VIRTUAL REALITY DASHBOARD DESIGN METHOD: AN ONTOLOGICAL APPROACH

LIEW KOK LEONG

UNIVERSITI KEBANGSAAN MALAYSIA

VIRTUAL REALITY DASHBOARD DESIGN METHOD: AN ONTOLOGICAL APPROACH

LIEW KOK LEONG

THESIS SUBMITTED IN FULFILMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

INSTITUTE OF VISUAL INFORMATICS
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2025

REKA BENTUK PAPAN PEMUKA REALITI MAYA: PENDEKATAN ONTOLOGI

LIEW KOK LEONG

TESIS YANG DIKEMUKAKAN UNTUK MEMPEROLEH
IJAZAH DOKTOR FALSAFAH

INSTITUT INFORMATIK VISUAL
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*	Liew Kok Leong
No. Pendaftaran *Registration No.*	P119039
Fakulti/Institut *Faculty/Institute*	Institut Informatik Visual (IVI)
Program Pengajian *Program of Study*	Sarjana / **Doktor Falsafah** | *Masters* / ***Doctor of Philosophy***
Tajuk Tesis *Thesis Title*	Virtual Reality Dashboard Design Method: An Ontological Approach
Mel-e/*Email*: p119039@siswa.ukm.edu.my	No. Telefon/*Tel.No:* 012-3931809

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: 11 Nov 2025

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

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

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

Tandatangan Penyelia / *Supervisor's Signature*:

Nama / *Name*:

Cop Rasmi / *Official Stamp*:

Tarikh / Date: 12.11.2025

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

Tandatangan/*Signature*:

Nama/*Name*:

Tarikh/*Date*: 20/11/2025

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.

24 November 2025

LIEW KOK LEONG
P119039

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude to Associate Professor Dr. Mohammad Nazir Ahmad, my main supervisor and Co-Supervisor Dr. Ummul Hanan Binti Mohamad, for their invaluable guidance, support, and encouragement throughout this research journey. Especially on their expertise, insightful feedback, and unwavering patience have been instrumental in shaping this thesis. I am truly grateful for the time and effort he dedicated to mentoring me, and for constantly inspiring me to push the boundaries of my work.

I would also like to extend my sincere appreciation to the Institute of Visual Informatics (IVI), Universiti Kebangsaan Malaysia, for providing a conducive research environment and access to cutting-edge facilities that have been essential in completing this study. The collaborative atmosphere and knowledge-sharing opportunities at IVI have significantly enriched my research experience.

Special thanks go to ARB Berhad for their support and contribution during the practical phases of this project. Their provision of technical resources and insights into industry applications of immersive technologies have added immense value to the development and validation of the VR Dashboard Design Method (VRDDM). The collaboration has allowed this research to maintain a strong connection with real-world challenges and solutions.

Lastly, I am profoundly grateful to my family and friends for their unwavering support and understanding during this long and demanding journey. Their encouragement has been my source of strength during the most challenging phases of this thesis.

To all who have contributed in ways big and small, directly or indirectly, your support has been a cornerstone of this accomplishment.

ABSTRAK

Pemantauan pertanian pintar telah menjadi cabaran global yang kompleks, memerlukan pendekatan sistematik untuk mengekalkan dan memantau hasil pertanian berkualiti tinggi. Walaupun banyak kajian telah meneroka sistem pertanian pintar dengan menggunakan teknologi seperti IoT, pembelajaran mesin, dan data besar, terdapat jurang yang ketara dalam penyelidikan yang memfokuskan kepada papan pemuka Realiti Maya (VR) untuk tujuan pemantauan, terutamanya dalam pertanian pintar. Kajian ini menangani ketiadaan pendekatan bersatu dalam reka bentuk papan pemuka VR dengan memperkenalkan Kaedah Reka Bentuk Papan Pemuka Realiti Maya (VRDDM) sebagai penyelesaian alternatif untuk meningkatkan penggunaan atau fungsi sistem pemantauan pertanian pintar. Masalah ini berpunca daripada kekurangan kaedah standard dalam reka bentuk papan pemuka VR dalam pertanian pintar dan keperluan yang lebih meluas untuk kaedah reka bentuk papan pemuka VR yang bersatu dalam pelbagai domain. Kajian ini menggunakan Metodologi Penyelidikan Reka Bentuk Sains (DSRM) dengan inspirasi daripada Business Model Ontology (BMO) untuk membangunkan VRDDM, yang menjadi sumbangan utama. Selain itu, teori Perspektif Psikologi Ekologi (EPP) turut disertakan untuk melengkapkan kerangka konsep VRDDM. Kaedah ini berasaskan kepada kajian naratif literatur sedia ada, mengenal pasti kesamaan dalam pelbagai karya berkaitan reka bentuk papan pemuka. Kesamaan ini diformalkan ke dalam Ontologi Reka Bentuk Papan Pemuka Realiti Maya (VRDDO) menggunakan Pendekatan Ontologi Bersatu (UOA), menyediakan kerangka berstruktur untuk merangkumi prinsip reka bentuk yang dikenalpasti. Prototip papan pemuka untuk pemantauan pertanian pintar dibangunkan menggunakan VRDDM untuk menunjukkan aplikasi praktikalnya. Fasa penilaian melibatkan maklum balas daripada pihak berkepentingan, termasuk cadangan untuk metrik tambahan dan penambahbaikan utiliti, untuk memperhalusi dan meningkatkan kaedah secara iteratif. Kajian ini menyumbang dengan mempermudah pendekatan ontologi standard untuk reka bentuk dan pembangunan papan pemuka VR, merasionalisasikan proses dan menghapuskan amalan ad-hoc. Pembangunan VRDDM didasari oleh asas teori kukuh EPP yang dimanfaatkan oleh UOA, BMO, dan Unified Foundational Ontology (UFO). Hasil penggunaan VRDDM menawarkan bantuan teori dan praktikal kepada pembangun ICT untuk lebih memahami reka bentuk dan pembangunan papan pemuka VR daripada perspektif ontologi serta mempromosikan perkongsian pengetahuan, kegunaan semula, dan membolehkan evolusi pengetahuan yang berstruktur dalam bidang pengetahuan VR.

ABSTRACT

Smart farming monitoring has become a complex global challenge, necessitating systematic approaches to maintain and monitor high-quality agricultural produce. While numerous studies have explored smart farming systems, leveraging technologies like IoT, machine learning, and big data, there remains a significant gap in research focused on Virtual Reality (VR) dashboards for monitoring purposes, particularly in smart agriculture. This study addresses the absence of a unified approach in VR dashboard design by introducing the Virtual Reality Dashboard Design Method (VRDDM) as an alternative solution to enhance the utilization or function of smart farming monitoring systems. The problem stems from the lack of a standardized method for designing VR dashboards in smart farming and the broader need for a unified VR dashboard design method across domains. Limited attention has been given to establishing a standardized design methodology, especially within the context of smart farming. This study employs the Design Science Research Methodology (DSRM) with inspiration from the Business Model Ontology (BMO) to develop the VRDDM, which serves as the main contribution. Additionally, Ecological Psychological Perspective (EPP) theory is incorporated to further supplement the VRDDM conceptual framework. The method is based on a narrative review of existing literature, identifying commonalities across various dashboard design-related works. These commonalities are formalized into the Virtual Reality Dashboard Design Ontology (VRDDO) using a Unified Ontological Approach (UOA), providing a structured framework to encapsulate the identified design principles. A prototype dashboard for smart farming monitoring is developed using the VRDDM to demonstrate its practical application. The evaluation phase involves soliciting feedback from stakeholders, including suggestions for additional metrics and utility improvements, to iteratively refine and enhance the method. This research contributes by facilitating a standardized ontological approach to VR dashboard design and development, streamlining the process and eliminating ad-hoc practices. The development of the VRDDM is governed by a strong theoretical foundation of EPP that are leveraged by UOA, BMO, and Unified Foundational Ontology (UFO). The results of VRDDM utilization offer theoretical and practical helps for ICT developer to better understand the VR Dashboard Design and Development from ontological lens and promoting knowledge sharing, reuse and enabling structured knowledge evolution in the VR body of knowledge.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ANOVA	Analysis of Variance
BMC	Business Model Canvas
BMO	Business Model Ontology
DSR	Design Science Research
DSRM	Design Science Research Methodology
EEG	Electroencephalogram Tracker
EPP	Ecological Psychology Perspective
GEN AI	Generative Artificial Intelligence
ICT	Information Computer Technology
IR 4.0	Fourth Industrial Revolution
IoT	Internet of Things
MMT	Musk Melon Terengganu
NLR	Narrative Literature Review
OD101	Ontology Development 101
ODM	Ontology Development Methods
POC	Proofs of Concept
RO	Research Objectives
RQ	Research Questions
SDG	Sustainable Development Goals
UFO	Unified Foundational Ontology
UI	User Interface
UML	Unified Modelling Language
UOA	Unified Ontological Approach
UX	User Experience
VP	Visual Paradigm
VR	Virtual Reality

VRD1	VR Dashboard Designer
VRDDM	Virtual Reality Dashboard Design Method
VRDDO	Virtual Reality Dashboard Design Ontology
VRDev1	VR Dashboard Developer

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

The average age of farmers has increased, and the number of farmers has decreased. However, only some young people are willing to participate in agriculture. New strategies for farming are an urgent need. Techniques like robotics, artificial intelligence, and virtual reality (VR) are introduced to agriculture to reduce labour needs and boost yields simultaneously. VR is a computer-generated technique in a simulated environment to bring auditory and visual experiences to people. It has been a hot spot of technology at home and abroad and is integrated into information science. As the VR technique has developed into a more advanced and mature process, it has had many applications in gaming, entertainment, medicine, education, military, and agriculture. Even now, more and more concepts and applications to use in agriculture to improve farming efficiency are being discussed. Agriculture equipment is always expensive in some undeveloped countries, which farmers cannot afford. However, VR is cheaper than most current agricultural technologies because it does not need substantial technical maintenance support. It uses a simple user interface and great immersive technology. More and more people, especially the young generations, are excited to participate in the VR experience. Overall, a dashboard in agriculture is promising and could improve its practices manifold.

A VR dashboard is a digital platform that provides users with a range of customisable. Interactive data visualisations and analytical tools in a VR environment. This dashboard can give users a more immersive and interactive way to analyse and interact with data. Here are some of the benefits of using a VR dashboard:

a. Increased engagement: VR technology can provide a more engaging and immersive experience than traditional dashboards, improving users' motivation to explore and interact with data.

b. Improved data analysis: VR dashboards can offer users more advanced data visualisation tools, allowing them to analyse complex data sets in new and innovative ways. This can lead to improved insights and better decision-making.

c. Enhanced collaboration: VR dashboards can provide a collaborative environment where users can analyse and interpret data in real-time.

d. Customisable and flexible: VR are highly customisable, allowing users to create the environment and visualisation that suit their needs.

e. Accessibility: VR dashboards can be accessed from anywhere worldwide, making it easy for teams and individuals to collaborate on projects in real-time.

In summary, VR dashboards provide a more engaging, collaborative, and innovative way to interact with data. As VR technology advances, the potential applications for VR dashboards are likely to expand, making them a powerful tool for data analysis and decision-making in various fields.

1.2 RESEARCH BACKGROUND

The demand for food, especially in developing countries, is increasing along with the income level of these countries (Phasinam et al. 2022). As a developing and agricultural country, Malaysia is struggling with insufficient food production for its people. Local Malaysian newspapers have reported that the Malaysian government had to import food worth RM63.6 billion last year. This is due to the lack of machinery to cultivate suitable and quality agricultural land and seeds. Other factors affecting uncultivated agricultural land are its remote location in the interior, infrastructure such as roads to access the farm, significant capital needed for fertiliser costs, labour, and control from wildlife attacks. It is reported that there are 103,000 hectares of idle land throughout Malaysia, which could fulfil the food supply demands of Malaysians if the land were to be fully utilised (Aida et al. 2022; Isa 2022; Wahid 2022). Furthermore, farmers who actively cultivate farmlands face various challenges in ensuring that results support a more sustainable life. Among the challenges farmers face are the lack of water, low water quality, limited yields, unpredictable climate, less suitable land for cultivation, and an undisciplined workforce. Agriculture is a great challenge, especially for small-scale farmers (Phasinam et al. 2022; Said Mohamed et al. 2021). Moreover, smart farming still needs to be widely implemented, especially in developing countries like Malaysia.

Only a few farmers have taken several initiatives to apply information communication technology (ICT) in agriculture. An innovative fertigation system for chilly crops has been built in collaboration between corporate companies and local farmers' organisations. The system uses Internet of Things (IoT) technology to measure the concentration of fertiliser, and the quantity of irrigation water, record the humidity and temperature of the crop and perform pesticide management. Farmers can access the recorded data via smartphones without going to the farm. This initiative has yielded higher profits than traditional cultivation methods (Kamisan 2020; MDEC 2020; Verdouw et al 2021).

1.3 MOTIVATION

A significant transformation in agriculture is essential to increase the country's gross domestic product by taking the opportunity from the era of the technological rise of the Industrial Revolution (IR4.0) to address the issue of traditional farming monitoring by utilising ICT technology in agriculture such as drones, IoT, and VR monitoring (Aida et al. 2022; MDEC 2020; Rakhra et al. 2022). VR monitoring dashboards have been implemented in China for learning and training purposes to ensure that farming culture can be sustained for a young generation (Cheng et al. 2018; Ye et al. 2018). Thus, VR helps farmers understand the best suitable crops for their fields and how to monitor them by visualising data for monitoring purposes. This situation shows that a VR dashboard design is significant, especially in agriculture.

1.3.1 Intersection Key Areas

Figure 1.1 illustrates the intersection of three critical domains that form the foundation of this research. The convergence of Virtual Reality Dashboard Design Method (VRDDM), Ontology Engineering, and smart farming monitoring issues represents the core focus area of this study. Smart farming has evolved into a sophisticated domain where agricultural producers face mounting challenges in monitoring crop quality, environmental conditions, and resource utilization. Traditional monitoring approaches often fall short in providing the immersive, intuitive visualization needed for complex agricultural data streams generated by IoT sensors, machine learning algorithms, and big data analytics. The integration of VR technology offers unprecedented opportunities to transform how farmers and agricultural managers interact with monitoring systems, enabling spatial understanding of farm conditions and real-time decision-making capabilities.

The dashed circle representing "Ontology-based VRDDM" emerges as the primary artifact of this research, synthesizing knowledge from all three domains. This ontology-driven approach addresses the critical gap in standardized VR dashboard design methodologies specific to agricultural monitoring contexts. By grounding the VRDDM in ontological principles through the Unified Ontological Approach (UOA) and drawing inspiration from Business Model Ontology (BMO), this research establishes a systematic framework that moves beyond ad-hoc design practices, ensuring consistency, knowledge reusability, and structured evolution in VR dashboard development for smart farming applications.

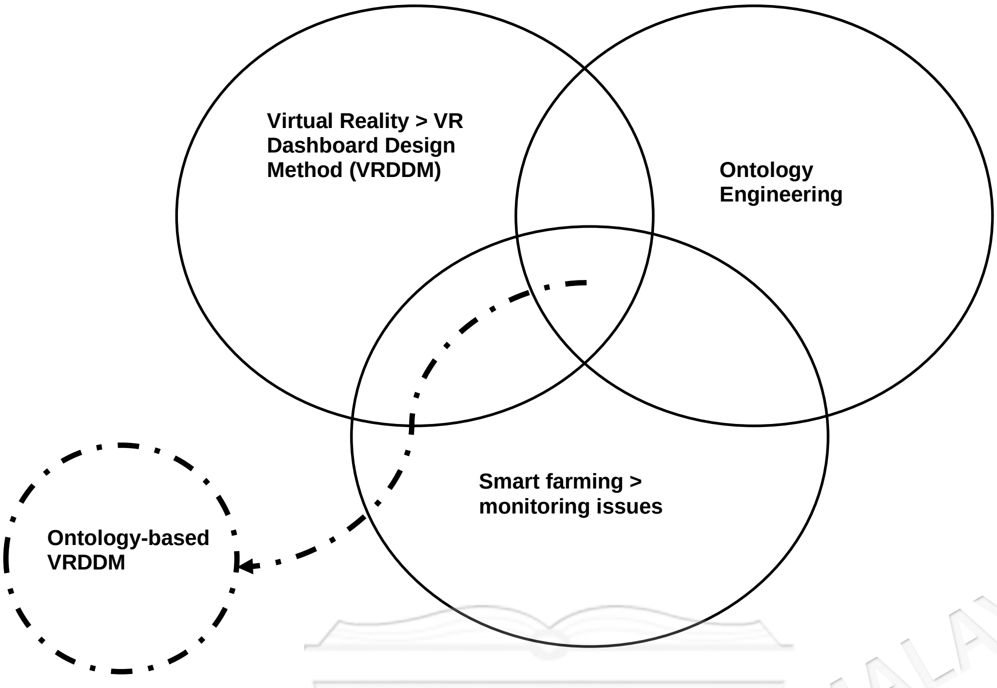


Figure 1.1 Intersection Key Areas

1.4 PROBLEM STATEMENT

Many previous researchers have focused on how ICT can help in sustainability and meet the challenges in agriculture through monitoring and controlling various agricultural parameters. Kaburuan et al. (2019) proposed IoT for automated indoor micro-climate horticulture, focusing on parameters such as temperature, humidity, and light intensity to optimize growing conditions. Verdouw et al. (2021) presented digital twins in smart farming based on IoT for farm management, enabling farmers to remotely monitor operational parameters including equipment status, resource allocation, and real-time farm activities. Dubois et al. (2021) designed a forecasting model based on machine learning using supervised learning algorithms in the irrigation of potato crops, identifying soil moisture levels, weather patterns, and crop water requirements as key parameters for irrigation optimization. Durai and Shamili (2022) proposed Smart Farming using Machine Learning and Deep Learning Techniques to predict outcomes based on parameters such as soil conditions, crop health indicators, and environmental factors, thereby reducing manual labour and boosting farm productivity. Furthermore, Roukh et al. (2020) utilized big data that facilitates IoT, drones, and farm monitoring as data-driven farming, integrating parameters across multiple sources including aerial imagery, sensor networks, and yield data.

However, although postulated by many previous studies on the advantages of implementing ICT technology or smart farming (Durai & Shamili, 2022), there has still been no research that highlights the monitoring methods in smart agriculture, mainly using a VR dashboard. The study of VR dashboards mainly focuses on several perspectives. For example, Arjun et al. (2022) developed 2D and 3D dashboards in smart manufacturing to investigate how users interpret the information in the dashboards. Mukhopadhyay et al. (2022) used a 3D dashboard to mimic an office to measure social distance to prevent COVID-19 dissemination.

Meanwhile, Weidner and Broll (2022) investigated traffic situations using a 3D dashboard for a better perspective. Setti and Csapo (2021) focused on building 2D spaces in 3D environments, and a study by Lutters and Damgrave (2019) helped the decision-making process in manufacturing by using a VR dashboard to present real-time situations in a production environment. Bartosh and Gu (2019) used VR technology to improve the existing prototype of street view. The health domain also takes advantage of the VR dashboard, as Vock et al. (2021) highlighted in their study on the potential of health-tracking applications. Millais et al. (2018) also studied a VR dashboard in data exploration to compare user favoritism between 3D and 2D dashboards. The potential of position tracking also has been given a specialty by Baltabayev et al. (2018) for using VR technology combined with sensors in their study.

