, challenges, and future directions. *Semantic Web* 11(1): 125–138.

Tufte, E. R. 2001. *The Visual Display of Quantitative Information*. 2nd Edition. Connecticut: Graphics Press LLC.

Uschold, M. & Gruninger, M. 1996. Ontologies: Principles, methods and applications. *The Knowledge Engineering Review* 11(2): 1-62.

Uschold, M. & King, M. 1995. Towards a Methodology for Building Ontologies. *Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing*, pp. 1-13.

Uschold, M. 1996. Building ontologies: Towards a unified methodology. *Proceedings of Expert Systems '96 the 16th Annual Conference of the British Computer Society Specialist Group on Expert Systems*, pp. 1-18.

Vázquez-Ingelmo, A. 2019. Extending a dashboard meta-model to account for users' characteristics and goals for enhancing personalization. *LASI Spain 2019: Proceedings of the Learning Analytics in Higher Education*, pp. 35-42.

Vazquez-Ingelmo, A., Garcia-Penalvo, F. J. & Theron, R. 2019. Information dashboards and tailoring capabilities-a systematic literature review. *IEEE Access* 7: 109673-109688.

Venable, J. R. 2006a. A framework for design science research activities. *Proceedings of the 2006 Information Resource Management Association Conference*, pp. 1-6.

Venable, J. R. 2006b. The role of theory and theorising in design science research. https://www.researchgate.net/publication/228670522 [4 July 2023].

Venable, J., Pries-Heje, J. & Baskerville, R. 2016. FEDS: A framework for evaluation in design science research. *European Journal of Information Systems* 25: 77–89.

vom Brocke, J., Hevner, A. & Maedche, A. 2020a. Introduction to design science research. In. vom Brocke J., Hevner, A. & Maedche A. (eds.). *Design Science Research*, pp. 1-19. Cham: Springer Nature.

vom Brocke, J., Winter, R., Hevner, A. & Maedche, A. 2020b. Accumulation and evolution of design knowledge in design science research: A journey through time and space. *Journal of the Association for Information Systems* 21(3): 520–544.

Walls, J. G., Widmayer, G. R. & El Sawy, O. A. 1992. Building an information system design theory for vigilant EIS. *Information System Research* 3(1): 36–59.

Wang, X. & Chan, C. W. 2001. Ontology modeling using UML. *Proceedings of the 7th International Conference on Object Oriented Information*, pp. 59-68.

Weigand, H., Johannesson, P. & Andersson, B. 2021. An artifact ontology for design science research. *Data and Knowledge Engineering* 133: 101878

Wexler, S., Shaffer, J. & Cotgreave, A. 2017. *The Big Book of Dashboards: Visualizing your Data Using Real World Business Scenarios*. New York: John Wiley & Sons.

Wiegmann, P. M., Talmar, M. & de Nijs, S. B. 2023. Forging a sharper blade: A design science research approach for transition studies. *Environmental Innovation and Societal Transitions* 48: 100760

Wu, A., Wang, Y., Zhou, M., He, X., Zhang, H., Qu, H. & Zhang, D. 2021. MultiVision: Designing analytical dashboards with deep learning based recommendation. https://github.com/Franches/MultiVision [5 May 2023].

Xenya, M. C., D'Souza, E., Woelorm, K. O. D., Nii Adjei-Laryea, R. & Baah-Nyarkoh, E. 2020. A proposed iot based smart waste bin management system with an optimized route: A case study of Ghana. *Proceedings of the 2020 Conference on Information Communications Technology and Society*, pp. 1-5.

Yap, A. Y. 2020. Creating business analytics dashboard designs using visualization methodologies: Case methods for innovative analytics pedagogy. *Information Systems Education Journal* 18(5): 25-33.

Yigitbasioglu, O. M. & Velcu, O. 2012. A review of dashboards in performance management: Implications for design and research. *International Journal of Accounting Information Systems* 13(1): 41–59.

Youcef, B., Ahmad, M. N. & Mustapha, M. 2021. Ontophaco: An ontology for virtual reality training in ophthalmology domain - A case study of cataract surgery. *IEEE Access* 9: 152347–152378.

Yu, F., Pasinelli, M. & Brem, A. 2018. Prototyping in theory and in practice: A study of the similarities and differences between engineers and designers. *Creativity and Innovation Management* 27(2): 121–132.

Yun Arifatul Fatimah, Kannan Govindan, Rochiyati Murniningsih & Agus Setiawan. 2020. Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: A case study of Indonesia. *Journal of Cleaner Production* 269: 122263.

Zhou, L. & Wang, Q. 2009. Knowledge discovery and modeling approach for manufacturing enterprises. *Proceedings of the 3rd International Symposium on Intelligent Information Technology Application*, pp. 291–294.

APPENDIX A

TRANSCRIPT OF INTERVIEW – DASHBOARD DEVELOPER 1 (DD1)

May 21, 2025, 10:56AM

Ahadi Bin Mohd Nasir started transcription

Ahadi Bin Mohd Nasir 0:04
How are you today?

DD1 0:09
I'm good. I'm fine. How about you?

Ahadi Bin Mohd Nasir 0:13
I'm OK too. I hope you're doing well. First of all, thank you so much for taking the time to be part of this interview session. And more importantly, thanks again for being willing to design a mock-up dashboard using the IDDM Canvas.

Ahadi Bin Mohd Nasir 0:32
As one of the early users of the IDDM Canvas, your involvement has been very important — not just in testing the framework, but also in shaping how it might work in real-world development. Your feedback today will give me valuable insight into how practical and effective the method really is from a designer's perspective.

DD1 0:58
Mm hmm.

Ahadi Bin Mohd Nasir 1:00
This session is recorded purely for academic analysis, and all your responses will remain confidential. Your name and organisation will not appear in any report or publication. If at any point you'd like to skip a question, just let me know. So, if you're ready, I'd like to start by asking you about your overall experience using the IDDM Canvas in your design process. Is that OK?

DD1 1:31
Yeah, this is my first time using a very technical and academic-driven framework to design a dashboard. Overall, I think the experience was good. It gave me a lot of new insight in terms of planning.

Ahadi Bin Mohd Nasir 1:55
Right. Good to hear that.
All right, let's start with the section A and section A will focus on the usability, OK? My first question, how easy was it to understand and apply the IDDM canvas in your dashboard design process?

DD1 2:14
OK.
Actually, it was easy to use after I understood the structure. The IDDM Canvas is practical and clear. The 12 sections gave me a full map, from defining the purpose, all the way to planning for continuous improvement.
I usually work with Power BI or Python, but for this project, I used Tableau.

Ahadi Bin Mohd Nasir 2:51
Mm hmm.

DD1 2:51
As you've seen from the mock-up I shared, I followed the Canvas step by step while visualising I-MORSYS recycling data.

Ahadi Bin Mohd Nasir 2:56
Mm hmm.

DD1 3:05
The Audience section helped me differentiate views, for example, between local council staff and operations managers. Normally, I go straight into visuals, but IDDM made me think first. That saved a lot of rework later.

Ahadi Bin Mohd Nasir 3:17
All right.
OK. The second question is, did 12 sections of the IDDM Canvas feel comprehensive and relevant to your needs?

DD1 3:34
Yes, of course.
The 12 sections covered everything I need.
From setting goals, choosing direct data, planning layout up to dashboard review. Using Tableau, I applied the Canvas directly to the iMORSYS data and realised that sections like Evaluation and Continuous Improvement are usually skipped in normal projects.

Ahadi Bin Mohd Nasir 3:49
Mm hmm.

DD1 4:04
In this case, IDDM reminded me to include recycling performance metrics that could be tracked monthly. So it felt like the Canvas helped me zoom out and design with the big picture in mind.

Ahadi Bin Mohd Nasir 4:08
Mm hmm.

Ahadi Bin Mohd Nasir 4:26
OK, great. How user friendly was the overall flow and structure of the methodology.

DD1 4:36
Very user friendly. It felt like following a checklist. Each part flowed nicely into the next. Tableau doesn't allow too much flexibility in some aspects, but because of the IDDM Canvas, I had already planned the layout and user interface before building.

Ahadi Bin Mohd Nasir 4:47
Mm hmm.
Mm hmm.

DD1 4:58
So before I building the dashboard so this could help me focus on what works within Tableau instead of changing things halfway.

Ahadi Bin Mohd Nasir 5:02
Right.

DD1 5:12
For example, I processed raw CSV files based on the Data Source and Data Processing sections — making sure only valid data records go into the dashboard. That saved me a lot of debugging time during review.

Ahadi Bin Mohd Nasir 5:50
OK.
Thank you for the answer.
All right, we now move to Section B on the effectiveness.
So OK, the first question under this section, to what extent did the IDDM help you address the specific needs of your intended dashboard users?

DD1 6:08
It helped a lot.

Ahadi Bin Mohd Nasir 6:10
OK.

DD1 6:10
I clearly defined user roles from the beginning using the Audience section which made the dashboard more focused. For example, KDEBWM officers needed strategic KPIs, while recycling staff needed operational insights.

Ahadi Bin Mohd Nasir 6:18
Mm hmm.
Hmm.

DD1 6:32
IDDM guided me to separate those into different zones and filters. Without IDDM, I might have tried to combine everything into one page, which is easier , but it's not what the client really wants. Now each view feels more intentional.

Ahadi Bin Mohd Nasir 6:53
Thanks.
OK. The next question, how did the method guide your choices for data selection and visualization techniques?

DD1 7:09
IDDM guided me to select only relevant data from iMorsys and match it with visual styles that suited user goals. During Data Processing, I cleaned and filtered only current-year records. In terms of visualisation, I used line charts to show trends and KPIs over time, clearer for time-based metrics.

Ahadi Bin Mohd Nasir 7:14
Mm hmm.
Mm hmm.

DD1 7:24
Since Tableau has its own strengths and limitations, I had to balance performance and clarity based on what mattered most to users.

Ahadi Bin Mohd Nasir 7:52
OK.
All right.
The third question under this section did the IDDM improve the overall quality and purposefulness of your final dashboard?

DD1 8:04
I can say yes, absolutely. It gave structure to the whole process and made the final product more focused and useful. One improvement I made was adding a feedback section and monthly comparison, inspired by the Evaluation and Continuous Improvement sections. That's something I've never done before. So overall, the dashboard I delivered felt more mature and aligned with both stakeholder goals and real data usage.

Ahadi Bin Mohd Nasir 8:40
OK.
Now we are in section C on the completeness right. The first question under this section were there any important aspects of dashboard design that the IDDM did not cover adequately?

DD1 8:55
Yes, this is my opinion from my perspective.
They doing this mock up on user onboarding for example.

Ahadi Bin Mohd Nasir 9:02
Mm hmm.

DD1 9:04
Many users don’t know how to use Tableau filters or interactive elements. While IDDM covers functionality and improvement, I think it would be helpful to include a section that reminds developers to add user guides or training tips — especially for public-facing dashboards.

Ahadi Bin Mohd Nasir 9:30
OK.
I take note on that, alright.
On the next question, the second question under Section C did any part of the method feel redundant or unnecessary in your workflow?

DD1 9:46
Not really.

Ahadi Bin Mohd Nasir 9:47
Mm hmm.

DD1 9:48
At first, I thought Style and Layout were overlapping — but later I saw the difference. Style helped define colours and consistency, while Layout guided arrangement. That distinction helped especially when I had to resize views for mobile responsiveness.

Ahadi Bin Mohd Nasir 9:59
Mm hmm.

Ahadi Bin Mohd Nasir 10:12
Mm hmm.
OK. The third question, how well were Information Governance principles incorporated in the IDDM Canvas?

DD1 10:46
Very well. As a Tableau developer, I can’t manipulate raw data inside the dashboard. So I rely fully on clean, official data. IDDM’s Data Source and Data Processing sections reminded me to validate all input before visualising.

Ahadi Bin Mohd Nasir 11:02
Mm hmm.

DD1 11:10
So again, like I just like mentioned before.This reduced the risk of showing outdated or broken numbers to stakeholders. It also helped justify why I excluded certain metrics where source data was unstable.

Ahadi Bin Mohd Nasir 11:58
OK, we now move on to the next section, section D on the impact. OK. The first question under this section how did using the IDDM compared to your previous dashboard design approaches?

DD1 12:15
Previously, I relied on experience and client briefs. I would just start sketching or building in Tableau or other platform like Power BI. With IDDM, I followed a structured process, starting with defining the purpose and audience, then aligning everything accordingly.

Ahadi Bin Mohd Nasir 12:30
Mm hmm.

DD1 12:34
It felt more like designing a solution, not just a dashboard. I wasn't just visualising data, I was solving a real problem using verified iMORSYS insights.

Ahadi Bin Mohd Nasir 12:43
Mm hmm.

Ahadi Bin Mohd Nasir 13:08
The second question under the section did it influence your decision making or workflow in any specific way?

DD1 13:16
Yes, yes, definitely.
IDDM forced me to think about the "why" and "who" before building anything. I created separate filters and views based on the User Interface section, allowing each role to focus on what matters to them.

Ahadi Bin Mohd Nasir 13:29
Mm hmm.

DD1 13:35
It also made me document my decisions — like why I used line charts instead of bar charts, or why I skipped a KPI due to unstable data. That's something I never did before.

Ahadi Bin Mohd Nasir 13:45
Right.