Therefore, as summarised, based on the previous studies on VR dashboards, none of these studies focusing on VR dashboard monitoring have given attention to the method of designing VR dashboard monitoring in smart farming. Monitoring the crop is critical because yields without careful supervision will result in high losses. However, the monitoring process is challenging when it involves large or isolated crop fields (Roukh et al. 2020). Many costs are at stake to monitor a large farm, such as the cost of workers and dealing with the various attitudes of the workers, soil fertility, irrigation, and even control of insects and pests. The problem is that there needs to be a standard method for designing a VR dashboard in the smart farming field, in particular, and it is necessary to have a unified version of the VR Dashboard Design Method in general; thus, designing a VR dashboard can be simplified and hassle-free. Therefore, this study aims to ensure a standard (unification) method for constructing VR dashboards to be crafted and applied for innovative farming monitoring purposes.

Verdouw et al. (2021) presented digital twins in smart farming based on IoT for farm management, which enables farmers to remotely manage their farms‘ operations. Durai and Shamili (2022) proposed Smart Farming using Machine Learning and Deep Learning techniques, which can predict the outcomes based on collected data to reduce manual labour and boost the productivity of the farms. Monitoring the crop is critical because yields without careful supervision will result in high losses. However, the monitoring process is challenging when it involves large or isolated crop fields (Roukh et al. 2020). Many costs are at stake to monitor a large farm, such as the cost of workers and dealing with the various attitudes of the workers, soil fertility, irrigation, and even control of insects and pests. With the advent of the 4IR era, VR dashboards have become a new way to visualize the monitoring aspects of the farm. Unfortunately, related works on designing VR dashboards such as those reported in (Arjun et al. 2022; Mukhopadhyay et al. 2022; Weidner & Broll 2022; Setti & Csapo 2021; Lutters & Damgrave 2019; Bartosh & Gu 2019; Vock et al. 2021; Millais et al. 2018; Baltabayev et al. 2018; Yoo et al. 2018; Heinemann et al. 2024; Lei et al. 2022) are not standard, are based on an ad-hoc manner, and do not clearly convey on how the VR dashboards were designed in a systematic way. The problem is that, there needs to be a standard method for designing a VR dashboard in the smart farming field, in particular, and it is necessary to have a unified version of the VR Dashboard Design Method (VRDDM for short), in general; and thus, designing a VR dashboard can then be simplified and hassle-free.

1.5 RESEARCH QUESTIONS

Derived from the identified problem, the questions of this study are presented below:

1. Question 1: What key knowledge domains are critical for designing a functional VR dashboard in data-intensive environments?

2. Question 2: How can an ontological framework be proposed to systematically organize the knowledge necessary for designing functional VR dashboard?

3. Question 3: How design method can be applied to create VR dashboard that functionally monitor and visualize precision agriculture data?

1.6 RESEARCH OBJECTIVES

Motivated by the factors discussed in the problem statement section above, the following VR dashboard design objectives should be met to answer the research questions:

1. Objective 1: To identify the fundamental knowledge domains essential for developing an adequate method for designing functional virtual reality dashboards.

2. Objective 2: To propose an adequate ontological framework that systematizes the knowledge required for designing virtual reality dashboards.

3. Objective 3: To apply a design method for creating virtual reality dashboards that functionally monitor and visualize precision agriculture data and evaluate its effectiveness via feedback from VR developer and VR designer.

1.7 RESEARCH SCOPE

The scope of this study is divided into several elements:

a. This study involves designing and developing a VRDDM framework based on ontological representation for VR technology to monitor crops.

b. This research methodology is rooted in the design science research methodology, whereby this paradigm is well received and recognised by researchers in the information system discipline.

c. The developed VR dashboard for monitoring smart farming will be tested for the VRDDM framework.

d. The quantitative or qualitative method used is more for evaluating the VRDDM framework and VR Dashboard or prototype of the VR system developed in the study; it is not the main methodology used in the thesis study.

1.7.1 Research Strategy Diagram

The scope of this study is illustrated in our research strategy diagram, which is rooted in a common Design Science Research process model given by Peffers et al. (2008), as shown in Figure 1.2. The research strategy diagram presented in Figure 1.2 illustrates the conceptual flow and methodological framework of this study, providing a clear visual representation of how each phase contributes to achieving the research objectives. Rooted in the widely recognized Design Science Research (DSR) process model proposed by Peffers et al. (2008), this diagram adapts and extends the original framework to reflect the unique requirements of this study. Specifically, it integrates ontological development, immersive system prototyping, and iterative validation, aligning these activities within the context of precision agriculture and virtual reality (VR) dashboard design. By mapping the stages and interconnections visually, the figure serves as a roadmap guiding the research process from problem identification to artefact evaluation and knowledge dissemination.

The diagram begins with problem identification and motivation, the foundational phase of the DSR cycle. Here, the study identifies critical gaps in existing literature and practices related to VR dashboard design for smart farming. Existing approaches are often fragmented, ad hoc, and lack a systematic methodology for incorporating user-centered design principles in immersive environments. This phase establishes the rationale for developing a new methodological framework, VR Dashboard Design Method (VRDDM) and its supporting ontology (VRDDO). The problem space is contextualized within the broader themes of digital transformation in agriculture and the need for actionable, immersive data visualization tools to enhance decision-making among farmers and agronomists.

Following this, the definition of objectives for a solution takes center stage. In this phase, the research specifies clear, actionable objectives derived from the problem analysis and literature review. These objectives include identifying critical knowledge domains for VR dashboard design, developing an ontological framework to organize this knowledge systematically, and applying a design method for creating functional VR dashboards. The objectives are not only theoretically grounded but also validated through initial consultations with subject matter experts in VR development and precision agriculture. These consultations help refine the scope, ensuring relevance and feasibility in real-world applications.

The design and development phase occupies a central role in Figure 1.2, reflecting its importance within the DSR paradigm. Here, the VRDDO is first conceptualized and developed by synthesizing insights from prior VR application studies (VRdash01–VRdash12) and incorporating theoretical foundations such as Ecological Psychology and the Unified Ontological Approach. The ontology structures key concepts, relationships, and processes necessary for VR dashboard design, serving as a semantic backbone for the subsequent development of VRDDM. The VRDDM then operationalizes these concepts into a practical framework guiding designers through the creation of immersive dashboards. This framework addresses multiple aspects, including UI/UX design principles for 2D and 3D spaces, interaction design processes, data visualization strategies, and storyboarding techniques.

An important addition in this phase is the integration of Generative AI tools to support rapid prototyping and visualization. By using AI-assisted storyboarding, the research enhances the efficiency and creativity of the design process, allowing for early validation of conceptual models before full-scale development. This integration represents a novel methodological contribution, demonstrating how AI can complement human creativity in immersive system design.

The demonstration phase is where the artefacts are instantiated in real-world scenarios. The study develops two Proof-of-Concepts (PoC1 and PoC2) as operational embodiments of VRDDM. PoC1 offers a holistic view of smart farming sensor data, while PoC2 focuses on selective, sensor-specific data visualization for granular analysis. These PoCs are tested in controlled environments with actual users, including VR designers and developers, to assess their usability, functionality, and alignment with user needs. This iterative process allows for refinement and ensures that the artefacts are not only theoretically sound but also practically viable.

Next, the evaluation phase systematically assesses the artefacts against predefined metrics derived from design science principles. This includes evaluating VRDDO's semantic consistency, VRDDM's methodological usability, and the PoCs' functional effectiveness in immersive data visualization. The evaluation involves both qualitative and quantitative methods, including expert interviews, heuristic evaluations, and user feedback analysis. These methods ensure a comprehensive understanding of the artefacts' strengths and limitations, feeding back into potential revisions for improved alignment with the research objectives.

The final stage in the diagram is communication, emphasizing the dissemination of findings through academic publications, conferences, and practitioner-oriented channels. By sharing the outcomes, the study contributes to the broader DSR community and informs practitioners seeking to implement similar solutions in other domains. Communication also involves translating the artefacts into reusable design patterns and guidelines, ensuring their applicability beyond the immediate context of smart farming.

Figure 1.2 highlights the iterative nature of this process. Arrows looping back from evaluation to design signify the feedback-driven refinements that characterize effective DSR. This cyclical flow embodies the principle of continuous improvement, allowing each iteration to build upon the insights of the previous cycle. Furthermore, the diagram includes parallel tracks for theoretical development (VRDDO) and practical implementation (PoCs), illustrating the study's commitment to balancing rigour and relevance.

Overall, the research strategy diagram not only visualizes the methodological flow but also reflects the layered contributions of this study. It demonstrates how foundational theory (ontology), operational frameworks (VRDDM), and applied artefacts (PoCs) are interwoven into a cohesive research strategy. This alignment ensures that the study addresses both academic and practical gaps, advancing knowledge in immersive system design while delivering tools that directly benefit stakeholders in precision agriculture.

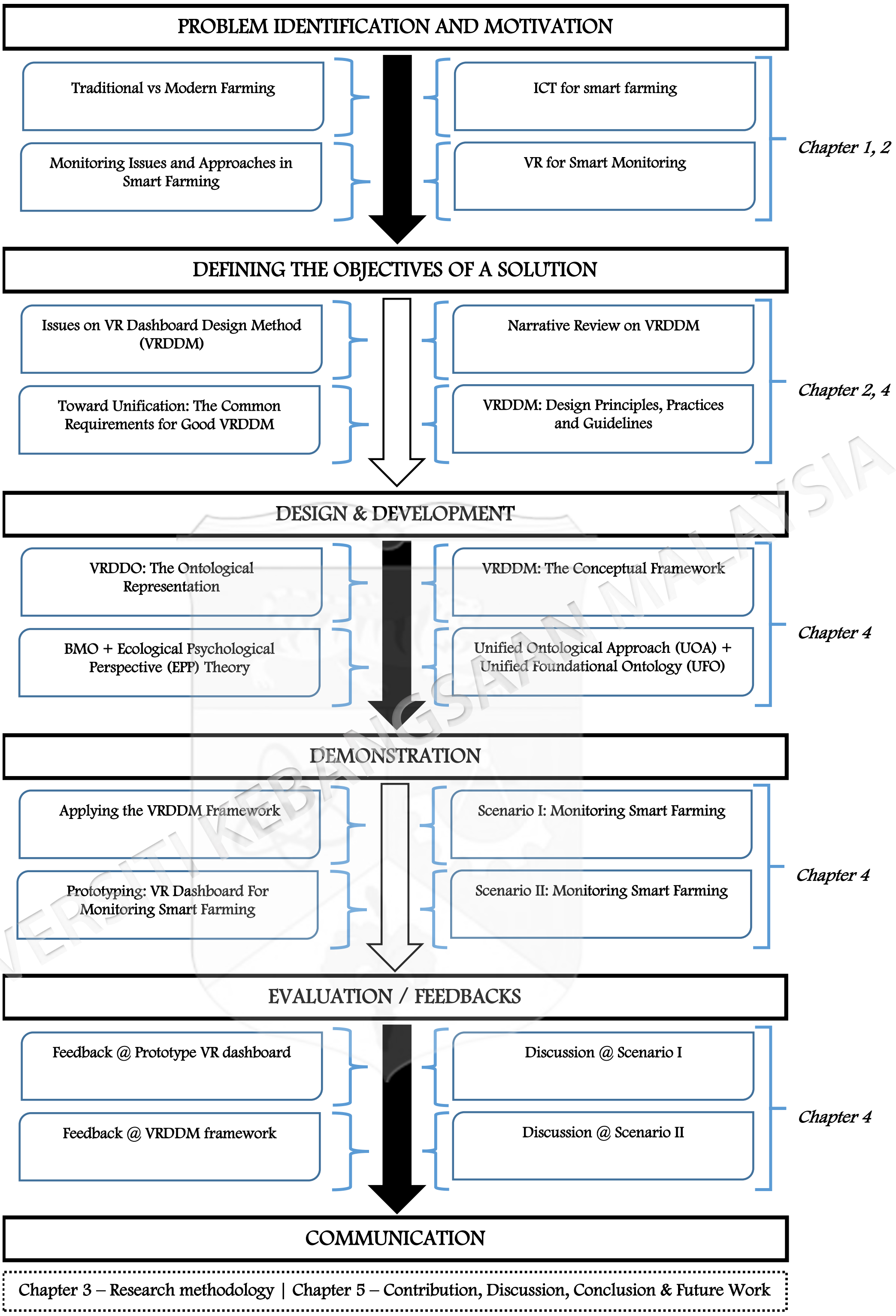


Figure 1.2 Research strategy diagram

1.8 THESIS OUTLINE

The remaining part of this thesis is organised in Table 1.1 as follows:

Table 1.1 Thesis outline

Chapters	**Title and Summary**
Chapter 2	*Literature Review* This chapter presents and discusses the prior research related to this study. Most recent studies associated with the research area are analysed to motivate the investigation of the study.
Chapter 3	*Research Methodology* Part I: Overview of Design Science Research Methodology Chapter 3, Part I gives introductory and basic knowledge on design science research methodology in the Information Systems discipline. *Part 1I: Application of Design Science Research Methodology* Chapter 3, Part II discusses the methodology used or its application to conduct the study, including the research approach to be used and a step-by-step description of the research design.
Chapter 4	*Part 1: Design & Development of VR Dashboard Design Method* In Part I, Chapter 4 designs and develops the VR dashboard method for monitoring smart farming using appropriate design tools guided by some common design principles and best practices such as VR UI/UIX principles. *Part II: Demonstration & Evaluation of VR Dashboard Design Method* In Part II, Chapter 4 evaluates the outcomes from Chapter 4 in multiple scenarios.
Chapter 5	*Discussion and Future Work*

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

Agriculture is the world's largest food supply industry. As reported by Kc et al. (2018), by 2050, world food production will increase by up to 70% to meet the needs of the world’s population. Yet farmers often struggle with various challenges from the environment (e.g., pest attacks, droughts or floods) or human management issues (i.e., workers). This causes farmers to suffer often losses that affect the world's food supply production. If this continues, it will reduce the food supply, affecting the global food supply crisis. Therefore, farmers need to switch to ICT technologies to increase productivity and to be more effective, such as by adopting intelligent farming.

Smart farming is a new era in farming streaming in the growing IT world. Innovative farming technology driven by robotics, automation, analytical data, and IoT promises lucrative returns to farmers. This is because the technology used is more efficient, and saves some resources such as fertilisers and pesticides, helps make decisions, and reduces staff expenses. In Section 2.2, an in-depth past study discussion on traditional versus modern agriculture will be presented. Section 2.3 and the sub-sections below will discuss ICT involvement in intelligent farming, ICT methods, issues and approaches, and conclusions. Meanwhile, Section 2.4 and the sub-sections within will highlight the past studies related to VR dashboards to answer the research questions raised. In Section 2.5, a brief discussion is presented about ontology and finally, Section 2.6 summarizes all sections under Section 2.2 until Section 2.5.

2.2 AGRICULTURE: TRADITIONAL VS MODERN

Traditional farming has been practised since ancient times to ensure food production. This method of cultivation depends on fertilisers, pest control, and various other requirements to ensure maximum production, which is highly dependent on the knowledge and experience of the farmer. Farming is a significant sector in Malaysia and around the world. The farming landscape has also changed according to the current era's changes to secure the agricultural industry's sustainability by moving into smart farming. According to El Chami et al. (2020), to ensure the sustainability of the agricultural sector, it must fulfil the following criteria; (i) meet human needs through production, (ii) be economically competitive, and (iii) preserve the environment for the long term. Table 2.1 summarises innovative farming technology studied by previous researchers to draw attention to how technology has transformed agriculture.

Table 2.1 Smart farming technology research year 2022-2019

Smart farming technology	Aim	References
Machine learning and deep learning	Predict the total cost needed for cultivation	(Durai & Shamili, 2022)
Sensor-based irrigation	Real-time monitoring to facilitate in decision making process	(Sarpal et al., 2022)
Big data technologies, IoT and knowledge-based system	Forecasting and prediction	(Alwis et al., 2022)
Artificial intelligent (AI) and IoT	Predict ad auto-optimise microalgae smart farming process	(Lim et al., 2022)
Blockchain, and IoT	Balance energy consumption and parameters of atmospheric conditions in greenhouse	(Jamil et al., 2022)
Fuzzy logic, and IoT	Smart system to enhance productivity for low-cost outdoor oyster mushroom farms	(Thong-un & Wongsaroj, 2022)
IoT	Identifying red palm weevil larvae to protect date palm trees at early stage of infestation	(Esmail Karar et al., 2022)
IoT, and machine learning	Framework for detecting and classifying intrusions into IoT networks used in agriculture	(Raghuvanshi et al., 2022)
Internet of Things (IoT)	Real-time digital information monitoring	(Verdouw et al., 2021)
Robot, and automation	Smart seed sewing robot for farming activities	(Kumar & Ashok, 2021)
Blockchain, IoT, AI, deep learning	Assist cultivators with data collection, processing, monitoring, and making correct decisions on the farm	(R. Kumar et al., 2021)
Machine learning	Smart water irrigation monitoring	(Dubois et al., 2021)
Smart monitoring sensor	Real-time weight prediction to support related decisions for smart production monitoring	(Wang et al., 2021)
IoT	Monitoring humidity temperature, and soil moisture for farming activities.	(Podder et al., 2021)
IoT, and data analytics	Implement smart farming system based on three-layered architecture (agriculture perception, edge computing, and data analytics)	(Rodríguez et al., 2021)
Gas-sensing array	Pesticide use on agricultural product	(Skotadis et al., 2020)
Cloud-based management system	Smart farming management system	(Roukh et al., 2020)
Big data	Improved in particular livestock production, animals' welfare, and farming processes	(Fote et al., 2020)
Big data	Plant health sensing (nitrogen requirement)	(Yang et al., 2020)
IoT	Monitoring farming conditions	(Doshi et al., 2019)
Blockchain, and fuzzy logic	Smart consumption of water in small, medium-scale gardens and fields.	(Munir et al., 2019)
IoT	The monitoring system of performance of indoor micro-climate horticulture	(Kaburuan et al., 2019)

2.3 INFORMATION COMMUNICATION TECHNOLOGY (ICT) FOR PRECISION AGRICULTURE (SMART FARMING)

Information Communication Technology (ICT) has emerged as a transformative force in agriculture, enabling the transition from conventional farming practices to precision agriculture, commonly referred to as smart farming. By integrating advanced digital tools and systems, ICT supports data-driven decision-making that enhances productivity, resource efficiency, and sustainability. As illustrated in Table 2.1, ICT applications in agriculture encompass diverse areas such as remote sensing, geographic information systems (GIS), Internet of Things (IoT) devices, and data analytics platforms. These technologies facilitate real-time monitoring of soil health, crop growth, weather conditions, and resource usage, empowering farmers with actionable insights for informed interventions.

The adoption of ICT in agriculture also addresses critical challenges, including labor shortages, climate variability, and the need for sustainable resource management. However, despite these advancements, several issues persist in monitoring systems, including data fragmentation, lack of interoperability, and limited user-friendly interfaces, which are further elaborated in Section 2.3.1. Recognizing these challenges, recent studies have explored immersive technologies such as Virtual Reality (VR) as potential solutions. Section 2.3.2 delves into the role of VR in smart farming monitoring, highlighting its potential to revolutionize user interactions with complex agricultural data through immersive visualization and intuitive dashboard designs.

2.3.1 Monitoring Issues and Approaches in Smart Farming: A Review

Many farmers face difficulties in monitoring the crops or livestock on their farms due to various constraints, especially those living in rural areas. However, the help of a combination of sensors or IoT and cloud technology can help solve the problem of monitoring in rural areas (Sarpal et al. 2022; Verdouw et al. 2021). Pest attacks are a significant problem for farmers. Excessive use of pesticides and water can destroy crops, leading to huge losses. Therefore, farmers often face problems ensuring suitable pesticide spraying and crop irrigation. With the help of monitoring data obtained from the analysis of various factors, farmers can make the right decisions regarding the maintenance of their farms (Doshi et al. 2019; Dubois et al. 2021; Kumar et al. 2021; Podder et al. 2021). Changes in weather and soil acidity also contribute to the ups and downs in farming faced by farmers. Farmers must ensure the appropriate time and soil conditions for the cultivation process to ensure maximum yield. This problem can be overcome with IoT-based monitoring and machine learning that can inform in advance about the weather and soil conditions (Kaburuan et al. 2019). Combining ICT technology and VR technology will enable the development of agricultural research to be done more effectively and perfectly. The following sections discuss the study of VR technology conducted in agriculture.

2.3.2 Using Virtual Reality (VR) for Monitoring Smart Farming Conditions

Virtual Reality (VR) technology is emerging as a promising tool for monitoring and managing agricultural operations, offering immersive visualization capabilities that overlap with other ICT technologies such as drones, artificial intelligence (AI), the Internet of Things (IoT), and advanced data analytics (Agrawal et al. 2023). These integrated systems create a rich ecosystem where real-time data from sensors, drones, and IoT devices can be visualized in 3D environments, allowing farmers to monitor crop conditions, soil health, weather patterns, and resource utilization in a more intuitive and engaging manner.

Although Kumari et al. (2022) acknowledge that VR systems can be costly to implement in agricultural settings, the long-term benefits often outweigh the initial investment. Crimaldi et al. (2021) emphasize that modern farmers are increasingly willing to invest in such technologies to gain competitive advantages and improve operational efficiency compared to traditional farm management practices. The immersive nature of VR offers users a sense of proximity to their data, transforming abstract information into tangible visual experiences that facilitate better understanding and faster decision-making.

Despite its potential, research on the use of VR specifically for agricultural monitoring remains limited. Most existing studies focus on training, education, or simulation applications in agriculture, leaving a gap in exploring VR as a monitoring tool for precision farming. This underlines the need for further investigation into how VR dashboards can be designed to enhance user experience (UX) and usability for farmers, especially in contexts where rapid response to environmental changes is crucial. By placing users closer to their data through immersive visualization, VR holds the potential to revolutionize monitoring practices in smart farming and support more sustainable and informed agricultural management.

2.3.3 Conclusion

Based on the discussions in Sections 2.3.1 and 2.3.2, it is evident that the application of Virtual Reality (VR) within the realm of smart farming is still in its infancy, with limited studies exploring its full potential for agricultural monitoring and management. While ICT technologies such as IoT, AI, and drones have been extensively applied to support precision agriculture, the integration of VR remains relatively underexplored, particularly in the development of user-centered interfaces for real-time data visualization and decision-making. This gap presents significant opportunities for researchers to investigate innovative ways to harness VR’s immersive capabilities to address challenges in smart farming, such as complex data interpretation and user engagement. The next section will therefore shift focus to a broader review of design methods for VR dashboards, encompassing diverse application domains including, but not limited to, agriculture to identify transferable principles and inform the development of effective VR dashboard frameworks.

2.4 VIRTUAL REALITY (VR) DASHBOARD DESIGN METHODS: A REVIEW

VR dashboards are popular information dashboards in visual analytics. These dashboards provide valuable information for the end-user to monitor, analyse, and make decisions (Ma & Millet 2021). In this respect, Subotin (2019) emphasises that the fundamental intention of a dashboard is to create accessible compounded data that is easier to understand for the user. Therefore, the interface introduces the data to be clean and uncomplicated to minimise users’ cognitive load and time spent searching. Subotin (2019) also postulates that the essential characteristics of an effective dashboard are (i) communicating information quickly, (ii) displaying information clearly and efficiently,

(iii) showing trends and changes in data over time, (iv) being easily customisable, and (v) presenting important widgets and data components effectively in a limited space. An effective dashboard design also has to be guided by (i) project goals, (ii) the nature of the data, and (iii) the needs of the users.

Huang et al. (2022) describe VR as the artificial creation of a three-dimensional environment assisted by computer systems and sensor technology. In this artificial three-dimensional environment, every object, including the user himself, has a position and posture relative to the coordinate system. VR aims to mimic and interact naturally and physically through a particular interface where users can organise data spatially and build a 3D representation of the data, holding and examining it as they do in the physical world. In today's world, users can also interact with data to interpret the data, such as using map applications. However, VR applications, such as the user’s living room, are usually bounded by space. Therefore, using a VR walker is an alternative to solve this problem, but this approach causes a cognitive burden on the user (Rauschnabel et al. 2022). This VR dashboard immerses technology and raises the remarkable evolution in the field of the illustrative world as it has a great prospect as a solution in more advanced surveillance, which could save the company's future costs by investing in VR technology (Harz et al. 2021). Some studies also indicate that VR can save lives by providing a virtual view before the actual process occurs (Masullo et al. 2022; Muñoz et al. 2022; Vankov et al. 2021).

Regrettably, despite all studies highlighting the cruciality of dashboard design, the conclusions of past studies on VR dashboard design show that the details of how the dashboards are developed, such as the methods or common approaches used, are not distinctly reported. Most studies focus on the benefit of VR in facilitating users in daily work or life without emphasising how the VR dashboard is developed in detail. Therefore, this section investigates commonalities and shared components that are essential requirements for a VR-based dashboard to answer the research questions raised in Chapter 1 (Section 1.5). The identified needs are crucial when proposing a VR Dashboard Design Method (VRDDM). To identify those requirements, this section attempts to answer the following questions:

1. Are there any existing standard best practices in the current VRDDM? What are the key steps in VRDDM?

2. Are any tools, diagrams, or techniques used in the existing VRDDM?

3. What is the application domain reported in the current VRDDM? Are there any UI (User Interface) /UX (User Experience) design principles or factors adopted in VRDDM?

4. What are the current links between the theory and practice of VRDDM?

Within five years, many studies have been using VR to assist daily life in various fields. Nevertheless, only a few studies in VR technology discuss monitoring dashboards using built-in VR technology. The following section discusses 12 research papers related to VR technology-based dashboard monitoring, as shown in Table 2.2, to answer the above question.

Table 2.2 Studies in VR dashboard

References and Acronym	Best Practice	Key Steps	Tools/ Algorithms/Techniques	Domain	UI/UAX principles	Theory/Practice adopted
Arjun et al. (2022) VRdash01	None	<u>Develop 2D dashboard</u> 1. Preliminary study on how users interpret the graphs 2. Collect and analyse data 3. Clustering algorithms 4. Develop software for four visualisation techniques and five sets of questions <u>Develop 3D dashboard</u> 1. Design and conduct user study using six types of visualisation techniques 2. Develop and set up a VR environment of six charts and a set of four questions. Arrange sensor/nodes according to the axis for all six charts 3. Describe algorithms for analysing gaze-based metrics and cognitive load 4. Calculate fixation and saccade 5. Investigate three types of revisit sequences	<u>Develop 2D dashboard</u> **Tools** • Digital twin sensor • Tobii Eye-X tracker **Techniques** • Analysis of Variance (ANOVA) • Steichen's study **Algorithms** • Expectation-Maximation <u>Develop 3D dashboard</u> • **Tools** • HTC Vive Pro Eye • EmotivBCI • Emotiv Insight EEG tracker • Unity3D game engine • NASA TLX • SUS questionnaire • Digital twin sensor **Techniques** • Velocity threshold	Smart factory	• Scale • Visual hierarchy • Balance • Contrast • Gestalt	Fitt's Law

… to be continued

… continuation

		6. Analyse two parameters of revisit sequences 7. Divide pupil dilation into sections	fixation identification method • Digital Signal Processing Least square fit Coefficient of determination • ANOVA **Algorithms** • Butterworth lowpass filter			
Mukhopadhyay et al. (2022) VRdash02	None	1. Set up each room with IoT sensors and cameras 2. Replicate material in meeting room in the twin 3. Develop 3D and set up VR environment using Unity3D 4. Configure interactive dashboard inside a VR workspace simulator 5. 2D coordinates are mapped to 3D coordinates of the virtual world using ray cast operation 6. Map sensors with weather properties 7. Render 4096 frames to generate a single frame 8. Investigate two different types of visualising techniques 9. Prepare dataset	**Tools** • Digital twin sensor • Unity3D • YOLOv3 • Probuilder • ProGrids • TurboSquid • Sketchfab • Physical based rendering • Post-Processing of Unity • NavMeshAgents of Unity • User Data Protocol • Real-time streaming protocol • Mixamo • UnrealROX	Health	• Scale • Visual hierarchy • Balance • Contrast • Gestalt	Convolutional neural network (CNN) model

… to be continued

… continuation

		10. Modelling digital twin based on five dimensions 11. Visualise performance in both real and synthetically generated images 12. Visualise heatmaps of the class activation 13. Test synthetic image with different parameters	• Keras • ILSVRC dataset **Algorithms** • Path tracing algorithm of Unity • ReLU • VAE **Technique** • CNN visualisation • Grad-CAM based visualisation • Baked global illumination (GI) • Punn's study • Realtime GI • ParallelEye dataset • Variable autocoders • Generative adversarial network (GAN) • SinGAN • Transfer learning technique • VGG16			
Weidner and Broll (2022) VRdash03	None	1. Perform pre-study to gain information about surrounding 2. Setup driving simulation environment - car mock-up	**Tools** • Unreal Engine 4.18.3 & 4.22.3(UE4) • Driving simulation software (STISIM)	Vehicle	• Scale • Visual hierarchy • Balance	None

… to be continued

… continuation

		3. Design preliminary TOR visualisation to mimic current traffic situation 4. Participants who took a seat in the simulators were encouraged to think aloud during drive and give attention to the dashboard 5. Collect and analyse participants' comments	• volfoni Edge RF glasses • volfoni ActivHub RF50 • Optitrack Motive • NASA TLX • DALI **Techniques** • ANOVA **Algorithms** • Mean Pupil Diameter Change Raye (MPDCR) • Mean Blink Duration Change (MPDC)		• Contrast • Gestalt	
Setti and Csapo (2021) VRdash04	Workflow Process	None	**Tools** • MaxWhere	Training and education	• Scale • Visual hierarchy • Balance • Contrast • Gestalt	None
Lutters and Damgrave (2019) VRdash05	Digital system references	None	**Tools** • Digital twins • Digital master • Digital prototype	Manufacturing	• Scale • Visual hierarchy • Balance • Contrast • Gestalt	None
Bartosh and Gu (2019)	Multi-scalar visualisation	1. Modelling city digitally by generating using GIS tools	**Tools** • GIS tools	Smart City	• Scale • Visual	None

… to be continued

… continuation

VRdash06		(ESRI CityEngine) 2. Visualising 3D city model using Unity3D Tools and SteamVR 3. Collecting urban data from open-source urban data (NYC Open Data website) 4. Mapping urban data in 2D and spatialised urban data for 3D visualisation 5. Designing UI using Google Earth VR and using Unity3D for interactive UI	• Unity3D tools • SteamVR • Google Earth VR		• Visual hierarchy • Balance • Contrast • Gestalt	
Vock et al. (2021) VRdash07	Combining immersive AR HMD and smart phone	1. Interview with focus group and gain insight from prior work 2. Designing Interactive Dashboard in Augmented Reality (IDIAR) for supervising mobile invention study 3. Adopt multimodal interaction approach using head gaze and touch; head gaze and voice; and touch input. 4. Collect data in user study in user training phase by using IDIAR on HMD and smart phone 5. Simulate actual work practice	**Tools** • Microsoft HoloLens (Augmented Reality HMD) • Unity3D • TeamViewer **Technique** • Multimodal interaction techniques • Cross-device Interaction technique	Health	• Scale • Visual hierarchy • Balance • Contrast • Gestalt	None

… to be continued

… continuation

		as tasks and detect irregularities, error handling, and definition of data-based rules				
Millais et al. (2018) VRdash08	Workload and insight-based evaluation	1. Two VR data visualisations are created based on prior study – 'Be the Data' and 'Parallel Planes' for android smart phones 2. VR Be the Data – the concept is transposing a data point into VR environment based on Chen at al.'s study 3. VR Parallel Planes – based on Brunhart-Lupo et al.'s work, whereby an additional data dimension is added in the z-axis to create parallel coordinates visualisation 4. Conduct initial training stage with 16 participants introduced to 'think-aloud protocol' and to verbalise their thoughts, actions, and any insight produced through the process. 5. The participants explore the data visualisation tool without time constraints 6. Replace different datasets in	**Tools** • Google DayDream VR • Unity3D • NASA TLX **Technique** • ANOVA	Miscellaneous	• Scale • Visual hierarchy • Balance • Contrast	Be the Data Parallel coordinates visualisation

… to be continued

… continuation

		main stage for each participant and repeat the process as in training stage 7. All participants use unweighted version of NASA TLX Questionnaire to measure the task workload 8. Analyse data by transcribing and coding the transcript of think aloud from the participants 9. Measure TLX questionnaire with two-way ANOVA for main effects of medium using ‘Correct’ and ‘Incorrect’ codes			•	
Baltabayev et al. (2018) VRdash09	Immersive movement analysis	1. Develop two prototypes – SensorTagVR and Visensor/VR 2. SensorTagVR- • Collect data by using Texas Instruments SimpleLink Bluetooth low energy/Multi-standard SensorTag CC2650STK sensor (e.g., object temperature, humidity, pressure, acceleration and light-density) in VR cardboard	**Tools** • WebGL • Google Earth • Google Cardboard	Environmental	• Scale • Visual hierarchy • Balance • Contrast	Immersive analytics

… to be continued

… continuation

		• Bluetooth controller (VR-Sensorpark) to control user view in 3D • Raspberry Pi is used to position indoor tracking and transforming the devices into WiFi hotspots • Data in 2D app (android) is transferred to 3D website using WebGL 3. Visensor/VR – Visensor/VR app is used in Samsung Galaxy S6 smartphone to focus on measurement and comparison of luminance. • Three.js is used to load OBJ model, construct the plane and define the camera. • Kalman filter is used to filter statistical noise in a series of measurements				
Yoo et al.(2018) VRdash10	VR Body-Map	1. 11 participants given Pebble watch to track their incidental steps and Polar H7 heart rate monitor when playing VR games 2. The data gathered from	**Tools** • JavaScript-based generator • D3 JavaScript library **Techniques** • Quadratic Gosper Curve	Health	• Scale • Visual hierarchy • Balance • Contrast	L-systems

… to be continued

… continuation

		participants we studied for over 8 weeks 3. The data used to illustrate design space and also assumes the availability of Kinect data from game play to record whole body movement data 4. Calendar layout is used to indicate when participants played VR 5. A Lindenmayer system (L-system) is used to produce a compact timeline to shows the intensity of physical activity of the participants				
Heinemann et al. (2024) VRdash 11	VR Learning Analytics	• RePiX VR enhances computer graphics education through virtual reality technology. • VR tool teaches rendering pipeline core concepts effectively to novices. • Learning analytics and usability evaluations show positive outcomes for learners.	• RePiX VR tool for computer graphics education focuses on rendering pipeline. • xAPI statements used for learning behavior analysis in CG courses. • Multimodal learning analytics (MMLA) used to analyze pedagogical strategies. • Inductive approach applied to derive models	Academic/ Learning Tool	• Scale • Visual hierarchy • Balance • Contrast	Agile approach with periodic tests used for tool development.

… to be continued

… continuation

			from qualitative and quantitative data.			
Lei et al. (2022) VRdash 12	Intelligent manufacturing of art and design.	1. VR in smart manufacturing reviewed using PRISMA guidelines. 2. VR applications in intelligent manufacturing.	• Digital human models (DHMs) for virtual manufacturing. Big data-driven innovation for intelligent decision-making in manufacturing	Intelligent Manufacturing	• Scale • Balance	Smart manufacturing theory integrated with virtual. reality for practical applications

The acronym in Table 2.2 is used as the subsection in the discussion which is guided by the questions listed above.

2.4.1 VRdash01

The VR technology contributes to manufacturing by investigating how users interpret information from various graph topologies to produce dashboards featuring 2D and 3D visual modules based on Fitts' Law theory, as shown in a study by Arjun et al. (2022). The built-in 2D dimensional dashboard will evaluate different visual strategies based on user views. At the same time, the 3D dashboard is loaded with embedded IoT modules showing data sensors and investigating multimodal interactions with VR systems. As a result of 2D dashboard development, a new technique has been created to analyse gaze data based on soft clustering using the Expectation- Maximization (EM) algorithm. The steps in constructing 2D dashboard visualisation are made with a preliminary study of how the user interprets the information from the different graphs. The location of the view is taken using Tobii Eye-X as an eye-tracker to analyse the user's attention on the graph section using the EM algorithm and XB cluster validation index.

The results show that the bar graph with the highest accuracy and broader area has the lowest response time while performing the task. To build 3D dashboards, primitive graphical charts were compared and conducted in a VR environment. Comparisons were performed with six different 3D graph visualisation techniques consisting of two types of graphs and five visual variables. Gaze-based data and pupil diameters were collected using HTC Vive Pro Eye and the Emotive Insight EEG trackers to collect electroencephalogram tracker (EEG) data. The VR scene environment is set up using the Unity 3D engine, whereby the scene consists of a visualisation chart and four sets of questions. The target of this 3D dashboard is to differentiate visual, haptic, and multimodal feedback in a VR environment. Figure 2.1 illustrates the dashboard of bar graph and 2D visualisation.

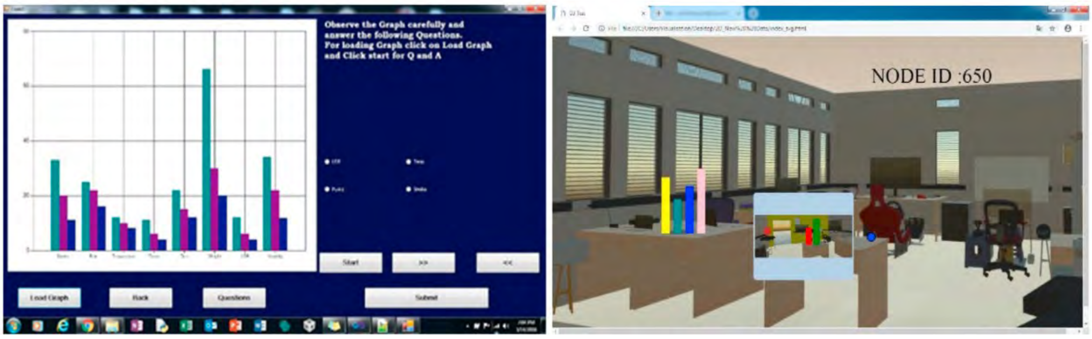


Figure 2.1 Dashboard of bar graph and 2D visualisation

2.4.2 VRdash02

A new method of digitally modelling twin existing office spaces and creating data sets consisting of individual data of different clothing postures and locations to generate custom data sets was proposed in the COVID-19 situation. Mukhopadhyay et al. (2022) developed an interactive dashboard based on data collected through sensors that would automatically indicate incarceration to prevent COVID-19 transmission. The interactive dashboard would display real-time total COVID-19 infection statistics at the placement site and measure the number of people in the space and their relative position and posture. The dashboard also displays temperature and humidity of the room that is measured using a DHT-11 sensor.