DD1 13:49
So it also made me document decisions clearly.
Like why I use a line chart instead of a bar chart?
Or why I skip a KB I when data was unstable?
That's something I never used to do before.

Ahadi Bin Mohd Nasir 14:05
OK. Would you consider using IDDM again for future projects

DD1 14:27
Definitely yes. For this iMorsys project, it helped me deliver a dashboard that was clean, focused, and aligned with user needs.

Ahadi Bin Mohd Nasir 14:33
Mm hmm.

DD1 14:39
I believe it works not only for operational dashboard like this, but also for strategic or public dashboards because it scales.

Ahadi Bin Mohd Nasir 14:43
Mm hmm.

DD1 14:49
I will definitely use IDDM again for projects involving multiple stakeholders or departments, because it helps reduce rework after presenting the dashboard to clients. Everything is already aligned on the Canvas, so I just follow whatever has been sketched and agreed upon there.

Ahadi Bin Mohd Nasir 15:15
OK.
So now we are in section E on the challenges and limitation I believe since this is the initial artifacts right, there will be some limitation on the IDDM canvas because I believe it is not perfect yet.
What were the main challenges you encountered while applying IDDM?

DD1 15:42
Initially, I felt like there were too many sections. It felt like a lot of paperwork before any real work began. But once I linked each section to my actual workflow in Tableau, it made more sense. The challenge was mental, slowing down to plan properly instead of jumping straight into visuals.

Ahadi Bin Mohd Nasir 15:48
Mm hmm.
DD1 16:21
Another challenge was interpreting evaluation and continuous improvement. So this is part quite confusing for me. At first I thought I had to build those metrics. This is from the perspective of developer.

Ahadi Bin Mohd Nasir 16:29
Mm hmm.
Right.

DD1 16:37
I felt that this session need me to build those metrics inside the dashboard. Later I realised they can be handled externally — like monthly reviews or feedback forms from the client side.

Ahadi Bin Mohd Nasir 17:18
Mm hmm.

Ahadi Bin Mohd Nasir 17:35
OK.
Noted on that, OK.
The next question.
Any platform-specific or project-related limitations?

DD1 17:48
Yes, Yes. Tableau is powerful but has some limitations. For example, gauge charts or dynamic tooltips aren't natively supported. So I had to use KPI cards and line charts instead. Also, since i-MORSYS data came in CSV, I had to preprocess it using Python or Excel before importing it into Tableau.

Ahadi Bin Mohd Nasir 18:15
Mm hmm.

DD1 18:18
So, while IDDM gave me the ideal structure, I still had to adapt to Tableu's technical limits and the quality of the data.

Ahadi Bin Mohd Nasir 18:31
Right.
OK, this will be the last question and the section right.
How flexible do you think the IDDM is when applied to different types of dashboards?

DD1 18:57
Very, very flexible. For this project, it worked well even with tight timelines and mixed data quality. I can see it being applied to both simple and complex dashboards. For simpler use cases, you can focus on 5 to 6 core sections. For more complex projects, you can apply all 12 sections in detail.

IDDM allows me to scale the process according to the project needs. That makes it practical for both internal operations and public-facing dashboards.

Ahadi Bin Mohd Nasir 19:33
OK.
All right.
Now we are in session F on the suggested improvement. OK, What suggestion do you have to improve the IDDM framework or the canvas?

DD1 20:03
I think IDDM is already solid. But to make it more developer-friendly, maybe add clearer notes or examples for Evaluation and Continuous Improvement. As a first-timer, it wasn't obvious that these steps can be external , like via survey or report, not always inside the dashboard.

Ahadi Bin Mohd Nasir 20:19
Mm hmm.

DD1 20:20
Second, include onboarding or training strategy. Many users don’t know how to use Tableau filters or tooltips. If IDDM reminds developers to include walkthroughs or demo videos, it’ll boost adoption, especially for public dashboards.

Ahadi Bin Mohd Nasir 20:31
Mm hmm.

Ahadi Bin Mohd Nasir 20:56
OK.
Thank you for that.
Now we are in the second question in Section F.
Are there any additional features, sections or tools you would like to see included?

DD1 21:12
Yes, a few optional optional blocks can be added:
User onboarding and training so that developers could think about tutorial or tooltips and then second accessibility checklist.
To ensure for colorblind friendly users font size, mobile compatibility and then lifecycle planning to include what happened after delivery, maintenance update version.

Ahadi Bin Mohd Nasir 21:33
Mm.
Mm hmm.

DD1 21:43
And maybe a template pack , showing real examples from different industries would help guide first-time users.

Ahadi Bin Mohd Nasir 21:45
Mm hmm.
OK.
Thank you for this sugesstion, OK.
I'll take a note on that, OK.
So now we are in the final section, Section G on the overall assessment.
So OK, the first question is on a scale of one to 10.
Right. So how would you rate the overall usefulness of the IDDM in your design process?

DD1 22:20
I would say.
I rate it 8 out of 10.
It gave me structure, made my work more user-focused, and helped prevent mistakes I usually only catch at the end. From defining the goal to planning updates, IDDM kept me in control.

Ahadi Bin Mohd Nasir 22:33
Mm hmm.

DD1 22:35
I usually will only catch at the end from defining the goal to planning updates. I didn't keep me in control, so this is the good thing about the IDDM.

Ahadi Bin Mohd Nasir 22:38
Right.

DD1 22:44
It's like having a blueprint, especially useful when dealing with real-world datasets like iMORSYS, where data isn't always perfect and expectations shift fasto it's like having a blueprint especially useful when dealing with real world data set like Moss.

Ahadi Bin Mohd Nasir 22:59
OK. The last question, OK.
Would you recommend this method to add the dashboard designers? Why or why not?

DD1 23:11
Yes, I would recommend it especially to those building dashboard for multiple stakeholders or public use.
It helps clarify user needs early, structure the thinking process, and avoid rework. Even if you're experienced with Tableau or other tools, IDDM reminds me to plan smarter, not just work harder.

Ahadi Bin Mohd Nasir 23:30
Mm hmm.

Ahadi Bin Mohd Nasir 23:37
OK.

DD1 23:38
It's not about replacing creativity, it's about building dashboards that actually work in the real world.

Ahadi Bin Mohd Nasir 23:46
Right. OK, alhamdullilah.
That's all for the question.
I won't take more of your time and I know you are busy and I truly appreciate you making your time for the session once again.
Thank you so much for your time, your insights, and your willingness to support this research, and your feedback is truly valuable and it will help me to improve not just the IDDM canvas, but also contribute to better dashboard design practices. So I really appreciate your role as one of the early contributors to this work. It means a lot, OK. Thank you once again and I wish you all the best in your ongoing work and project. Assalamualaikum and have a nice day.