The study used a convolutional neural network (CNN) model to simulate humanoid figures. To calculate the distance between humanoids, bound box references generated by YOLO based on a study by Punn were used, with the addition of a VGG16 classification model pretrained with the ILSVRC ImageNet dataset. The data was prepared by recording various short video scenarios in the physical and virtual environments. 9000 images were tested and classified according to three classifications: authentic images, synthetic images generated without ray tracing, and synthetic images generated with ray tracing. VR environments were built using Unity 3D tools for ray tracing. Meanwhile, NavMesh Agents of Unity were used for behaviour detection purposes. Figure 2.2 shows the dashboard of VR modelled the office space.

Figure 2.2 Dashboard VR model of the office space

2.4.3 VRdash03

A quick response is critical when a dangerous traffic situation occurs when taking over control of the vehicle's automation. There is a moment when situation awareness (SA) needs to take over the takeover request (TOR), which will determine the risk of an accident if the time is longer. Weidner and Broll (2022) simulated a stereoscopic 3D display (S3D) to better understand the traffic scenario than with a 2D display. This study used participants who did not have a driving-related task to further strengthen the results. Vehicle-to-vehicle (V2V) simulation was used to show the relative location of other vehicles in the form of icons.

The S3D display also shows a better 3D perspective because it can increase the sense of pressure in a real traffic situation. An in-depth analysis was conducted on the participants' behaviors and views, and the influence of the new visualization on their mental workload. This is to determine if the new technology has significant side effects in addition to potentially affecting the performance of the takeover. The 3D driving simulator is shows in Figure 2.3.

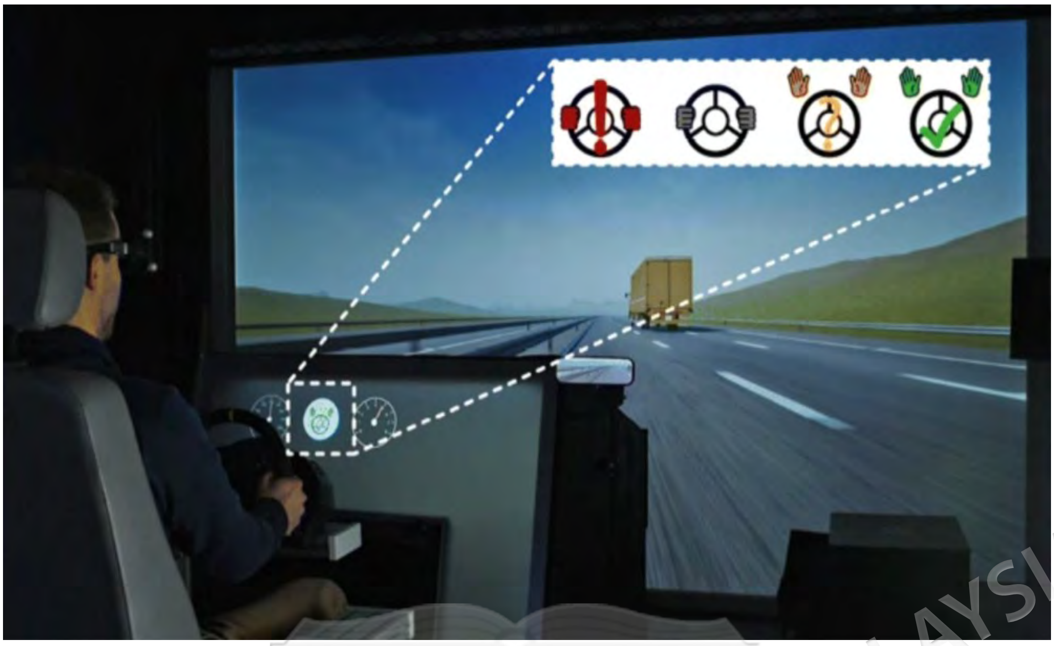


Figure 2.3 Driving simulator environment with front screen, car mock-up, and rear-view-mirror

2.4.4 VRdash04

Lack of interoperability is a significant barrier to VR users in education and training. To address this issue, Setti and Csapo (2021) proposed a universal and effective method for desktop users to integrate 2D content into a 3D environment. The focus of the study was given to desktop users to integrate 2D content as well as to configure dashboard layout in a 3D space to build 2D space in a 3D environment with the help of MaxWhere tools. This 2D content displayed in MaxWhere is known as smartboards, which include Chromium-based integrations, and can act as web browsers.

However, platforms other than MaxWhere face a challenge when the editing uses a gizmo approach; the geometric fixture that appears overlaid on the object operates as a transformation tool to manipulate the object, whereby the user has a problem of camera-object independence dilemma. Accordingly, this study proposed the dashboard layout editor to allow the camera viewpoint to be self-sufficient in arranging the smartboards and the workflow for in-situ spatial editing tools to create and manipulate for end users. The methodology was then validated for efficiency and comprehensiveness with the MaxWhere platform. Figure 2.4 and Figure 2.5 illustrate the 2D and 3D dashboards.

Figure 2.4 Dashboard of placement and addition of new smartboard to the scene by opening the 2D "pebbles" menu

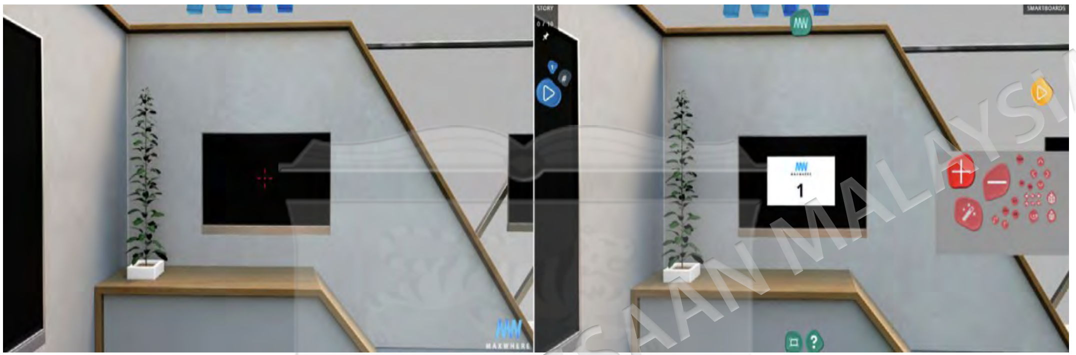


Figure 2.5 Dashboard of smartboard selection in 3D navigation mode

2.4.5 VRdash05

The production environment is critical because this process will determine the investment of a successful production company or vice versa. Prototyping is common in developing a product, but various strategies must be done to produce the prototype as planned. These processes typically involve unplanned planning that could affect the original investment or cost. Accordingly, Lutters and Damgrave (2019) studied using a virtual production environment, called the pilot production environment, to assist production engineers in evaluating and controlling machine tools and work processes. The pilot production environment represents the actual process environment by minimizing disruptions that may arise in the production environment.

For this reason, the digital system references are a core component linked to activities supporting the pilot production environment. Therefore, this research attempts to differentiate the task of each digital twin, digital master, and digital prototype in accordance of it being encapsulated in the digital system's reference, and present the output through the virtual dashboard. This virtual dashboard is purposely developed to give a better experience for the stakeholders in relevant stages of interaction, and acts as an interface of digital system references to present meaningful information to the stakeholder. In conclusion, this pilot production environment provides advantages in using the stakeholder investment wisely by using synthetic settings without any usual drawbacks, such as in some real environments as illustrates in Figure 2.6.

a) Infrastructure | b) Real, connected assets, for testing, validation and calibration | c) Virtually duplicated assets, for logistic simulation & analysis | d) Virtual assets added that are either remotely controlled or simulated

Figure 2.6 Visualisation in different levels of configuration in pilot production environment

2.4.6 VRdash06

Based on Google Earth VR technology, Bartosh and Gu (2019) proposed a multi-scale visualization that uses VR technology to integrate urban data, and some related geophysical aspects of the city are built interactively, and immersion is transmitted through a video game platform. This was done by upgrading the initial system prototype, where the initial prototype only allowed users to see three different views (i.e., aerial overview, a street view and a World Trade Center area), compared to the improved system prototype. Users can use the new prototype to use a street view guided by more detailed modelling of the surrounding buildings.

The UI design for users is based on reducing the user's memory burden by placing hand control button labels that are easy to see in the virtual environment and menus/commands that are easily reached through the touch of a button. Users can also control the data set using a laser pointer, and the same technique is used for air movement and two street scenes. Data structuring is done with various methods tested for graphic clarity, including traffic noise represented by two different colors and height topology. The production of flickering images is prevented by limiting the representation of overly complex data. As show in Figure 2.7 and Figure 2.8, the data visualised the city through the smart dashboard.

Figure 2.7 Layers of data visualised as overlays in the city

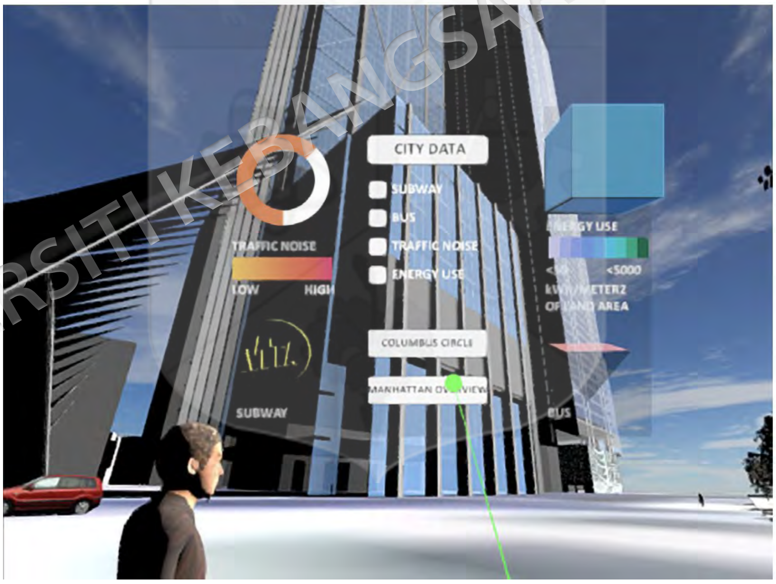


Figure 2.8 Street-level perspective data dashboard

2.4.7 VRdash07

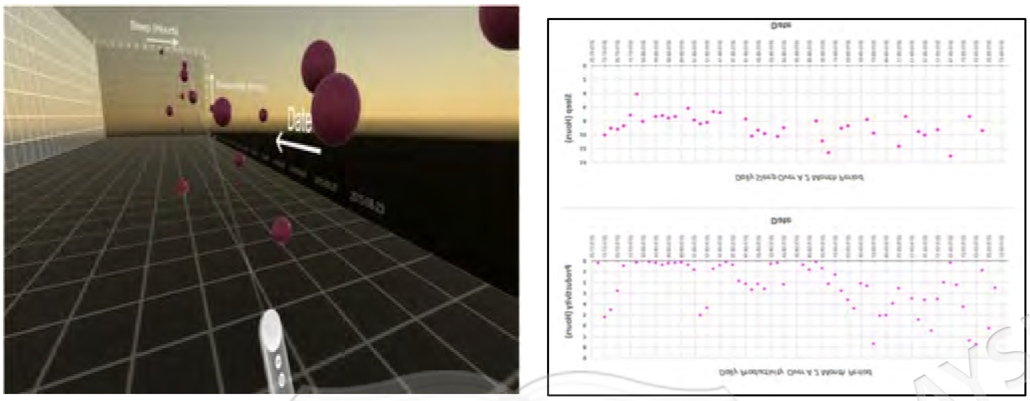
Mobile phones are now essential gadgets in everyday life. The sophistication of mobile phones, known as smartphones, allows users to track health levels using applications built into the mobile phone. Vock et al. (2021) studied the mobile health potential of the health tracking application in terms of its use and influence on individuals for several weeks. However, the researcher faced problems using mobile phones as the primary source to collect data, such as disconnection with participants or instrument malfunction. Data monitoring was also done manually, which is quite difficult compared to the VR and interactive dashboard in augmented reality (IDIAR), which consists of four dashboards, whereby the researchers can monitor and manage data interactively through the dashboards. The dashboards provide visual access to data that helps detect emerging data patterns and facilitate communication between researchers and the participants. A multimodal interaction approach serves those tasks using three interaction techniques: head gaze and touch, head gaze and voice, and touch input. Figure 2.9 illustrates IDIAR visualised data from smartphone.

Figure 2.9 IDIAR visualised data from ongoing mobile intervention study

2.4.8 VRdash08

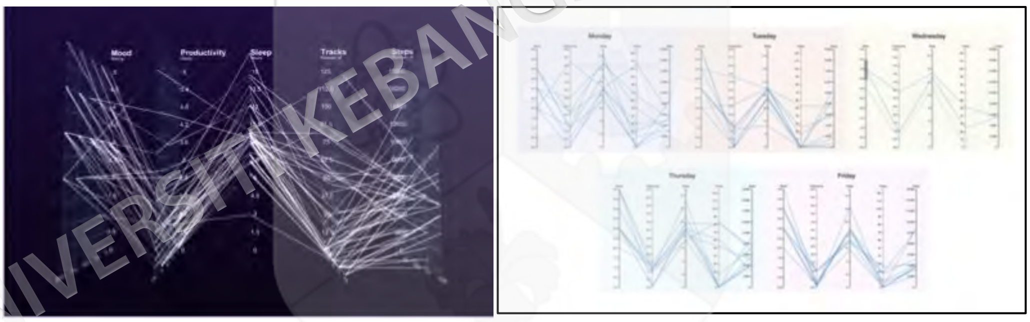
Data can be visualized into information that can be used to implement various business processes more efficiently. However, how can VR influence the user's approach to data exploration and understanding compared to 2D visualization? To gain insight into this, Millais et al. (2018) compared a 2D dashboard with two VR data visualizations. The first VR visualization is 'Be the Data', immersed in a three-dimensional scatter plot. The second is 'Parallel Planes', which allows the demonstration of n-dimensional datasets. The study reveals that the users prefer to stand while using VR devices instead of sitting in 2D visualizations. Moreover, the user feels more satisfied and closer to data in VR environments.

In general, users are more satisfied using VR data explorations. VR visualization has produced a more accurate understanding than traditional 2D dashboards. However, the task workload indicates no vast differences in task workload in traditional visualization and VR visualization. Therefore, VR is seen as having the potential to be applied in personal tracking that involves analysis and more active data deliberation. Figure 2.10 and Figure 2.11 describe the situation of ‘Be the Data’ and ‘Parallel Planes’.



(i) (ii)

Figure 2.10 (i) ‘Be the Data’ (VR) and (ii) Part of 2D dashboard equivalent for ‘Be the Data’ visualisation



(i) (ii)

Figure 2.11 (i) ‘Parallel Planes’ (VR) and (ii) Part of 2D dashboard equivalent for the ‘Parallel Planes’ visualisation

2.4.9 VRdash09

The use of smartphones in VR is very efficient, especially in recording data in 2D and visualizing it in 3D. In a study by Baltabayev et al. (2018), sensors are used for recording data such as object temperature, humidity, pressure, acceleration, and light intensity in a smartphone. VR cardboard headset is used as a VR scene shown using a smartphone. To control the view in 3D, SensorTagVR is built by combining four

Raspberry PIs for indoor position tracking. SensorTagVR is divided into two parts; a mobile app and web application.

The mobile app focuses on connecting external sensor devices via Bluetooth, processing, saving, and pairing the data with positional data from triangulation. The web application functions to explore the saved data in 3D space by generating VR scenes with WebGL. Meanwhile, the ViSensorVR used in the Samsung Galaxy S6 smartphone acts as a barometer and tracks data based on the global position system (GPS) to store longitude and latitude information. The barometer functions to obtain an accurate measurement of height information, and the Kalman filter is used to reduce the noise from the data provided by the barometer. Figure 2.12 and Figure 2.13 illustrate SensorTagVR and VSensorVR working through dashboard representation.

Figure 2.12 SensorTagVR – temperature sphere representation (left) and screen walkthrough (right)

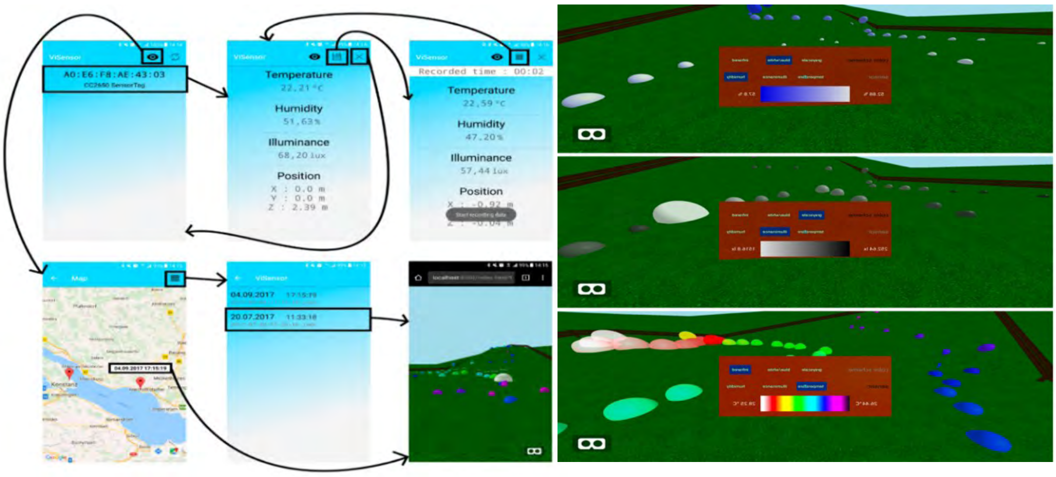


Figure 2.13 VSensorVR screen walkthrough (left) and 3D world in the web interface (right)

2.4.10 VRdash010

Exercise is crucial to maintaining good health, but it can be challenging to determine if an individual is engaging in enough physical activity. To address this, Yoo et al. (2018) proposed using VR to measure exercise activities, especially for individuals who lack the time or space for regular exercise. The study integrated three sensor data sources (heart rate, body map from VR gaming, and step data) and visualised them on an interactive dashboard or VRFit.

This provides the user with a comprehensive overview of their activity, including daily recorded activity, visual feedback, and a VR body map to illustrate a typical exercise regimen. The study collected data from 11 participants who played VR games while wearing a Pebble watch and a Polar H7 heart rate monitor. The data gathered from the participants was used to inform the dashboard's design and highlight the design space for such applications.