DD1 24:34
Welcome Salam.
Thank you so much for having me.

This is my honest review on this IDDM.
Hope this could help you throughout your PhD journey and then reflect the real world of this dashboard development.
I hope this small contribution from mine will help you to have this IDDM to be use across the world.

Ahadi Bin Mohd Nasir 25:05
I OK.
Thank you very much.

DD1 25:06
OK.
You're most welcome.

Ahadi Bin Mohd Nasir stopped transcription

APPENDIX B

TRANSCRIPT OF INTERVIEW – DASHBOARD DEVELOPER 2 (DD2)

May 15, 2025, 2.30 p.m

Ahadi Bin Mohd Nasir
OK, so I hope you are doing well and everything is fine with you. First of all, thank you so much for taking the time to be part of this interview session and more importantly, thank you again for being willing to design A mock up dashboard using the IDDM canvas.

DD2 3:16
You're welcome.

Ahadi Bin Mohd Nasir 3:19
As one of the early users of this IDDM canvas, your involvement has been really important and instrumental, not just in testing the framework, but also in helping to shape how it might work in real-world dashboard development. And your feedback today will give me valuable insight into how practical and effective the method really is from a designer's perspective.
For your information, this session is recorded purely for academic analysis purposes, and all your responses will remain confidential and your name and organization won't appear in any report or publication.

DD2 3:44
OK. Alright.

Ahadi Bin Mohd Nasir 3:58
And if any point you would like to skip a question, feel free to let me know. OK.
So if you are ready, I would like to start by asking about your overall experience using the IDDM canvas in your design process, OK.

DD2 4:05
Thank you.
OK.

Ahadi Bin Mohd Nasir 4:15
OK.
Let's begin with some questions about your experience using the IDDM canvas. So the first question is, how easy was it to understand and apply the IDDM canvas in your dashboard design process?

DD2 4:22
OK.
I found the IDDM Canvas surprisingly intuitive. At first glance, the 12 sections might seem overwhelming, but the structure made it easy to digest. It felt like a logical flow

that guided me step by step. I appreciated that it wasn't overly technical or academic; it was practical enough for immediate application to the dashboard design process

Ahadi Bin Mohd Nasir 4:53
OK.

DD2 4:59
I was quite satisfied with how it applied to one of my projects.
There were a couple of sections I had to revisit to fully grasp the newer concepts, but overall, the learning curve felt manageable.

Ahadi Bin Mohd Nasir 5:03
Mm hmm.
Mm hmm.

DD2 5:12
Hmm.

Ahadi Bin Mohd Nasir 5:12
All right.
So in IDDM canvas, there were 12 sections, yeah.

DD2 5:19
OK. Yep.

Ahadi Bin Mohd Nasir 5:20
So did the 12 sections of the IDDM canvas feel comprehensive and relevant to your design needs?

DD2 5:26
OK, for the most part, yes. The 12 sections did feel quite comprehensive.
They prompted me to think about aspects of dashboard design that I might have glossed over in my usual approach.
For example, the emphasis on understanding the user's specific tasks and the business context really grounded the design.
It gave me a stronger sense of purpose and helped guide my design decisions more intentionally.

Ahadi Bin Mohd Nasir 5:42
Mm hmm.
Mm hmm.

DD2 5:50
I felt like each section served a purpose, pushing me to consider different facets of the dashboard, from the initial requirements to the final presentation. There might have been one or two areas where the relevance felt slightly less direct for this particular dashboard, but I could still see their value in a broader range of projects.

Ahadi Bin Mohd Nasir 6:01
OK, in your opinion how user friendly was the overall flow and structure of the methodology?

DD2 6:17
OK. But first I thought the flow was quite logical.
It felt like a natural progression from understanding the 'why' behind the dashboard to the ‘how' of its creation and finally to evaluating its impact. The structure of the Canvas, breaking down the design process into distinct stages, made it less overwhelming.

Ahadi Bin Mohd Nasir 6:29
Mm hmm.

DD2 6:34
The structure of the Canvas, breaking down the design process into distinct stages, made it less overwhelming. It provided a clear roadmap to follow, which was especially helpful when we were navigating the initial stages of defining the dashboard's purpose and target audience. It prevented us from jumping straight into visualization without proper groundwork.

Ahadi Bin Mohd Nasir 7:09
Alright, so now we move on to Section B on the effectiveness? Are you ready?

DD2 7:13
OK.

Ahadi Bin Mohd Nasir 7:15
So I'd like to ask a few questions about how effective the method was for your design process.

DD2 7:15
OK.

Ahadi Bin Mohd Nasir 7:21
All right, this is the first question.

DD2 7:22
Right.

Ahadi Bin Mohd Nasir 7:24
To what extent did the IDDM help you address the specific needs of your intended dashboard users?

DD2 7:33
Oh alright.
The IDDM's strong emphasis on user analysis and task identification really pushed us to think from the users' perspective. The Canvas prompted us to clearly define who

would be using the dashboard, what their key questions were, and what actions they needed to take based on the information.

Ahadi Bin Mohd Nasir 7:56
Mm hmm.

DD2 8:02
This focus directly influenced our choices in terms of what data to include and how to present it, ensuring the final dashboard was much more tailored to their actual needs rather than just being a collection of data points.

Ahadi Bin Mohd Nasir 8:15
OK, alright.
The second question is, how did the method guide your choices for data selection and visualization techniques?

DD2 8:35
OK. In my opinion, The IDDM provided a solid framework for these crucial decisions. By first clearly defining the user needs and the dashboard's purpose , as guided by the initial sections, it naturally filtered the data we considered relevant.

Ahadi Bin Mohd Nasir 8:54
Mm hmm.

DD2 9:02
It naturally filtered the data we considered relevant because the methodology encourage us to think about the story we wanted to tell with the data, and then the selection of visualization that would effectively convey the story.

Ahadi Bin Mohd Nasir 9:06
Mm hmm.

DD2 9:19
to the specific audience. It wasn't just about picking fancy charts; it was about choosing the right visual representation to facilitate understanding and action. That particularly widely being used for the developer or designer, but it was about choosing the right visual to represent and and facilitate the user to understand and make action and decision.

Ahadi Bin Mohd Nasir 9:36
Mm hmm.
All right. OK. Throughout your experience, did the IDDM improve the overall quality and purposefulness of your final dashboard?

DD2 9:59
Absolutely, because I believe it did. By following the IDDM, the dashboard I developed felt more focused and intentional. It wasn't just visually appealing but it served a clear purpose in providing the right information to the right people at the right time. The methodology's structured approach helped us avoid potential pitfalls for example like

including irrelevant data or using confusing visualizations. The final result was a dashboard that felt more robust, user-centric, and ultimately more valuable.