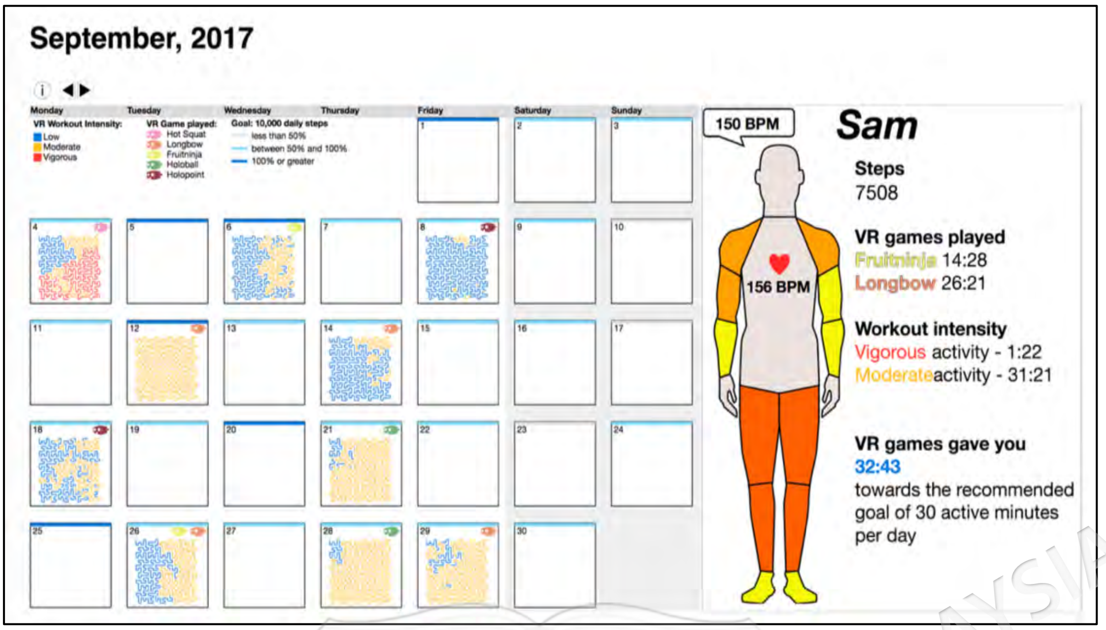


Figure 2.14 A screenshot of the dashboard on the 26th of September 2017 as the user played two games as described at the right of the figure

2.4.11 VRDash011

This study explores the use of virtual reality (VR) guided tours for teaching computer graphics fundamentals, with a focus on the rendering pipeline (Heinemann et al. 2024). The research, conducted using the RePiX VR application, employed an exploratory analysis of user interactions, gaze, and motion data. The findings revealed positive user impressions and learning outcomes, particularly for newcomers to computer graphics. By utilizing xAPI data and adhering to FAIR principles (Findable, Accessible, Interoperable, and Reusable), the study aimed to gain deeper insights into learners' behaviors and approaches.

The development of RePiX VR was grounded in theoretical foundations and prior research, with a strong emphasis on learning analytics processes. The study's outcomes underscored the importance of iterative development in creating user-friendly VR environments. Students' positive reactions to the VR experience suggest promising potential for this educational approach. These findings lay the groundwork for future evaluations involving a larger sample size, which could further validate the effectiveness of VR-based instruction in computer graphics education.

2.4.12 VRDash012

A study by Lei et al. (2022) examines the integration of immersive virtual reality (VR) in intelligent manufacturing (IM), exploring its potential to enhance decision-making, product performance, and cost efficiency. Through a systematic review of literature from 1990 to 2022, following PRISMA guidelines, the authors identify trends and challenges in VR applications for IM. While technological advancements have been significant, research combining VR and IM remains limited. The study emphasizes the importance of human-machine interaction and VR's creative potential in reconstructing environments for improved user engagement, aiming to provide insights into future research directions and practical applications in the manufacturing sector.

The work makes several key contributions to the field, including a comprehensive systematic review, identification of practical challenges, and a proposed conceptual framework for understanding VR's role in IM. It offers interdisciplinary insights to enhance human-machine interaction in smart factories and encourages technological advancement across industries. By providing practical advice for designers, users, and researchers involved in developing human-machine interfaces in smart factories, the paper contributes to the effective implementation of VR technologies. However, The work may overemphasize technological aspects while underexploring organizational, economic, or human factors that influence VR adoption in manufacturing. The framework may not be equally applicable across all sectors of manufacturing, given the diversity of manufacturing processes and environments.

2.4.13 Conclusion

A critical examination of prior VR dashboard studies reveals that although many emphasize technical implementation or visualization outcomes, few articulate how theoretical principles are systematically embedded into practice. Most frameworks (e.g., Arjun et al. 2022; Mukhopadhyay et al. 2022; Weidner and Broll 2022) adopt ad-hoc experimental designs focused on usability testing or hardware integration without grounding the development process in a cohesive theoretical foundation such as cognitive psychology, ecological interaction, or ontological modelling. Consequently, these works lack methodological transparency on why specific design decisions were made or how knowledge from theory could be reused or generalized across domains.

From a theoretical standpoint, the reviewed studies frequently reference design heuristics such as Gestalt principles or Fitts' Law but stop short of operationalizing these principles within a repeatable design framework. For instance, Setti and Csapo (2021) and Bartosh and Gu (2019) address spatial layout and usability challenges but provide no mechanism for linking those design insights to a reusable knowledge structure. Similarly, studies by Vock et al. (2021) and Millais et al. (2018) succeed in demonstrating immersive analytics potential but remain descriptive rather than prescriptive, lacking an ontological mapping that could translate experiential results into transferable design rules.

In the past five years, the number of studies exploring VR topics has kept increasing; however, not many studies have discussed in-depth VR dashboard design method development. As shown in Table 2.2, Arjun et al. (2022) and Lutters and Damgrave (2019) explore a VR technology dashboard in smart manufacturing. Arjun et al. (2022) studied how users interpret information based on different types of graphs that are useful for pointing out anomalies in current visualization techniques.

Meanwhile, Lutters et al. (2019) proposed the virtual dashboard as an insightful basis for decision-making. Instead, Bartosh and Gu (2019) have proposed multi-scalar visualizations for better viewing and exploring smart cities. Conveying the importance of having a common practice in designing the development of the VR dashboard, the research questions are discussed briefly based on Table 2.2 The researcher found some key points or essential remarks to be concluded or highlighted below.

a. Common Best Practices in Current VRDDM

Based on Table 2.2, studies are applying best practices in developing the VRDDM (Lutters et al. 2019; Setti & Csapo 2021). Setti et al. (2021) apply the workflow process in developing VRDDM, especially in editing operations for training or education purposes. The workflow process used is like Figure 2.15. The process started with the user adding the smartboard to the scene. It was followed by the smartboard selection of individuals or groups for further manipulation (position, orientation, size, and aspect ratio).

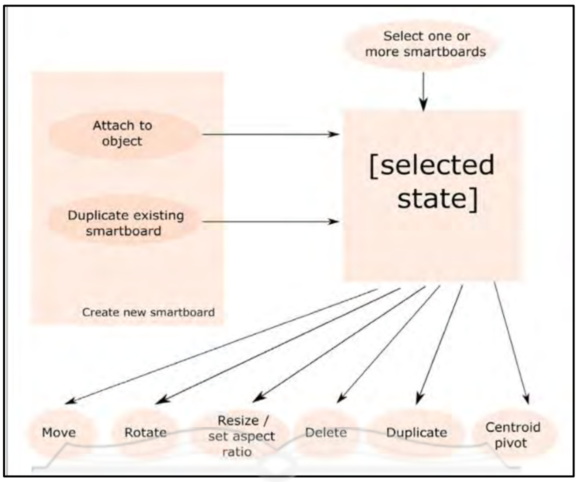


Figure 2.15 Workflow process of editing operation

Meanwhile, Lutters et al. (2019) implemented digital system references in manufacturing as their best practice. Digital system references constitute the digital twin, digital master, and digital prototype, as illustrated in Figure 2.16.

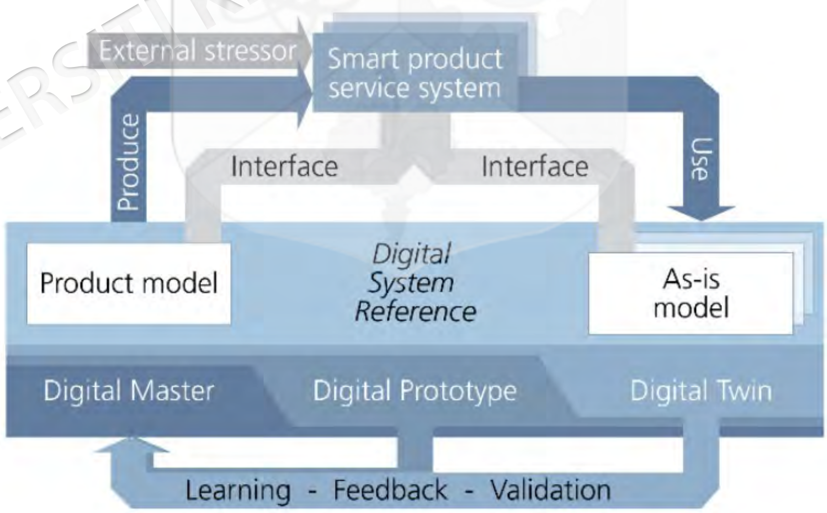


Figure 2.16 The digital system references the composition

The conglomerate of data, information, models, methods, tools and techniques which appointed the current states of the observed system is designated by the digital twin. The digital master is to intend the design and components as an apprehended outcome of the development cycle. Meanwhile, the digital prototype is responsible for forecasting (extrapolated/predicted) system states upon models, simulations, and users, resulting in meaningful perspectives associated with the inputs by the 'to-be' digital master and 'as-is' digital twin(s). Bartosh and Gu (2019) have presented the multi-scalar view approach to provide a more in-depth view that covers all user perspectives in exploring the cities by integrating additional data to cover multiple angles of user sight, as shown in Figure 2.17.

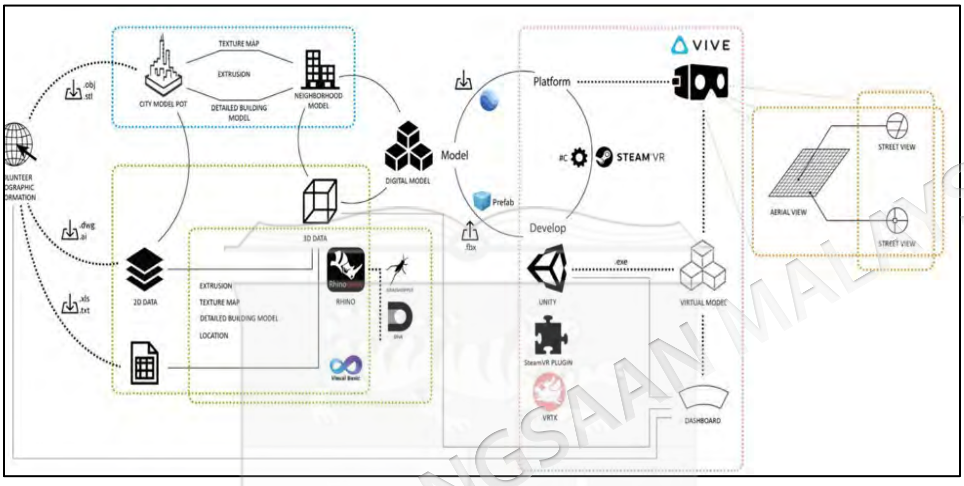


Figure 2.17 Diagram of work flow from digital model to data integrated virtual urban environment

Vock et al. (2021) assist mobile health researchers in their study by combining immersive AR HMD and smartphones. A smartphone's UI provides a context-sensitive UI that spontaneously accommodate selected elements and can be activated with voice commands. Millais et al. (2018) compared the traditional dashboard and VR visualizations in user data exploration task workload using workload and insight-based evaluation methodology. Based on immersive analytics developed by the previous study of HMD in various domains, this HMD technology is extended in the development of the environment with the addition of different types of sensors and support from other applications, called immersive sensor data visualizations (Baltabayev et al. 2018).

b. Key Steps in VR Dashboard Design

Key steps in dashboard design have been discussed by Arjun et al. (2022) and Mukhopadhyay et al. (2022). Arjun et al. (2022) state the key steps in dashboard design to facilitate smart factory development, starting with the 2D dashboard development process and ending with the 3D dashboard development process, as Table 2.2 lists. Meanwhile, Mukhopadhyay et al. (2022) describe developing virtual office steps to ensure social distancing and reduce the risk of spreading COVID-19. Table 2.2 shows that the process is started by setting up the cameras and digital twin sensors to capture the data. Afterwards, the process of building up the virtual environment, coordinating the virtual environment, mapping the sensor with the data, rendering the frames, and preparing the data set is done. In the study by Bartosh and Gu (2019), they started visualizing smart cities by modelling the data digitally, gathering and mapping the urban data, and finally developing VR UI. A study by Vock et al. (2021) started by conducting interviews with several focus groups of five domain experts and gathering information from previous studies. IDIAR is designed using four dashboards; (i) the main dashboard, (ii) a daily dashboard, (iii) a participant dashboard, and (iv) a management dashboard. In comparing traditional and VR visualisations, Millais et al. (2018) build two VR data visualisations and a 2D dashboard. After that, the training is conducted to gain the data for analysis. In an immersive sensor data visualisation study, Baltabayev et al. (2018) developed two sensor prototypes with different functions to collect data in a real environment and visualise it in a 3D environment. The noise in collected data was then filtered using the Kalman filter.

c. Tools, Diagrams, or Techniques Used in Existing Dashboard Design Method

Some previous studies mention the tools and techniques used, such as in Table 2.2, whereby the standard tools are Unity3D and digital twin sensors with several algorithms (Arjun et al. 2022; Baltabayev et al. 2018; Bartosh & Gu 2019; Lutters et al. 2019; Millais et al. 2018; Mukhopadhyay et al. 2022; Vock et al. 2021). Setti et al. (2021) implement the MaxWhere tool without describing other algorithms or techniques, as Lutters et al. (2019) emphasized digital system references as a tool. Some studies (Baltabayev et al. 2018; Bartosh & Gu 2019) used GIS tools and Google Earth VR to visualize smart cities and 3D environments. Vock et al. (2021) used Microsoft HoloLens as an AR Head-Mounted Display (HMD), TeamViewer, and multimodal interaction techniques in developing IDIAR to assist mobile health researchers. Google DayDream VR and Unity3D tools were used to develop VR visualizations. Meanwhile, NASA TLX was used as a questionnaire measurement tool, which was analyzed using the ANOVA technique in a study by Millais et al. (2018).

d. Application Domain in Current VR Dashboard Design Guidelines

Nowadays, there are many studies on VR dashboards in various fields, such as smart farming (Cheng et al. 2018; Said Mohamed et al. 2021; Ye et al. 2018), manufacturing (Arjun et al. 2022; Dávideková et al. 2017; Lutters et al. 2019; Masullo et al. 2022), advertising (Geng 2022), vehicles (Weidner & Broll 2022), data exploration (Millais et al. 2018), oil & gas (Garcia et al. 2019), health (Borrelli et al. 2022; Mukhopadhyay et al. 2022; Vock et al. 2021), education/training session (Setti et al. 2021) smart cities (Bartosh & Gu 2019), miscellaneous (Millais et al. 2018), and environment (Baltabayev et al. 2018).

e. UI/UX Design Principles or Factors Adopted in VR Dashboard Design Guidelines

UI/UX for traditional dashboards have different requirements than VR, because UI/UX design focuses more on user interaction based on other mediums such as a mouse, keyboard, or touch screen. At the same time, VR UI/UX involves the user directly by combining the user's body and senses with the help of tools for interaction. Therefore, users must use familiar tools in building VR UI/UX. A good practice involves not letting the user search for control buttons, and ensuring that the user can control the situation by mastering the unfamiliar environment as quickly as possible by reducing the learning curve. Most studies of VRDDM in Table 2.2 focus on user experience factors and interactive dashboards for users, with the addition of considering the user's memory load by building a UI that is easy to use and accessible to the user (Arjun et al. 2022; Baltabayev et al. 2018; Bartosh & Gu 2019; Lutters et al. 2019; Millais et al. 2018; Mukhopadhyay et al. 2022; Weidner & Broll 2022; Setti et al. 2021; Vock et al. 2021).

f. The Current Links between the Theory and Practice of VR dashboard Design Guidelines

Arjun et al. (2022) study work on Fitts's (1992) experiments, known as Fitts’ law in the VR setup. Mukhopadhyay et al. (2022) investigate CNN practices to uncover the detection of humanoid distance in the limited-sized dataset. Prior work by Chen et al. (2016) and Brunhart-Lupo et al. (2016) is extended by Millais et al. (2018) to develop two VR visualisations based on ‘Be the Data’ and ‘Parallel Coordinates Visualization’. Meanwhile, Baltabayev et al. (2018) facilitate immersive analytics to develop more advanced technology for monitoring environmental changes using sensors and GIS.

2.5 ONTOLOGY

The preceding review of VR dashboard studies has highlighted the fragmented and ad-hoc nature of current design practices, where visualisation tools are developed in isolation without a shared conceptual foundation. Despite numerous technical advancements, there remains no unified method capable of standardising how design knowledge is represented, reused, and evolved across different VR applications. This absence of structural integration limits scalability, reproducibility, and knowledge transfer between domains.

To overcome this fragmentation, an ontological approach is introduced as the guiding solution. Ontology provides a formal, machine-interpretable representation of concepts, relationships, and processes that define a particular knowledge domain. By using ontology as the backbone of design representation, it becomes possible to systematise VR dashboard knowledge, ensure semantic consistency among design components, and enable knowledge reuse across projects. In this research, ontology serves not merely as a theoretical tool but as the structural mechanism that transforms unorganised design experiences into a coherent methodological framework ultimately giving rise to the Virtual Reality Dashboard Design Ontology (VRDDO) and the Virtual Reality Dashboard Design Method (VRDDM) developed in subsequent chapters.

Ontology is used in various branches of research. In this study, ontology is used as a tool to convey the results of the study. In subsections 2.5.1 and 2.5.2, a brief description of what ontology is.

2.5.1 What is an Ontology?

Ontology, in its original sense, is a branch of philosophy that deals with the study of being, existence, and the fundamental nature of reality. It seeks to answer profound questions about what exists in the world, how these entities can be categorized, and the relationships that connect them. Philosophers have long used ontology to explore the nature of existence, asking questions such as: What entities or categories of entities exist? How are these entities defined and distinguished from one another? What kinds of properties and relationships are essential to their existence? These philosophical inquiries form the foundation of ontological thinking, which is concerned with structuring knowledge about reality in a systematic way.

In modern times, the concept of ontology has been adapted into the field of computer and information sciences, where it carries a more technical meaning. Here, ontology refers to a formal, explicit specification of a shared conceptualization of a domain. It defines a set of concepts, categories, properties, and the relationships between them, enabling both humans and machines to understand and communicate knowledge consistently. Ontologies provide a structured framework for representing domain knowledge, facilitating interoperability, data integration, and reasoning in complex information systems.

Within artificial intelligence (AI), ontologies play a pivotal role by enabling machines to process information semantically, moving beyond mere data storage to a more meaningful understanding of contexts and relationships. In semantic web technologies, ontologies support linking data across diverse systems, making information more accessible and useful. Similarly, in knowledge management, ontologies help organizations structure their knowledge bases, ensuring that information is organized in a way that reflects real-world relationships and is easy to retrieve and analyze. Thus, whether in philosophical discourse or computational applications, ontology is fundamentally concerned with the identification, categorization, and representation of entities, their properties, and their interrelationships. It provides a framework for understanding and modelling knowledge about the world, supporting both theoretical exploration and practical implementations in various domains.

2.5.2 Ontology for Supporting VR Design & Development

Ontology has been used to support the VR development life cycle, including in supporting VR dashboard design and development. Various disciplines implement ontology to facilitate VR dashboard design and development, as ontology is well-known for general-purpose concepts such as scientific experiments, healthcare, surgery, and education. VR technology has been well-known for its potential to assist scientific experiments for many years. Incorporating an ontology to support VR in scientific experiments can reduce or zero experiment errors (Chokwitthaya et al. 2023). A study by Mohamad et al. (2021) presents the ontology used in VR technology to assist the healthcare domain in medical education and training. Features of an ontology that can facilitate knowledge sharing and contribute to leveraging VR technology are also used in cataract surgery by proposing OntoPhaco (Youcef et al. 2021). VR has already changed the education landscape for years, especially in training, and with the structured framework of the ontology make it the most prominent mechanism in the large-scale case study of adult literacy in India (Chimalakonda & Nori 2020).