Ahadi Bin Mohd Nasir 10:48
Thank you for the answer.
Alright, now we move on to section C, which focus on the completeness, OK.

DD2 10:58
OK.

Ahadi Bin Mohd Nasir 11:01
Were there any important aspect of dashboard design that you felt that IDDM Canvas did not adequately cover?

DD2 11:12
OK, this is a good question.
While the IDDM was quite comprehensive,
I felt that perhaps a bit more explicit guidance, especially on the iterative design process and use it, user feedback loops user feedback loops could have been beneficial.
While it implicitly encourages user focus, more emphasis on actively seeking and incorporating user feedback throughout the development lifecycle might strengthen it.
And also, while Information Governance is mentioned, perhaps a more detailed breakdown of how to practically implement those principles within the dashboard design itself could be useful.

Ahadi Bin Mohd Nasir 11:56
OK, alright, I see. OK. Did any part of the method you feel redundant or unnecessary in your workflow.

DD2 12:09
For this project, I didn't find any section to be completely redundant. Each step, even if it seemed pretty to be straightforward, prompted a level of conscious consideration that I think was valuable. However, depending on the complexity and scope of a future dashboard project,

Ahadi Bin Mohd Nasir 12:25
Mm hmm.

DD2 12:31
some of the initial user analysis steps might feel a bit less intensive if the target audience is already very well-defined and understood.

Ahadi Bin Mohd Nasir 12:38
Mm hmm.

DD2 12:42
It might be helpful to have some level of adaptability based on project scale.

Ahadi Bin Mohd Nasir 12:50
Right. I think just now you commented on information governance. So now the third question I would like to ask in is how well information governance principles incorporated in the IDDM canvas.

DD2 13:08
IG was touched upon within the Canvas, prompting consideration for data quality, security, and compliance. However, I felt it was more of a reminder to consider these aspects rather than a deep dive into practical implementation strategies. For someone new to Information Governance, the IDDM might not provide enough specific guidance on how to ensure these principles are truly embedded in the dashboard design and deployment process.

Ahadi Bin Mohd Nasir 13:37
Mm hmm.

DD2 13:38
Perhaps a dedicated section or more detailed prompts could enhance this aspect.

Ahadi Bin Mohd Nasir 13:39
Mm hmm.

Ahadi Bin Mohd Nasir 14:10
All right.
My next question is, how did using the IDDM compare to your previous dashboard design approaches?

DD2 14:19
OK.
Using the IDDM felt more structured and deliberate compared to my previous, often more ad-hoc, approaches.

Ahadi Bin Mohd Nasir 14:26
Mm hmm.

DD2 14:26
Basically ad hoc approach because in the past I might have jumped into data exploration more quickly by looking to add or probably a competitor, because the idea of forced a step back to really understand the why and The Who.

Ahadi Bin Mohd Nasir 14:41
Mm hmm.

DD2 14:44
In the past, I might have jumped into data exploration and visualization more quickly. The IDDM forced a step back to really understand the 'why' and the 'who' before the 'what' and 'how.' This resulted in a more thoughtful and user-centered design process.

Ahadi Bin Mohd Nasir 14:48
OK.

DD2 14:52
It felt less like just building a dashboard and more like designing a solution.

Ahadi Bin Mohd Nasir 15:06
All right. Did it influence your decision-making or workflow in any specific way?

DD2 15:13
Oh yes, it does. Because they made me more conscious of the user's tasks and the context in which they would be using the dashboard.

DD2 15:21
This directly influenced the types of visualizations I considered and the level of detail I included. It also made me more disciplined about documenting the design rationale at each stage, which is something I haven't always been consistent with in the past.

Ahadi Bin Mohd Nasir 15:30
Mm hmm.

DD2 15:37
It provided a clear framework for making design decisions based on user needs and business goals, rather than just personal preference or technical feasibility or for some fancy graphic.

Ahadi Bin Mohd Nasir 16:04
OK. All right.
Would you consider using the DDM methodology again for your future projects?

DD2 16:13
Sure, why not?
I would consider using the IDDM again. I found the structured approach and the emphasis on user-centricity to be very valuable.

Ahadi Bin Mohd Nasir 16:14
Mm hmm.

DD2 16:22
While I might adapt certain aspects based on the specific project requirements, the core principles and the Canvas itself provide a solid foundation for effective dashboard design. I think it has the potential to consistently lead to more impactful and user-friendly dashboards.

Ahadi Bin Mohd Nasir 16:33
Mm hmm.
All right, now we move on into section E, which is the challenges and limitation, which I think is very important.
I need your very honest opinion on the IDDM canvas.

DD2 16:50
OK.

Ahadi Bin Mohd Nasir 16:54
All right.
The first question is what were the main challenges or difficulties you encountered while applying the LDM?

DD2 16:55
OK.
The main challenge wasn't necessarily with the methodology itself, but rather with the initial effort required to thoroughly complete each section of the Canvas. It takes time and focused effort to really dig deep into user needs and define clear objectives

Ahadi Bin Mohd Nasir 17:42
Mm hmm.

DD2 17:47
In a fast-paced project environment, there might be a temptation to rush through these initial stages. However, I also realized that investing that time upfront ultimately saved time and rework later in the process. Another minor challenge was interpreting some of the sections in the context of our specific project – a few examples or templates within the Canvas might be helpful for different scenarios.

Ahadi Bin Mohd Nasir 18:04
Alright. Did any platform specific or project related limitation affect your experience?

DD2 18:14
To some extent, yes. The visualization capabilities of the specific platform we were using did influence some of our choices.
However, the IDDM Canvas helped us first identify the ideal visualizations—what we actually wanted to show—before evaluating how closely we could implement them within the platform's constraints.
I've also explored various platforms, and I found that some align more closely with the structure and logic of IDDM than others.

Ahadi Bin Mohd Nasir 18:42
Mm hmm.

DD2 18:47
Project timelines did put some pressure on the initial deep-dive into user research,
but we tried to adhere to the IDDM principles as much as possible within those constraints.

Ahadi Bin Mohd Nasir 19:18
So in your case, you're using Looker Studio, is it?

DD2 19:21
Yeah, I did. I prefer using Looker Studio because it's more user-friendly. When I want to teach users, it has intuitive and interactive features that help users understand things in a short time, rather than me using a complicated or programming-heavy platform.

Ahadi Bin Mohd Nasir 19:56
OK. In applying the IDDM, you helped me develop two distinct types of dashboards. The analytical dashboard and operational dashboard. So, in your opinion, how flexible do you think the IDDM is when applied to different types of dashboards?

DD2 20:11
OK. Actually, the dashboard clearly separates two sets of information.
The first one is the operational dashboard, and the second is the main dashboard, which is analytical.

Ahadi Bin Mohd Nasir 20:35
Analytics. Yeah.

DD2 20:36
Yeah. So, the operational dashboard focuses more on transactional data, where it shows a list of statistics and status updates.
While the analytical dashboard gives you more insight, basically, information that helps you make decisions and take quick action based on that data.

Ahadi Bin Mohd Nasir 21:06
Right.

DD2 21:06
That's the key difference between the two. But IDDM is quite clear in guiding the design process. It makes the steps easier to follow.
In fact, it's a good framework because, when using IDDM, it helps you pause and think through the core requirements, rather than just jumping straight into making visualisations.

Ahadi Bin Mohd Nasir 21:48
So what you mean is—it's really flexible?

DD2 21:56
Yes, in this case, I'd say it is. It allows flexibility, and it can be adapted depending on the dashboard's purpose.

Ahadi Bin Mohd Nasir 22:00
All right.

DD2 22:01
Oh.

Ahadi Bin Mohd Nasir 22:02
OK.
Now we move on to the last section.
The last section is on the suggested improvement.

DD2 22:12
OK.

Ahadi Bin Mohd Nasir 22:14
So, you've already used the IDDM Canvas to develop two mock-up dashboards. I'd like to ask, do you have any suggestions on what could be improved in the IDDM framework or the Canvas itself?

DD2 22:34
I think having more explicit guidance or examples for different project scales and types of dashboards would be beneficial, like a version of the Canvas tailored for smaller or less complex projects. Also, as I mentioned earlier, it would be good to expand the Information Governance (IG) section with more practical implementation tips and place more emphasis on it.

Ahadi Bin Mohd Nasir 22:52
Mm hmm.

DD2 22:57
Including sections about design and user feedback integration would also be valuable.
Maybe even a companion guide with templates or best practices for each part of the Canvas.

Ahadi Bin Mohd Nasir 23:03
Mm hmm.
OK.
Are there any additional features, sections, or tools you would like to see included in the Canvas?

DD2 23:21
A section or prompts specifically addressing accessibility considerations would be a great addition, ensuring dashboards are usable by everyone. Also, perhaps a section that encourages thinking about the dashboard's lifecycle and maintenance plan. Finally, some links to relevant resources or best-practice examples for different visualization types within the Canvas itself could be very helpful.

Ahadi Bin Mohd Nasir 23:34
OK. Noted.

DD2 23:34
Finally, some links to relevant resources or best-practice examples for different visualization types within the Canvas itself could be very helpful.

Ahadi Bin Mohd Nasir 23:44
Right.

Ahadi Bin Mohd Nasir 23:54
OK, I see . Alright, we move on to the final section, the overall assessment, OK. On a scale of one to 10, how would you rate the overall usefulness of the lDDM in your design process?

DD2 24:09
OK.
To be honest, I would rate the overall usefulness of the IDDM as an 8.5. It provided a valuable structure and a user-centric approach that significantly improved the quality and purposefulness of the dashboard we developed. The framework prompted thoughtful consideration of key design elements that might have been overlooked otherwise.

Ahadi Bin Mohd Nasir 24:16
OK.
Right.

Ahadi Bin Mohd Nasir 24:35
OK.
OK. Lastly, would you recommend this method to other dashboard designers? Why or why not?

DD2 24:47
Yes, I would definitely recommend the IDDM to other dashboard designers, especially those who are looking for a more structured and user-focused approach. It encourages a deeper understanding of the 'why' behind the dashboard, leading to more effective and impactful designs.

Ahadi Bin Mohd Nasir 24:56
Mm hmm.
Mm hmm.

DD2 25:03
While it requires an initial investment of time and effort to fully embrace, the benefits in terms of clarity, user satisfaction, and overall dashboard quality are well worth it. It's a methodology that helps you move beyond just displaying data to truly designing for understanding and action.

Ahadi Bin Mohd Nasir 25:54
OK, alhamdulillah.
That's all for the question.

DD2 25:58
OK, thank you, it was a good discussion.

Ahadi Bin Mohd Nasir 26:00
I won't take up more of your time. I know you're busy, and I truly appreciate you making time for this session.
If I have any follow-up questions, maybe we can set another short session.

DD2 26:20
Sure.

Ahadi Bin Mohd Nasir 26:25
From your answers just now, I'll process them together with feedback from two more respondents.
Then I'll do the thematic analysis. If there's anything I need to clarify, I'll reach out again.

DD2 26:25
Yeah, sure.

Ahadi Bin Mohd Nasir 26:34
Anyway, once again, thank you very much for your time. I really appreciate your feedback.

DD2 26:50
Thanks to you too.

Ahadi Bin Mohd Nasir stopped transcription

APPENDIX C

TRANSCRIPT OF INTERVIEW – WASTE MANAGEMENT EXPERT (WME)

May 19, 2025, 11:48AM

Ahadi Bin Mohd Nasir 0:18
OK. Can you hear me?

WME 0:20
Yes, I can.

Ahadi Bin Mohd Nasir 0:22
All right.
I hope you are doing well today and everything is going smoothly on your side.

WME 0:37
Everything is going well, and I hope that everything is well on your side as well.

Ahadi Bin Mohd Nasir 0:42
Thank you. Alright. First of all, thank you so much for making the time to participate in this interview. I know you have a packed schedule and I truly appreciate your willingness to support this research. I really value your role and experience in this industry, especially with your involvement in overseeing waste management operations at a broader, strategic level. Your input will add an important real-world layer to this evaluation.

WME 1:12
I'm pleased to help. Yup.

Ahadi Bin Mohd Nasir 1:14
All right. Thanks.
Alright, just to provide a bit of context. This session is part of my PhD research, which focuses on improving the way dashboards are designed in the context of smart waste management. As part of this study, I've developed a methodology called the IDDM Canvas,short for Information Dashboard Design Method. This method was used to guide the development of two mock-up dashboards under a conceptual system called i-MORSYS, which stands for Intelligent Monitoring Recycle System.
i-MORSYS was designed as a conceptual smart waste management system that visualises both operational and analytical data, focusing on recycling performance, carbon impact, and public awareness.

WME 1:28
OK.

Ahadi Bin Mohd Nasir 1:37
This method was used to guide the development of two mock-up dashboard. And a conceptual system called i-MORSYS which stand for intelligent monitoring recycle system. So i-MORSYS was designed as a conceptual waste management

system that visualizes both operational and analytical data, focusing on recycling performance, cover impact and public awareness.
Today's session is meant to gather your feedback on how relevant and practical these dashboards are from the perspective of someone deeply involved in the industry.
The session will be recorded purely for analysis purposes, and your identity will remain confidential. If there's any question you'd prefer to skip, just let me know.

WME 2:26
OK.
Thank you.

Ahadi Bin Mohd Nasir 2:30
Are you OK now?

WME 2:31
Yes, I am ready as ever.