2.6 RELATED THEORY

Theorists have examined diverse fields, including theatre, psychology, ethology, perception, communication, computer science, and learning theories, to comprehend the emerging virtual reality (VR) technology and its potential applications across sectors like education. Leveraging relevant theories can inform the design of ontologies, which are formal representations of knowledge, for VR dashboards. These theories offer structured conceptual models to envision and shape user experiences, enabling the development of intuitive and immersive virtual interfaces based on use cases. There are several theories that are closely related to VR technology.

2.6.1 Computers-as-Theater Perspective

The Computers-as-Theater Perspective, proposed by Brenda Laurel (2004), suggests adapting principles of effective drama to the design of interactive computer programs, particularly virtual reality. Laurel argues that drama and human-computer interaction share a common goal: creating artificial realities that enhance the potential for action cognitively, emotionally, and aesthetically. The theory emphasizes structuring virtual reality experiences as organic wholes with dramatic structural characteristics like storytelling, enactment, intensification, compression, unity of action, closure, magnitude, and willing suspension of disbelief. These elements aim to promote engagement, agency, and emotional involvement. However, if applied to the design of a VR dashboard for smart farming, this theory may have limitations. While dramatic elements could enhance the user experience, the primary goal of such an application is likely to be efficient data visualization and control rather than storytelling or emotional catharsis. The theory's focus on mimetic contexts and enactment may not align well with the functional and pragmatic requirements of a smart farming dashboard, where usability, clarity, and real-time data presentation are likely priorities. Consequently, while some dramatic principles could potentially enhance engagement, applying the Computers-as-Theater Perspective too rigidly might compromise the application's practical utility and user-friendliness.

2.6.2 Situated Learning Perspective

The Situated Learning Perspective, as theorized by Hilary McLellan (1996), suggests that learning occurs best when it is situated within the context and environment in which the knowledge will be applied. This theory proposes that knowledge is a product of the activity, context, and culture in which it is developed and used. Consequently, effective learning should occur through apprenticeship, collaboration, reflection, coaching, multiple practice, and articulation of learning skills within realistic or virtual surrogate environments that mimic the actual work setting.

While the Situated Learning Perspective offers valuable insights for designing immersive and contextual learning experiences, its reliance on highly realistic virtual environments may pose a challenge when applied to the design of a VR dashboard for smart farming applications. Agriculture and farming involve complex interactions with natural environments, living organisms, and dynamic weather conditions that may be difficult to replicate accurately within a virtual environment. Oversimplification or inadequate representation of these factors could lead to a disconnect between the virtual learning experience and the real-world application, potentially undermining the core principles of situated learning. Additionally, the theory's emphasis on apprenticeship and collaboration may not seamlessly translate to individual learning experiences facilitated by a VR dashboard. Careful consideration and adaptation of the theory would be necessary to ensure effective and meaningful learning outcomes within the constraints of a smart farming VR application.

2.6.3 Ecological Psychology Perspective

The ecological psychology perspective, proposed by J.J. Gibson (1986), provides a theoretical foundation for virtual reality (VR) design. It emphasizes the importance of affordances, which are the distinctive features of objects that help us perceive and understand how to interact with them. Gibson argues that perception is an active process, where our senses actively seek information from the environment to coordinate movements and maintain balance. The theory suggests that virtual environments should provide affordances that mimic real-world objects and environments, allowing users to perceive and interact with them naturally. However, when applying this theory to the design of a VR dashboard for smart farming applications. However, While the theory provides valuable insights into creating natural and meaningful interactions, the complexity and nuances of real-world farming practices may not be easily captured in a virtual setting, potentially limiting the effectiveness of the VR dashboard in certain aspects of smart farming operations.

2.7 GENERATIVE AI APPLICATIONS IN DASHBOARD DESIGN

The evolution of dashboard design, particularly in the context of Virtual Reality (VR), has been shaped by a growing need for user-centered, dynamic, and context-aware interfaces that facilitate real-time decision-making. As the complexity of data and user environments increases, traditional design methodologies face challenges in scalability, responsiveness, and adaptability (Card et al. 1999; Weidner & Broll 2022). The integration of Generative Artificial Intelligence (GenAI) into dashboard design workflows represents a transformative opportunity to address these challenges. GenAI, powered by large language models (LLMs) such as OpenAI's GPT-4 and Google's Gemini, has demonstrated capabilities in natural language understanding, pattern recognition, and creative synthesis that align closely with the requirements of advanced dashboard systems (Perkins 2024; Naeem et al. 2025).

This section explores the potential applications of GenAI in the development of the Virtual Reality Dashboard Design Method (VRDDM). It examines how GenAI supports key aspects of dashboard design, including rapid prototyping, ontology development, thematic analysis, and user-centered design. It also critically discusses the technical and ethical considerations involved in employing GenAI tools.

2.7.1 Enhancing Design Efficiency and Creativity with GenAI

One of the most notable contributions of GenAI to dashboard design lies in its ability to enhance efficiency and foster creativity. Traditional design approaches, while methodical, are often resource-intensive and require iterative cycles of prototyping and user feedback (Shneiderman 1996). In contrast, GenAI tools can generate multiple design alternatives based on initial user requirements or environmental parameters, significantly reducing design time.

Perkins (2024) demonstrated how ChatGPT's advanced data processing capabilities enabled researchers to analyze large datasets and propose preliminary themes with greater speed than manual approaches. Similarly, in the context of dashboard design, GenAI could be employed to suggest interface layouts, data visualization techniques, and even user interaction flows. These suggestions would be informed by existing design principles, domain-specific ontologies, and prior user studies, allowing designers to explore a broader design space without the constraints of manual iteration cycles.

This generative capacity is particularly critical in VR dashboards for smart farming, where data heterogeneity and environmental variability demand adaptable and innovative solutions. The VRDDM framework, which emphasizes user interaction with ecological affordances (Gibson 1979), could benefit from GenAI's ability to propose context-aware visualizations that reflect real-world complexities.

2.7.2 Human-AI Collaboration in User-Centered Design

An important consideration in dashboard design is ensuring that systems are tailored to user cognition and workflows. The ecological psychological perspective adopted in VRDDM stresses the importance of affordances that align with users' perceptual and motor capabilities (Norman 2013). GenAI can play a pivotal role in this regard by analyzing user interaction logs, transcribing verbal feedback, and generating summaries that highlight usability issues or feature requests.

Perkins (2024) and Naeem et al. (2025) underscore the role of GenAI as a co-pilot rather than a replacement for human designers. While AI tools excel in processing and summarizing large volumes of data, they require human oversight to interpret subtle contextual cues, cultural nuances, and ethical considerations. This hybrid approach ensures that dashboards are not only efficient and innovative but also deeply grounded in the lived experiences of their intended users.

2.7.3 Technical and Ethical Considerations

The integration of GenAI into dashboard design workflows is not without challenges. As Perkins (2024) notes, GenAI outputs are subject to "hallucinations," where fabricated information may be presented as factual. Such errors, if not identified, could lead to flawed design decisions. Similarly, the stochastic nature of LLMs raises concerns about result reproducibility, a key requirement for methodological rigor.

Naeem et al. (2025) recommend providing AI systems with comprehensive contextual information, including research aims, theoretical underpinnings, and methodological considerations, to enhance reliability. This aligns with VRDDM's ontology-driven approach, which requires semantic precision to ensure dashboard integrity.

Ethical considerations also loom large, particularly regarding data privacy. When using AI tools to process user feedback or domain literature, safeguards must be implemented to prevent unauthorized data retention or misuse by AI service providers (Raji et al. 2020). Furthermore, transparency in how GenAI outputs inform design decisions is essential to maintain accountability and user trust.

2.7.4 AI Integration in VR Dashboard Design Storyboarding

The process of storyboarding in Virtual Reality (VR) dashboard design is pivotal for conceptualizing and communicating the intended user experience, interactions, and data visualizations before full-scale development. Traditionally, storyboarding relies heavily on manual sketches and iterative human-centered refinements, which can be time-consuming and limited by the subjective creativity of individual designers (Weidner & Broll 2022). The advent of Generative Artificial Intelligence (GenAI) offers a compelling opportunity to augment and accelerate this process by providing intelligent assistance in ideation, visualization, and narrative structuring.

Generative AI systems such as ChatGPT and image-based models (e.g., DALL·E, MidJourney) can function as co-creators in the storyboarding process. By processing initial textual descriptions of dashboard concepts, AI tools can generate preliminary visual layouts, suggest design alternatives, and even create scene-by-scene visualizations of user interactions within the VR environment. This capability reduces the cognitive load on designers and facilitates rapid prototyping of multiple storyboard variants for comparison and refinement.

For instance, if a designer provides a prompt describing a scenario where a farmer interacts with a VR dashboard to monitor soil moisture levels, GenAI can generate a sequence of images depicting the farmer’s VR experience. These visuals might include hand gestures for selecting data layers, eye gaze interactions with 3D visualizations, and feedback animations when a parameter threshold is crossed. Such AI-generated storyboards not only save time but also help surface creative solutions that may not emerge in traditional brainstorming sessions.

This capability aligns closely with the ecological psychological perspective in VRDDM, where affordances must be carefully matched to user capabilities (Norman 2013; Gibson 1979). AI-assisted storyboards can depict how users will perceive and act upon affordances in dynamic environments, thus ensuring design fidelity to human factors principles.

2.7.5 Automated Narrative Structuring and Scenario Building

Storyboarding in VR dashboard design is not limited to static images but involves the development of dynamic narratives that anticipate user journeys, contextual interactions, and system responses. GenAI models can analyze domain knowledge, user requirements, and usage contexts to propose coherent narratives that describe user flows within the VR environment. These narratives may include branching scenarios that account for different user behaviors, environmental conditions, or system states, supporting more comprehensive design planning.

Naeem et al. (2025) emphasized the role of AI in conceptualizing and synthesizing thematic elements into coherent models during qualitative analysis. Similarly, in VR dashboard storyboarding, AI can help structure the storyboard around key themes such as data transparency, usability, and immersive engagement, ensuring that each visual and narrative element aligns with overarching design goals.

For example, in smart farming applications, AI could suggest storylines where users transition between monitoring crop health in one scene and adjusting irrigation settings in another, ensuring continuity and logical flow across interactions. Such AI-generated scenarios can help designers anticipate user needs and potential system bottlenecks early in the design lifecycle.

Beyond textual narratives, advanced GenAI systems capable of multimodal outputs can directly contribute to the visual richness of storyboards. Tools like DALL·E or Stable Diffusion can transform descriptive prompts into detailed storyboard frames, while 3D modeling AIs can suggest spatial layouts for virtual dashboards. This functionality allows designers to prototype realistic user interfaces and environments without requiring deep expertise in graphic design or 3D modelling. This approach aligns with Mukhopadhyay et al.'s (2022) recommendation to integrate immersive design guides and modelling tools early in VR dashboard development. With AI assistance, storyboards can evolve from flat, 2D sketches into interactive prototypes that simulate user interactions within a VR space. Such high-fidelity storyboards can then serve as communication tools for interdisciplinary teams, facilitating collaboration between designers, developers, and domain experts.

2.7.6 Toward Intelligent Storyboarding Workflows

Looking forward, integrating GenAI into VR dashboard storyboarding could lead to intelligent workflows where AI not only assists in ideation but also learns from iterative feedback to refine storyboard quality. Machine learning models trained on past storyboard successes and failures could proactively suggest design improvements, enhancing both efficiency and design quality over time.

This vision supports the VRDDM's ontological approach by embedding semantic awareness into storyboard generation. AI-assisted storyboards would thus not only depict visual scenes but also encode relationships between dashboard elements, user actions, and environmental contexts, creating a rich design artifact that bridges conceptualization and implementation.

2.8 SUMMARY

The review of VR dashboard studies (VRdash01–VRdash12) reveals that most prior works were conducted in isolated domains such as manufacturing, healthcare, and urban visualization, with limited focus on agricultural or environmental monitoring contexts. While these studies demonstrate the feasibility of immersive data visualization, they often lack domain-specific frameworks that address real-world monitoring challenges such as multi-sensor integration, data semantics, and spatial reasoning required in smart farming. Furthermore, none of the reviewed works propose a unified methodological structure that links theoretical perspectives with systematic dashboard design processes.

This research directly addresses those gaps by extending the understanding of VR dashboards into the context of smart farming monitoring and by introducing a

Virtual Reality Dashboard Design Method (VRDDM) grounded in ontological and psychological theories. The VRDDM not only formalizes the fragmented design practices observed in past studies but also provides a replicable framework for applying VR dashboard design in other data-intensive monitoring domains. By doing so, this study situates VR dashboard research within a new applied context while offering a theoretically informed foundation for future immersive system development.

In Chapter 2, it is essential to understand the overall situation on relevant material on smart farming in the general sense and then narrow it down to interesting areas on how VR can be applied to the smart farming context and subsequently investigated further from the perspective of VR dashboard design method that would meet smart farming contextual data, information, and knowledge, by giving more emphasis on reviewing related works on VR dashboard design method. As a result, the researcher found that research into established methods of designing VR dashboards is not matured and is still ongoing due to many variables or contextual factors according to the application domain and the purpose of the VR dashboards to be developed. Therefore, finding commonalities in the standard or shared components or requirements essential to VR dashboards is crucial when proposing a VR dashboard design method. In the next Chapter 3, the researcher attempts to apply the Design Science Research Methodology (DSRM) to assist this research to provide a design artefact type of "Method", which is how a new VR dashboard design method can be crafted. An ontology is used to support the VR dashboard design and development, which will be further discussed in Chapter 4.

CHAPTER III

METHODOLOGY

3.1 INTRODUCTION

Regardless of the research discipline, the research method is always essential. The research method could be a tool to explore the problem further and promote reasoning clarification and assumption. In Information Systems (IS), numerous research methods diverge in research process aspects, techniques, and ideology. Therefore, this chapter explores and propounds the research methodology embraced in this study for designing the development methodology, namely Design Science Research (DSR). DSR's fundamental fortification is to produce things that provide human purposes. It also aims to solve problems identified in the organisation (Hevner et al. 2004). Weigand et al. (2021) implement the DSR approach to produce ontology artefacts in their study. Meanwhile, the DSRM is applied in e-health, studied by Gregório et al. (2021).

This chapter is structured as follows. Section 3.2 overviews prevailing research paradigms in information systems research and introduces DSR. Section 3.3 investigates the design science research method and presents its phases, outputs, and evaluation methods. Section 3.4 offers the research design of this thesis and its recurrence to provide the reader with all-encompassing research. Section 3.4 summarises the chapter. This chapter also demonstrates the grounds behind choosing the DSR as a tool to accomplish this research

3.2 RESEARCH PARADIGMS IN INFORMATION SYSTEMS

The research paradigm was studied decades ago, and some scholars have defined this research paradigm. Bailey (1982) postulates that: "Research paradigms represent the "mental window through which the researcher views the world". Meanwhile, McArthur

(1992) explained a research paradigm as: ‘‘an overriding viewpoint that shapes ideas and action. A paradigm shift occurs when ideas and practices taken more or less for granted under the old paradigm are reassessed under the new. Such a shift occurred in the sixteenth century when Copernicus claimed that the Earth went around the Sun and in the nineteenth century with Darwin’s theory of natural selection’’.

Burke (2007) stipulates that the research paradigm could act as a set of lenses for the researcher to enable them to investigate and view more clearly the fieldwork within a particular set of established assumptions, thus merging the abstract use of the paradigm with the practical application of conducting the study. Most commonly, four paradigms have been extensively used in information system research: Positivism, Interpretive, Advocacy, and Pragmatism (Willcocks & Mingers 2004). The term information science is used when debating theoretical and philosophical ideas in information systems, whereby it explains the science and theory in the information systems field (Burke 2007). Past researchers have inspected the elucidation of research paradigms to give the best lens for the researcher in information science. Hevner et al. (2004) categorised information science by two paradigms: natural science (or behavioural science) and design science. Natural science’s primary focus is understanding reality, explaining or predicting human or organizational behaviour, and producing general theoretical knowledge.

Meanwhile, compared to design, science is concerned with designing novel and innovative artefacts to serve human and organisational purposes (Hevner et al. 2004; March et al. 1995). These two approaches are complete with each other, whereby the discovery of natural science might be helpful in design science to enhance the quality of the findings to provide the best to humankind. Hevner et al. (2004) present a conceptual framework for information research that combines behavioural science and design science paradigms, as illustrated in Figure 3.1.

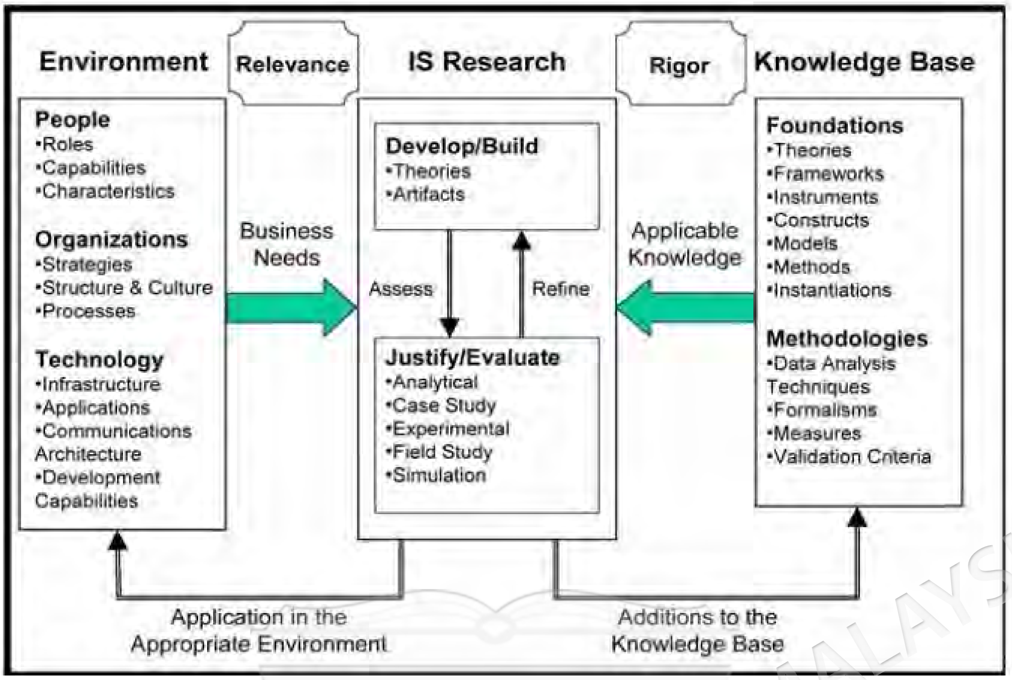


Figure 3.1 Information systems research framework
Source: Hevner et al. 2004

Hevner et al. (2004) introduced an influential conceptual framework that integrates the paradigms of behavioural science and design science within the realm of Information Systems (IS) research, as illustrated in Figure 3.1 of their work. In this framework, they differentiate the core objectives of the two paradigms. Behavioural science primarily focuses on the development, validation, and justification of theories that seek to uncover truths about human behavior, organizational processes, and technological interactions. Its ultimate goal lies in producing explanatory and predictive knowledge that enhances our understanding of existing phenomena.

In contrast, design science emphasizes the creation and rigorous evaluation of innovative artefacts such as models, methods, constructs, and systems with the explicit aim of delivering utility. This paradigm seeks to solve real-world problems by developing practical solutions that can be directly applied in organizational contexts.

Importantly, Hevner et al. (2004) argue that the dimensions of truth and utility are not mutually exclusive but rather deeply intertwined. The utility of a designed artefact might stem from underlying truths not yet fully recognized, while theoretical insights from behavioural science can inform and inspire the design of novel, effective artefacts. This symbiotic relationship underscores the complementary nature of both paradigms in advancing research in information technology.