Ahadi Bin Mohd Nasir 2:32
All right.
OK. So if you're ready, let's begin with a few general questions. So my first question is how well do current dashboard reflects the operational and strategic information needs of your organization?

WME 2:51
The dashboards are highly effective in delivering the relevant data and visual insights tailored to my organization's needs. The operational efficiency and strategic planning, more specifically, in the overall process of executing what is required. It is quite effective.
So operationally, for instance, they provide real-time and historical data on key variables such as collection, pickup locations, and frequency which help in assessing service performance and making quick adjustments where needed. Strategically, the dashboards offer time-series comparisons, trends by material type, and region-specific analysis that support long-term planning, policy formulation, and forecasting for recycling growth or potential efficiency improvements. This layered approach ensures that both frontline staff and decision-makers have the information they need at their respective levels.

Ahadi Bin Mohd Nasir 3:56
All right.
It's a good answer.
All right. We move to my next question.
Which dashboard features do you find most useful or most helpful for monitoring and reporting purposes?

WME 4:13
I find that what is most helpful from the dashboard features would most probably be the visualizations, such as the bar chart, spy charts, and trend graphs. Those are among the most helpful features because they provide a quick and clear understanding of any complex datasets.

So the ability to filter this data by, for instance, time, location, material type, and client categories would also allow me to dynamically interact with the dataset, thereby supporting ad-hoc analysis and generating customized reports for different audiences. In particular, features like tooltips, drill-down capabilities, and export options streamline the process of preparing internal and external reports.

Ahadi Bin Mohd Nasir 5:05
All right, throughout your experience, are there any areas where the dashboards fall short in delivering value to your day-to-day tasks?

WME 5:16
Well, I think that while the current dashboard provides very strong foundational metrics and visualization, I think it could benefit more from integration of more advanced technologies such as generative AI. This would allow users to interact with the dashboard using natural language queries, significantly improving data accessibility and interpretation, especially for non-technical staff. Furthermore, some domain-specific operational data such as vehicle availability, downtime, and maintenance schedules are not yet integrated, which could enhance daily task planning.

Ahadi Bin Mohd Nasir 6:01
All right.
Thank you for your answer.
I think we have completed the three questions on the section A focusing on dashboard relevance and utility. All right, we move to section B, if you're OK.
All right, so it should be particularly on domain specific metrics.
All right.
My first question, does the dashboard include key indicators that are commonly used in waste management? For example, CO2 collection with and also material breakdown.

WME 6:32
Yes, I would say that the dashboard successfully incorporates key performance indicators. That is very much relevant to the waste management industry. These include the CO2 equivalent metrics for tracking carbon emission reductions, which are very critical for environmental, social governance, reporting, and compliance. Apart from that, recyclables collection volume data helps assess both operational throughput and environmental impact. The material breakdown categories allow for strategic analysis of recyclable flows, source separation effectiveness, and material recovery potential. These indicators form the backbone of performance measurement in recycling and sustainability programs.
The source separation effectiveness and the material recovery potential which is vital for business development within this area. These indicators form the backbone of performance measurement in recycling and sustainability programs.

Ahadi Bin Mohd Nasir 7:31
We move to the next question. Second question ,and domain-specific metrics alright. Are there any critical domain-specific metrics that are missing or underrepresented?

WME 7:47
I would think yes, absolutely. There are certain specific metrics that are missing or underrepresented.
So I would say that to make the dashboard more useful, I think there are a few key metrics that we could add, things like vehicle tracking and feed efficiency, which would include fuel usage, the truck idle time, and optimization of routes, can really help to add more domain specific metrics in waste management.
It would also be available to track the inventory of recyclable materials at different stages, like what is being collected in real time, what is being sorted, and what is being processed. On top of that, including contamination rates and rejected loads can improve quality control. And finally, having data on labor efficiency, broken down by facility or route, would provide even more insight. Bringing all of this together would really boost operational decision-making and increase transparency throughout the entire waste management process.

Ahadi Bin Mohd Nasir 9:08
All right. We move on to the third question and the domain-specific metric section. All right. How reliable or trustworthy do you find the way these metrics are visualised?

WME 9:22
So, to me, I think the current visualizations look quite good.
They are certainly accurate and clearly laid out, which really helps get the message across. That said, how people interpret them can depend a lot on how familiar they are with the data and the specific terms being used. The matrix themselves are solid, but to make the dashboards easier for any person to understand, no matter what their role is, I think it would add things like interpretive guides, definitions, and clear thresholds, like benchmarks or color-coded KPIs. That way, the insights are more accessible to a wider audience.

Ahadi Bin Mohd Nasir 10:09
All right.
Thank you.
OK.
We move on to the next section, Section C, on the interpretability and clarity.
OK. My first question at the dashboard is it to interpret for users at different levels, for example, field staf, managers and policy makers?

WME 10:31
It's an interesting question since I believe that interpretability is largely dependent on the specific uses, domain expertise rather than their specific roles.
So for example, if a field staff member is familiar with the collection, weight and routing data, I think they may understand certain visuals better than a policy maker. However, more strategic summaries such as performance trends or system metric might be more accessible to the upper management. So, a well-structured dashboard with clearly labelled sections and tooltips would improve usability across all levels. no matter what their domain expertise is.

Ahadi Bin Mohd Nasir 11:20
OK, based on the two mock-up dashboards that I've shown to you, right, do you find the layout and visual elements intuitive and informative?

WME 11:35
Mostly yes, the dashboard elements are thoughtfully designed and I would say it is generally intuitive for users with moderate tech proficiency. So, the layout I see it supports the logical flow of information, and certain dynamic elements, such as the filters and zoom options, enhance the user experience even further.
Nevertheless, additional onboarding or tool tips, as I have mentioned before would also help first users, particularly if they come from outside the waste management domain. There is a balance to strike; overly simplifying the interface could limit depth and flexibility, while overcomplicating it could overwhelm users. If we overcomplicate the dashboard, it may also overwhelm the users.

Ahadi Bin Mohd Nasir 12:31
OK. Would this dashboard support rapid understanding or require training for proper interpretation?

WME 12:40
Most certainly, I think a baseline at least level of training is recommended, especially for stakeholders or users who are not deeply involved in the daily operations or new hires. Of course, it really depends on the capability of the individual and how I would say tech savvy the person is.

Ahadi Bin Mohd Nasir 13:01
Mm hmm.

WME 13:02
And most probably those who regularly engage with waste management data can most certainly derive insight straight away with little to no training. So integrating a short user guide or embedded help function would further support wider usability and would make the dashboard usable for a larger audience.

Ahadi Bin Mohd Nasir 13:26
OK. We are now in Section D, where the question is focusing on adoption and integration.
So the first question under this section is, how likely is it that this dashboard could be adopted within your department or organization?