3.3 DESIGN SCIENCE RESEARCH METHODOLOGY: AN OVERVIEW

Design Science Research (DSR) is an established paradigm in the Information Systems (IS) domain that aims to create and evaluate artefacts designed to solve identified problems while simultaneously contributing to theoretical knowledge. Unlike traditional research paradigms that often emphasize observation and explanation, DSR actively engages in building and refining artefacts such as models, methods, constructs, and instantiations (Hevner et al. 2004). In this thesis, DSR serves as the foundational methodology for developing the Virtual Reality Dashboard Design Method (VRDDM), a framework that addresses the gaps in designing VR dashboards for smart farming. The methodology ensures that the research outcomes are both practically applicable and theoretically robust.

This section provides a detailed explanation of two critical frameworks presented in Figures 3.2 and 3.3, which serve as the conceptual and procedural cornerstones of this study. Figure 3.2 outlines Hevner et al.'s (2004) seven guidelines for conducting design science research in IS, while Figure 3.3 illustrates Peffers et al.'s (2007) Design Science Research Methodology (DSRM) process model. Together, these frameworks offer a comprehensive understanding of how to structure and conduct DSR effectively.

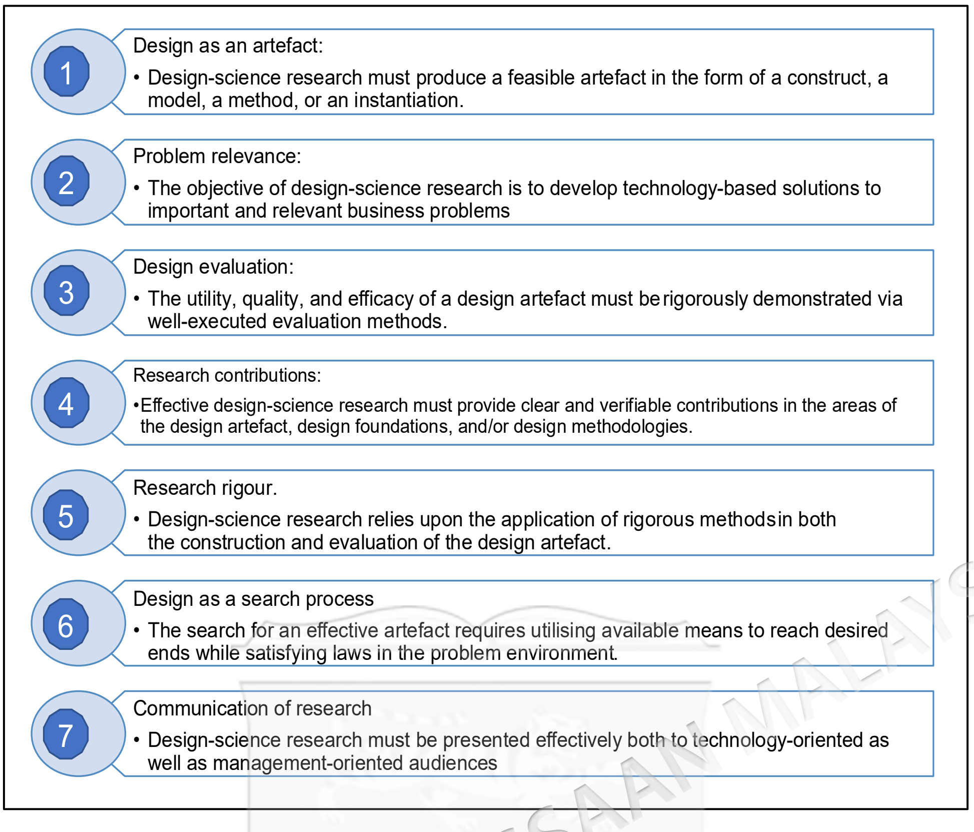


Figure 3.2 Seven guidelines for design science

Source: Hevner et al. 2004

Figure 3.2 illustrates the seven guidelines proposed by Hevner et al. (2004) for conducting design science research within IS. These guidelines act as principles to ensure that DSR studies maintain scientific rigor and relevance, balancing the dual objectives of utility (practical solutions) and truth (theoretical contributions). Each guideline is explained below in the context of VRDDM.

Guideline 1: Design as an Artefact

This guideline emphasizes the creation of viable artefacts as a core outcome of DSR. Artefacts can take many forms, including constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented systems). In the VRDDM context, the artefact is a comprehensive design methodology that guides the development of VR dashboards for smart farming. This includes ontological frameworks, UX principles, and practical templates tailored to the complexities of immersive environments. The VRDDM artefact embodies both theoretical advancements and practical tools to address real-world agricultural monitoring challenges.

Guideline 2: Problem Relevance

A critical element of DSR is ensuring that the problem addressed is relevant and significant. The research must focus on issues that are not only theoretically interesting but also practically pressing. In this study, the identified problem is the lack of a standardized, systematic approach for designing VR dashboards in smart farming a field characterized by complex, multidimensional data and the need for intuitive user interfaces. Existing VR dashboard designs tend to be ad-hoc, lacking consistency and transferability across applications (Arjun et al. 2022; Weidner & Broll 2022). The VRDDM framework directly addresses this gap, making the research highly relevant to both academia and industry.

Guideline 3: Design Evaluation

Evaluation is essential in DSR to demonstrate the utility, quality, and effectiveness of the designed artefact. This guideline calls for rigorous assessment using both naturalistic and artificial evaluation methods, such as case studies, experiments, simulations, and proof-of-concept implementations. In this thesis, the VRDDM framework and the prototype VR dashboard undergo evaluation through demonstration in simulated smart farming environments and feedback from domain experts. Metrics such as usability, effectiveness in supporting decision-making, and alignment with user needs provide evidence of the artefact's validity.

Guideline 4: Research Contributions

A robust DSR study must contribute to the knowledge base of IS. Contributions can take several forms: the invention of new artefacts, development of design theories, or enhancement of existing methodologies. The VRDDM makes multiple contributions: (1) a unified ontological framework for VR dashboard design, (2) a methodological blueprint for immersive dashboard development, and (3) empirical insights into the challenges of applying VR technologies in agriculture. These contributions advance both theory and practice by addressing a recognized gap in the literature and providing actionable solutions.

Guideline 5: Research Rigor

This guideline emphasizes the importance of conducting DSR with scientific rigor, ensuring the artefact is grounded in established theories and validated through appropriate methods. Rigor is achieved in this study by drawing upon theoretical underpinnings such as Ecological Psychology (Gibson 1979), Business Model Ontology (Osterwalder, 2005), and established UX principles. The iterative design-evaluation cycles embedded in the VRDDM development process further strengthen the methodological soundness of the research.

Guideline 6: Design as a Search Process

Design science views the creation of artefacts as a search process to find effective solutions within a problem space. This involves exploring and refining potential solutions through iterative cycles of design, testing, and evaluation. In VRDDM, this search process is evident in the development of prototypes (PoC1 and PoC2), where successive iterations incorporate insights from usability testing and domain expert feedback to optimize dashboard functionality and user experience.

Guideline 7: Communication of Research

Finally, DSR requires that research outcomes be effectively communicated to both academic and practitioner audiences. In this thesis, communication involves disseminating findings through scholarly publications, conference presentations, and the thesis itself. The clear articulation of VRDDM's theoretical foundations and practical applications ensures accessibility to a broad audience, fostering adoption and further refinement. Hevner et al.'s (2004) guidelines provide a robust framework for ensuring the scientific validity, relevance, and impact of DSR projects. Applied to

VRDDM, these guidelines ensure that the resulting framework is not only innovative but also theoretically sound and practically valuable.

Design science is a research paradigm mainly on developing and validating arbitrary knowledge. However, Peffers et al. (2007) emphasised that until now, the focal point in a study in information systems ignored the development of the consensus process, which is essential in the information systems domain. Hence, they proposed a methodology for the production and presentation of design research in information systems, which consists of six rules, as illustrated in Figure 3.3. The objective is to provide a mutually acceptable framework for future researchers to validate design science research without hassle.

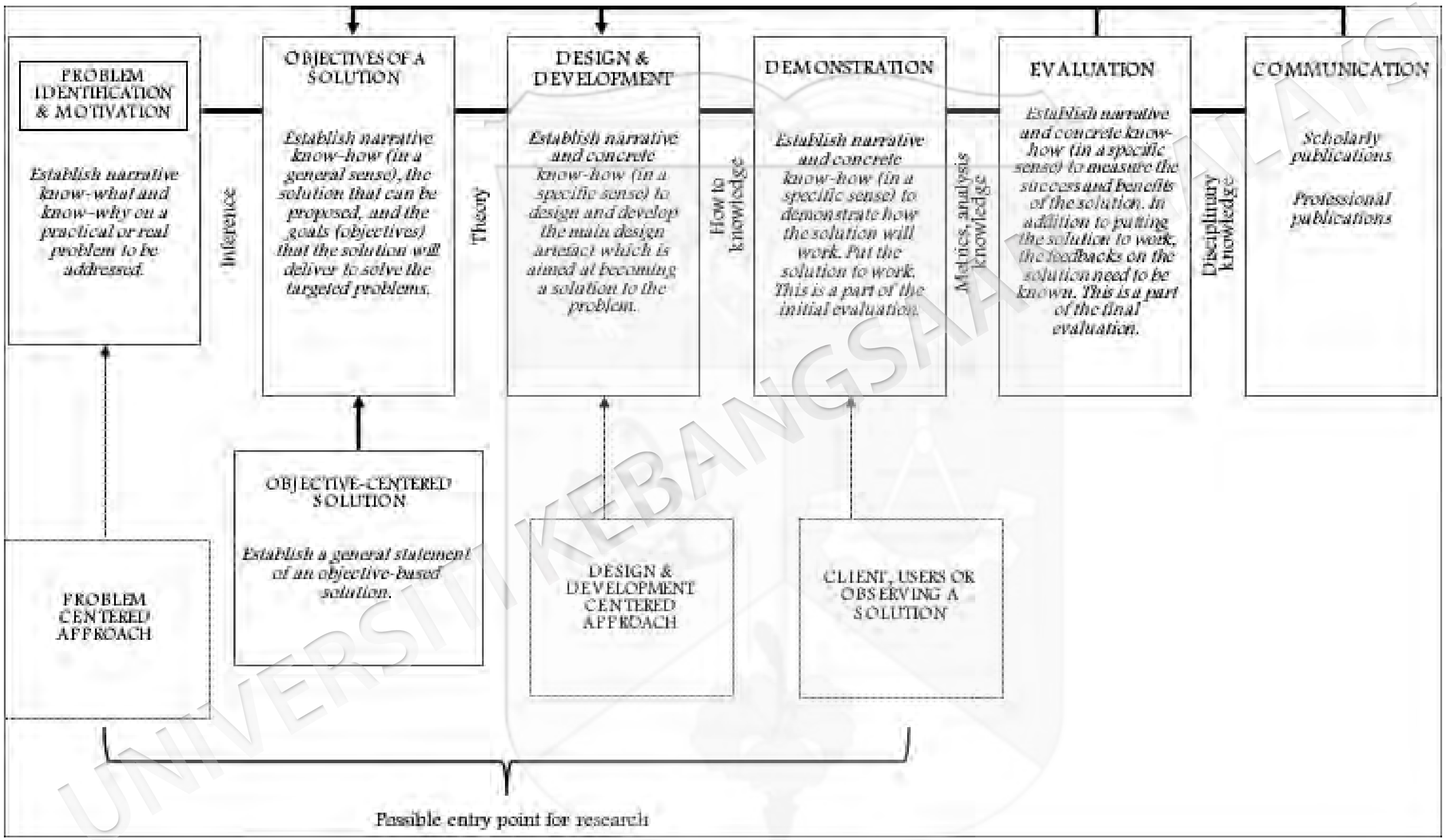


Figure 3.3 Design science research model (DSRM) process model

Source: Peffers et al. 2007

Figure 3.3 is adapted from Peffers et al. (2008), whose DSRM process has become the benchmark framework for artefact-driven research in the information-systems field. It highlights five iterative phases problem identification, objective definition, design and development, demonstration, and evaluation supported by a final communication phase. This generic model provides the theoretical foundation for this study by ensuring methodological rigor, traceability, and reproducibility across artefact iterations. However, the model itself remains intentionally broad and does not specify domain-specific adaptations, which motivates the need to tailor it to immersive VR dashboard design research.

3.3.1 Problem Identification and Motivation

Prior to the proposed DSR framework by Hevner et al. (2004), the problem identification is seen as essential in the DSR process, as well as debated by Kuechler and Vaishnavi (2008) and Peffers et al. (2007) to be the first step of the research, where a specific research problem should be defined and the value of a solution should be justified to ensure that the audience of the research understand the problem, thus motivating them to endure the outcome of the solution. Identifying specific problems and justifying the value of the solution to the problem is the main goal activity in this phase (Peffers et al. 2007). Nevertheless, Peffers et al. (2007) emphasised that as a result of the design process being unavoidably one of the limited and incremental solutions, the artifact pinpoint problem is not obligatory to translate directly to the objectives. Therefore, the research has to exhibit knowledge of the current state of the art and the pertinence of the identified problem.

3.3.2 Define Objective of the Solution

Peffers et al. (2007) identified defining the objectives of a solution as the second phase in DSR. The second step aims to surmise the objectives of a solution from the problem definition and knowledge of what is possible and feasible. The task in this phase requires knowledge of what is practicable and possible in the problem. There are two formations in the solution of the objectives that can be defined. First, it can proceed in qualitative form (e.g., clarification on how the prospect of a new artefact can provide a solution that has not been addressed); second, in the form of a quantitative approach (e.g., contributing to a new solution that is much better than the existing one). Therefore, to execute this phase, the necessary resources that encompass knowledge on the ongoing status of the problem, keep giving solutions, and their capability is indispensable.

3.3.3 Design and Development

The third phase of the research methodology focuses on the design and development of artefacts, which are created as tangible solutions to address the identified problems and objectives outlined in earlier stages. According to Hevner et al. (2004), Kuechler et al. (2008), and Peffers et al. (2007), these artefacts can take multiple forms, including conceptual constructs, theoretical models, methods, frameworks, system instantiations, or even the discovery of new properties within technical, social, and information systems. Essentially, artefacts represent the embodiment of the proposed solution, grounded in both theoretical foundations and practical requirements. The design process involves defining the architecture, components, and functional relationships of the artefact to ensure that it effectively aligns with the objectives and resolves the core issues identified in the problem statement. This phase also requires critical decisions about design parameters and iterative refinements to optimize the artefact's functionality, usability, and relevance to the target domain.

To successfully develop the artefact, it is imperative to integrate domain-specific knowledge, theoretical insights, and practical considerations. Resources such as relevant literature, existing technological infrastructures, and stakeholder inputs provide the foundational support needed for this phase. Additionally, an understanding of the underlying theories and frameworks contributes significantly to shaping the artefact's structure and capabilities. For instance, in the context of the Virtual Reality Dashboard Design Method (VRDDM), this phase would involve translating ontological representations into functional prototypes, applying UX design principles, and incorporating immersive visualization techniques to build a usable VR dashboard for smart farming. The resulting artefact must not only meet the functional requirements but also demonstrate its viability through initial testing and evaluation, setting the stage for the subsequent assessment of its effectiveness in real-world scenarios.

3.3.4 Demonstration and Evaluation

The fourth phase of the methodology proposed artefact demonstration on how the use of the artefact could solve the problem. Peffers et al. (2007) postulate the importance of demonstrating the proposed artefact usage in conveying the pinpointed problem in DSR. This could involve many methods such as experimentation, simulation, case study, proof, or other appropriate activities. Therefore, the important resource required in this phase is the knowledge of how the artefact can be used to address the problem.

Meanwhile, the fifth phase, namely, evaluation, involves observing and measuring how well the artefact underpins a solution to the problem. This activity needs knowledge of relevant metrics and the proper technique in the analysis. The evaluation process can be conducted in many forms depending on the problem characteristic and the artefact. Despite that, feedback from the users/clients, the survey of users/clients' satisfaction or the simulation dashboard can be used to resemble artefact functionality and result with defined objectives. Previous researchers noted the evaluation as the key phase in demonstrating the utility, relevance, and efficacy of the design artefacts (Hevner et al. 2004; March et al. 1995; Walls et al. 1992).

3.3.5 Communication

The final phase of the Design Science Research (DSR) methodology is communication, which focuses on effectively disseminating the knowledge, insights, and artefacts developed during the research process. This dissemination is crucial for ensuring that the contributions of the study reach both academic and practitioner audiences, enabling others to build upon, validate, or apply the findings in real-world contexts. Peffers et al. (2007) emphasize that this phase should convey the relevance and utility of the artefacts, the rigor of the research process, and the implications of the results. Communication can take various forms, including dissertations, journal articles, conference presentations, technical reports, or even workshops and seminars for industry stakeholders. The ultimate goal is to make the knowledge accessible and actionable for those in both research and practice communities.

Peffers et al. (2007) further suggest that DSR publications can follow a structure similar to that of behavioral science papers. This involves beginning with a clear definition of the research problem, followed by a comprehensive literature review to establish the theoretical context. Subsequently, the development of hypotheses, description of the artefact design and development, data collection methods, analysis, presentation of results, discussion of implications, and a concluding summary are presented. Such a structured approach ensures that the communication is systematic, coherent, and persuasive, highlighting both the theoretical contributions and the practical value of the research outcomes.

3.4 DESIGN SCIENCE RESEARCH METHODOLOGY: AN APPLICATION

3.4.1 Identify Problem and Motivation

Problem identification is made by highlighting current problems in the traditional agricultural process compared to ICT technology, especially in VR monitoring using a VR dashboard. The past studies selected as research material involve the development of a dashboard using VR technology. Through these studies, I identified the problem that there is a gap in the current and previous studies, where there is no literature that discusses in detail how to build as well as the necessary standards to build a VR dashboard. Therefore, an apparent motivation to develop a VR dashboard design method (VRDDM) is obtained for this study.

3.4.2 Define the Objectives of a Solution

In this study, the objectives of the proposed solution are derived systematically from the research questions, which are themselves informed by insights gathered from prior studies and the articulated problem statement. These objectives address critical challenges related to the Virtual Reality Dashboard Design Method (VRDDM), particularly concerning user experience (UX) design principles, current practices, established guidelines, and their applicability within the smart farming domain. To ensure relevance and rigor, a narrative literature review was conducted to explore existing approaches and highlight limitations in current VR dashboard implementations. This review process revealed a significant research gap, underscoring the need for a structured and ontologically grounded framework like VRDDM to support immersive data visualization and decision-making in agricultural contexts. Consequently, the defined objectives not only aim to bridge theoretical gaps but also to provide practical solutions tailored to the dynamic and data-rich environments of smart farming systems.

3.4.3 Design and Development

The Virtual Reality Dashboard Design Method (VRDDM) framework will be systematically designed and developed, incorporating an ontological representation that serves as its conceptual backbone. This ontological layer will ensure semantic clarity and consistency across the design elements, facilitating a standardized approach to dashboard development in virtual environments. Building upon the insights and gaps identified in prior studies, the design will intentionally address known issues related to UX design principles, user interaction complexities, and domain-specific requirements in smart farming applications.

Ontology design and modelling will play a crucial role during this phase, as it will define the relationships between key entities such as environmental variables, user roles, and actionable insights. The VRDDM framework will then be instantiated through the creation of a functional prototype: a VR dashboard tailored for smart farming monitoring tasks. This prototype will integrate real-time data visualization, user interaction mechanisms, and immersive navigation features.