WME 13:45
I would say that the adoption likelihood is extremely high since the dashboard is still, I guess, for the waste management industry.
So the dashboard is well aligned with our department responsibilities, which include tracking recycling outputs, the environmental impact, and aligning all the data with the sustainability goals of the company.
It also provides an efficient means of monitoring key performance indicators and generating necessary reports.

Ahadi Bin Mohd Nasir 14:20
All right, in your opinion, are they compatible with current workflows, data systems, or performance tracking mechanisms?

WME 14:28
I would say yes. The dashboards align well with existing workflows and data infrastructure. Since they handle the extraction, transformation, and loading process within the system, they reduce the burden on staff who would otherwise spend significant time cleaning and preparing the data manually. They can be integrated with current enterprise resource planning or geographic information system platforms with minimal adjustments.

Ahadi Bin Mohd Nasir 15:08
All right. In your opinion, what factors would support or hinder the integration of this dashboard into the existing operation?

WME 15:16
In terms of integrating these dashboards into existing operations, a few key factors could really help.
First, I think that a user-friendly interface and clear visuals would make adoption easier, and automating the data processing can save a lot of time.
It's also important that the dashboard works smoothly with current data platforms, so the performance of the hardware that supports the system is quite important as well.
On the other hand, there are some things that could get in the way.
For instance, I believe that legacy systems might not export data easily, or they may use formats that don't play well with the new dashboards.
Staff who are used to traditional methods might also resist the change, especially when transitioning to more advanced dashboard systems.

Ahadi Bin Mohd Nasir 15:52
Mm hmm.

WME 16:11
And there could also be a learning curve for new users.
So, to make the integration successful, it is going to be essential to have strong IT support and a good change management plan in place.

Ahadi Bin Mohd Nasir 16:23
Alright, now we move on to the next section, Sustainability and Compliance, under Section E. Do the dashboards support compliance-related reporting or regulatory submissions?

WME 16:41
Yes, I believe that the inclusion of CO_2 equivalent emissions, the weight of recyclables, and related key performance indicators enables organizations to prepare reports for sustainability standards, according to internationally renowned standards such as GRI, CDP, or other ESG-related investor communications.

Scope 1 emissions, which are direct emissions; Scope 2 emissions, which are indirect energy emissions; and Scope 3, covering upstream or downstream value chain data, can also be tracked more effectively within the current dashboard structure.

Ahadi Bin Mohd Nasir 17:21
OK. In your opinion, how well do these dashboards reflect the environmental targets or sustainability KPIs that your organisation is currently tracking?

WME 17:31
I would say that the dashboards are well equipped to reflect environmental key performance indicators, such as the volume of recyclables diverted from landfill, the CO_2 equivalent saved from emitting into the atmosphere, the reduction in fuel usage, and the optimization of vehicle routes.
These help evaluate performance against internal goals as well as external compliance benchmarks.

Ahadi Bin Mohd Nasir 17:58
Alright. Could the dashboards help promote sustainability awareness among internal teams or external stakeholders?

WME 18:05
Absolutely. I think that by visualizing the impact of the data, such as resources saved, emissions reduced, or the tonnage of recyclables collected, the dashboards can instill a sense of contribution and purpose among staff.
This can be further enhanced by integrating vehicle tracking, route efficiency maps, or geospatial information systems (GIS) overlays, which help teams visualise the scope of their efforts.
Features like friendly competition, performance benchmarking, and internal recognition can also reinforce engagement and motivation.

Ahadi Bin Mohd Nasir 18:41
OK. Now we move on to the final section, Section F: Overall Assessment.
So, the first question is: How would you rate the dashboards overall in terms of their usefulness and alignment with the needs of the waste management industry?

WME 18:59
I would confidently rate the dashboards 9 out of 10.
I think they are well-aligned with current industry requirements in terms of metrics coverage, interface functionality, and reporting capacity.
They effectively combine operational visibility with strategic foresight, which I believe is absolutely essential for modern waste and sustainability management.

Ahadi Bin Mohd Nasir 19:30
Alright.
Would you recommend these dashboards for wider use across the waste management sector?

WME 19:37
Yes, absolutely, without hesitation. I think that the dashboards have strong potential to support organizations in achieving operational efficiency, regulatory compliance, and environmental stewardship.
The modularity and ability to present complex data in a digestible format make them adaptable to various scales, for instance, from municipalities using them for performance benchmarking, to private operators generating reports as evidence of task completion.

Ahadi Bin Mohd Nasir 20:24
OK, this is my last question.
Since the dashboard I showed you is just a mock-up dashboard, not a fully functional one, in your opinion, what sort of improvements or refinements would you suggest to make it more impactful?

WME 20:43
I would most probably suggest adding more customization options.
For example, we could incorporate corporate branding through different colour schemes and company logos, to better align with the internal design standards of each organization.

Ahadi Bin Mohd Nasir 20:58
Mm hmm.

WME 21:00
It would also help make the dashboards more marketable and visually presentable for companies.
Additionally, aligning the design with corporate branding standards can enhance professionalism and stakeholder engagement.

Ahadi Bin Mohd Nasir 21:10
All right.

WME 21:11
We can also incorporate accessibility enhancements to cater to a wider demographic, especially individuals with disabilities.
This can include features such as larger text options, high-contrast visuals, and screen reader compatibility to support inclusivity.

Ahadi Bin Mohd Nasir 21:26
Mm hmm.

WME 21:35
Apart from that, multi-language support would help scale the dashboards across different regions and make them suitable for use by international organizations.

Ahadi Bin Mohd Nasir 21:48
Alhamdulillah, that concludes our session today.

I won't hold you any longer.
I truly understand how tight your schedule must be, and I sincerely appreciate you making the time for this interview.
Your perspective as someone directly involved in the field is extremely valuable.
What you've shared here will go a long way in helping me validate and refine this methodology.

WME 22:08
It is my pleasure to assist you with the interview.

Ahadi Bin Mohd Nasir 22:12
Alright, definitely.
What we've shared today will go a long way in helping me validate and refine this method so that it can truly meet the needs of practitioners in the real world.
So, once again, thank you for your insights, your honesty, and your support for this research.
I genuinely hope our paths cross again in the future, insha'Allah, perhaps when this work evolves into something even more impactful for the industry.

WME 22:34
Huh.

Ahadi Bin Mohd Nasir 22:39
Wishing you continued success in all your efforts and projects.

WME 22:45
Thank you very much as well.
It's been a pleasure to be part of this interview, and I wish you all the best in your research and in completing your PhD, insha' Allah.
Thank you.

Ahadi Bin Mohd Nasir 22:56
Thank you very much.

WME 22:57
Welcome.

Ahadi Bin Mohd Nasir stopped transcription