The prototype will undergo iterative testing across multiple environments and usage scenarios, including simulated smart farming settings, to evaluate its robustness, adaptability, and usability. Feedback from these tests will inform refinements to both the ontology and the VRDDM framework, ensuring it is practical and effective for real-world deployment.

3.4.4 Demonstration and Evaluation

The development of a prototype VRDDM marks a crucial step in the demonstration and evaluation process, allowing for tangible implementation and testing of the conceptual framework. This prototype will serve as a practical manifestation of the VR dashboard and VRDDM framework, enabling hands-on experimentation and refinement. The application of VRDDM will be demonstrated across various environments, providing a comprehensive understanding of its functionality and adaptability in different contexts. This multi-faceted approach to testing will yield valuable insights into the optimal design of the VR dashboard and the most effective implementation strategies for the VRDDM framework.

A key aspect of the evaluation process involves gathering and analyzing feedback from developers who implement the VRDDM. Their insights and experiences will be meticulously collected and summarized, offering a wealth of practical knowledge that can inform further improvements and optimizations. This feedback will be particularly valuable when evaluated in the context of smart farming scenarios, allowing for a targeted assessment of VRDDM's performance and utility in agricultural applications. By synthesizing developer feedback with the specific requirements and challenges of smart farming, the evaluation process will yield a nuanced understanding of VRDDM's strengths and areas for enhancement. This comprehensive approach to demonstration and evaluation ensures that the final VRDDM solution is not only theoretically sound but also practically effective and user-friendly, paving the way for its successful adoption in real-world agricultural settings.

3.4.5 Communication

The development of VRDDM in this study has far-reaching implications, offering potential benefits to various industries and researchers worldwide. To ensure the widespread dissemination of this valuable knowledge, professional publications will be strategically targeted as primary channels for sharing the research findings. This approach not only facilitates the transfer of information but also encourages further dialogue and collaboration within the scientific community. As part of the communication process, it is crucial to summarize and discuss the key research contributions, highlighting the innovative aspects of VRDDM and its potential applications across different sectors. This summary will serve as a cornerstone for crafting compelling articles and presentations that effectively convey the significance of the study. Additionally, the process of thesis writing, and presentation plays a vital role in communicating the research outcomes comprehensively. This thesis will provide an in-depth exploration of the methodology, results, and conclusions, serving as a valuable resource for future researchers and practitioners interested in VRDDM. Through these combined efforts of targeted publication, concise summarization of contributions, and thorough thesis preparation, the study's impact can be maximized, fostering advancements in the field and inspiring further innovations in related areas.

This study addresses a critical gap in the literature regarding the development and standardization of VR dashboards, particularly in the context of smart farming. Utilizing a design science research methodology, we identified the need for a VR dashboard design method (VRDDM) is identified and a framework with ontological representation to address this gap is developed. The research encompassed UX design principles, practices, and guidelines specific to the agricultural domain. A prototype VR dashboard for monitoring smart farming was created and tested in various environments to validate the VRDDM framework. The iterative process of demonstration and evaluation led to refinements in both the dashboard design and the framework. This research contributes valuable insights to the field of VR application in agriculture and has potential implications for other industries, paving the way for future advancements in VR dashboard development and implementation.

Figure 3.4 presents a comprehensive overview of a research process, focusing on the development of a standardized method for designing Virtual Reality (VR) dashboards in smart farming. The diagram is structured into three main columns: "Research Processes," "Activities Involved," and "Outputs," illustrating the sequential steps of the research project from problem identification to final communication of results.

The study began with a comprehensive literature review focusing on three key areas: the comparison between traditional and modern farming methods, various approaches in smart farming, and the application of ICT and VR technologies for smart monitoring. Through this review, the study aims to gain an in-depth understanding of current challenges and issues in smart farm monitoring approaches. This initial process helps identify specific problems related to VR dashboard design methods in the context of smart farming. The exploration of existing literature and current practices provides a solid foundation for understanding the gaps and challenges in the field, ultimately highlighting the critical issues that need to be addressed in VR dashboard design methodology.

Building upon the identified problems, the next process is in defining the objectives of a solution. This process focuses on establishing a narrative review of the Virtual Reality Dashboard Design Method (VRDDM). The process involves analyzing existing approaches and methodologies to define common requirements for an effective VRDDM and its underlying design principles. Through careful examination of current practices and identified gaps, the research objectives are clearly defined and articulated. This process results in a comprehensive understanding of the issues surrounding VR dashboard design methods and establishes specific objectives that will guide the development of the solution.

The design and development process centers on creating an ontological representation of the Virtual Reality Dashboard Design Ontology (VRDDO). This process involves identifying and implementing foundational theories, specifically utilizing the Business Model Ontology (BMO) and EPP theory as theoretical frameworks. The implementation incorporates Unified Ontology Architecture (UOA) and Unified Foundational Ontology (UFO) to establish a robust conceptual framework for VRDDM. The output of this phase is a comprehensive ontology specifically designed for VR dashboard applications in smart farming, supported by a well-defined conceptual framework that guides the design process.

In the demonstration process, the VRDDM framework is put into practice through the development of a prototype VR dashboard specifically designed for smart farm monitoring. The demonstration involves practical implementation of the framework's principles and guidelines, resulting in a functional VR dashboard prototype. This phase focuses on bringing the theoretical framework into reality, allowing for hands-on testing and validation of the design method. The demonstration phase produces a tangible output in the form of a developed VR dashboard prototype, which serves as a proof of concept for the proposed design method.

The evaluation process encompasses a thorough assessment of the implemented prototype through various testing scenarios. Developer feedback is collected and analyzed regarding both the implementation of VRDDM and the prototype VR dashboard. This phase involves detailed discussions of all tested scenarios and comprehensive analysis of the feedback received. The evaluation process generates valuable insights through systematic testing and assessment, resulting in detailed evaluation results based on real-world testing scenarios, which helps validate the effectiveness and practicality of the proposed design method.

The final process focuses on synthesizing and disseminating the research findings. This involves summarizing and discussing the research contributions, followed by the preparation of the thesis document and its presentation. The communication phase ensures that all aspects of the research, from problem identification to evaluation results, are effectively documented and presented. The output includes comprehensive documentation of the research findings, contributions to the field, and recommendations for future work, all presented in a well-structured thesis format that effectively communicates the research's value and implications.

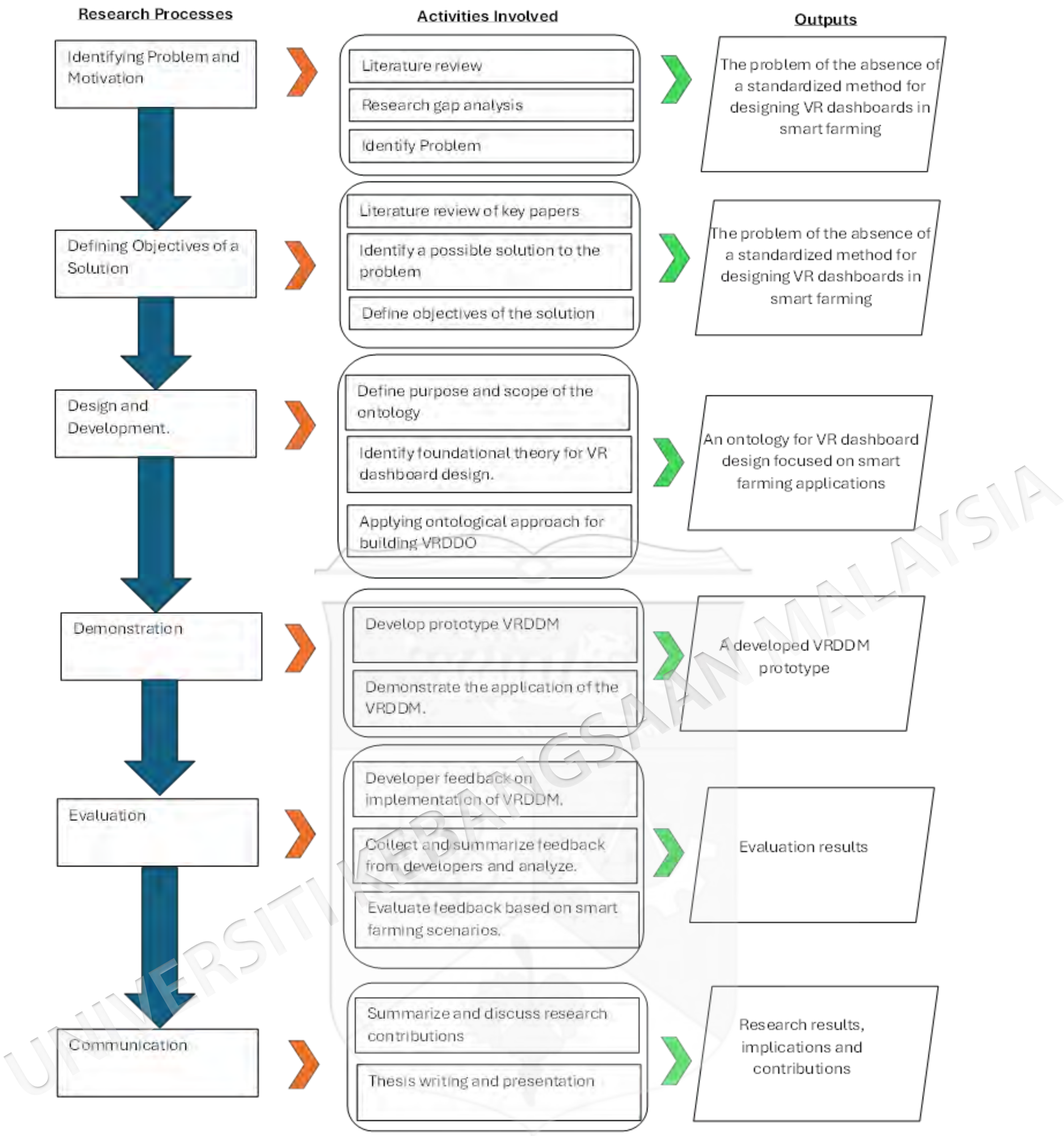


Figure 3.4 Summary of Research Design Based on the DSR Methodology

Figure 3.4 presents the customized research design for this study, expanding Peffers et al.'s original framework to align with the specific goals of developing the Virtual Reality Dashboard Design Method (VRDDM) and its supporting Virtual Reality Dashboard Design Ontology (VRDDO). While Figure 3.3 depicts the general DSRM flow, Figure 3.4 illustrates how each phase is operationalized within this research.

In the problem identification phase, the study defines the absence of a standardized method for VR dashboard design in smart-farming contexts. During objective definition, theoretical foundations such as the Unified Ontological Approach (UOA), Business Model Ontology (BMO), and Ecological Psychology Perspective (EPP) are integrated to inform the structure of the proposed method. The design and development phase transforms these theoretical elements into the ontological framework (VRDDO) that serves as the semantic core of VRDDM. Demonstration involves implementing two Proof-of-Concepts (PoC1 and PoC2) to validate usability and practical relevance, while evaluation captures expert feedback and iterative refinement. Finally, communication disseminates the results through academic and professional channels.

The main contribution visualized in Figure 3.4 lies in the synthesis of DSRM with ontology-based modelling to produce a repeatable, theory-driven methodology for VR dashboard design. This integration transforms the traditional DSRM cycle into a structured framework capable of handling immersive, multi-sensor, and interactive environments providing both theoretical advancement and practical guidance for future VR system researchers and practitioners.

3.5 SUMMARY

This chapter has outlined the methodological foundation underpinning this research, grounded in the Design Science Research Methodology (DSRM) as proposed by Peffers et al. (2008). The chapter began by situating DSRM within the broader information systems research paradigms and establishing its suitability for studies that focus on the creation and evaluation of artefacts. It then detailed how each phase of DSRM problem identification and motivation, objective definition, design and development, demonstration and evaluation, and communication was systematically applied in this research to develop the Virtual Reality Dashboard Design Method (VRDDM) and its supporting Virtual Reality Dashboard Design Ontology (VRDDO).

The methodology section also emphasized the iterative and integrative nature of the research process. Ontology engineering was incorporated within the DSRM framework to formalize the conceptual structures of VR dashboard design, ensuring that the resulting method is both theoretically grounded and practically reproducible. The inclusion of Ecological Psychology Perspective (EPP) and Business Model Ontology (BMO) provided additional theoretical rigor, linking human–environment interaction principles with systematic design modelling. These theoretical integrations strengthened the epistemological foundation of the study by bridging conceptual and empirical dimensions.

Furthermore, this chapter described how the methodology supports the development of artefacts that directly respond to the gaps identified in Chapter 2 specifically, the absence of a standardized design method for VR dashboards in smart farming contexts. The forthcoming chapter, Chapter 4: Design and Development, operationalizes this methodology by detailing the construction of the VRDDO, the formulation of the VRDDM, and their demonstration through two Proof-of-Concept (PoC) implementations. Collectively, these methodological steps ensure a coherent pathway from theoretical justification to practical application, thereby validating both the design and research contributions of this study.

CHAPTER IV

DESIGN AND DEVELOPMENT

4.1 INTRODUCTION

Few (2013) has defined a dashboard as “a predominantly visual information display that people use to rapidly monitor current conditions that require a timely response to fulfil a specific role”. A VR dashboard provides a visual display to the user by extracting or collecting data and manipulating data supplied through IoT (e.g., sensors, antenna, microcontroller) by using the data either from open-source databases, big data, and also manually gathered data such as from questionnaire form, a user manually inputs data through a graphical user interface (GUI) or even through VR equipment (e.g., HMD, eye gaze tracker) smartphone, and heart rate monitor (Arjun et al. 2022; Baltabayev et al. 2018; Bartosh & Gu 2019; Lutters & Damgrave 2019; Moran et al. 2015; Mukhopadhyay et al. 2022; Vock et al. 2021; Weidner & Broll 2022; Yoo et al. 2018).

Restate the widespread use of dashboards in practice; dashboard design remains subject to various challenges. Some recurring problems in dashboard design are poor use of space, superfluous or insufficient information, and unaesthetic visual elements. Deploying dashboards improves information comprehension and decision-making while synthesising large or disparate data types and sources (Conrow et al. 2023; Few 2013). Facing complex mobility data, developing a dashboard involves more than visualising data with existing methods. Additional aspects must be considered, such as data type, volume, frequency of updates, the dashboard’s purpose, and intended user base (Li et al. 2020; Stehle & Kitchin 2020). Therefore, VRDDM is believed to give a standard design to build a VR dashboard. This chapter presents the design and development process of VRDDM by defining the critical building blocks of VRDDM in Section 4.2. Each block will be discussed in the form of endurant and perdurat elements that become a foundation of the blocks. Section 4.3 will explain in more detail what endurant and perdurant involves in each key block; and the subsection below 4.3 will cover each fundamental block according to the classification of endurant and perdurant. Section 4.4 will introduce an ontology to build a Visual Reality Development Design Ontology (VRDDO) for each classification made. Meanwhile, Section 4.5 will discuss the evaluation process, which is the step involving the demonstration and evaluation process as described briefly in Section 3.4.4

4.2 THE KEY BUILDING BLOCKS FOR VRDDO

Based on previous studies presented in Chapter 2, twelve (12) key blocks have been emphasised in designing and building a VR dashboard. Therefore, these elements have been identified in building a standard method to design and build a VR dashboard. The twelve (12) key blocks as illustrated in Figure 4.1.

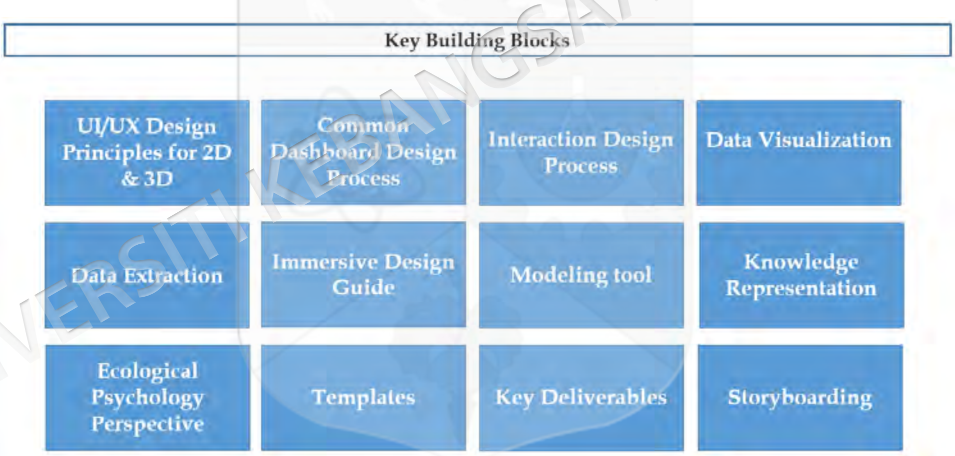


Figure 4.1 Key building blocks of VRDDO

The building blocks that constitute the Virtual Reality Dashboard Design Method (VRDDM) were derived and refined based on the limitations and insights identified in prior works discussed in Chapter 2 (VRdash01–VRdash12). For example, Arjun et al. (2022) and Lutters & Damgrave (2019) highlighted the importance of user-centric interfaces and operational visualization but lacked a formal design model to guide such development. These studies informed the UI/UX Design Principles component of VRDDM. Similarly, Setti & Csapo (2021) and Weidner & Broll (2022) contributed to understanding interaction design within immersive environments but did not provide a reusable framework; hence, VRDDM integrates their findings within a structured ontological schema to ensure consistency and replicability.

The Data Extraction and Visualization blocks were motivated by works such as Mukhopadhyay et al. (2022) and Vock et al. (2021), which demonstrated VR's potential for monitoring and real-time data interaction yet lacked a systematic linkage between data sources and interface components. VRDDM addresses this gap through ontology-driven data mapping and visualization design. Meanwhile, Bartosh & Gu (2019) and Baltabayev et al. (2018) informed the Immersive Design Guide through their exploration of spatial affordances and visual feedback mechanisms, which in VRDDM are formalized into ontological constructs for perceptual consistency.

Collectively, these prior studies shaped the conceptual foundation of the VRDDM building blocks while also revealing the need for a unified, theory-driven design method that connects visualization, interaction, and ontology. Chapter 4 operationalizes these concepts into a coherent methodological framework that responds directly to the fragmentation identified in Chapter 2's literature review.

4.2.1 UI/UX Design Principles for 2D and 3D

UI/UX principles are principles that developers must follow to ensure that users can fully utilise the built dashboard. In designing and building a VR dashboard, the principles that need to be followed are slightly different, considering that users can experience the 'true feeling' of exploring the world outside of reality. In 2D UI/UX design, depth is not primarily used as in 3D design, and 2D design is simpler, does not require more sophisticated software, and follows certain principles (Arjun et al. 2022; Millais et al. 2018). Therefore, 5 (five) main principles need to be emphasised in UI/UX visual or 3D design, as suggested by Siang (2022) and Gordon (2020), namely scale, visual hierarchy, balance, contrast, and gestalt. Many previous studies also implemented the principle in their VR dashboard design and development (Arjun et al. 2022; Baltabayev et al. 2018; Bartosh & Gu 2019; Lutters et al. 2019; Millais et al. 2018; Mukhopadhyay et al. 2022; Setti et al. 2021; Weidner & Broll 2022; Vock et al. 2021).

Scale refers to the relative size of the elements found in the design to create a depth effect. It is closely related to the principle of visual hierarchy, especially in 3D design which further shows the element's importance compared to other elements. Scale can also provide a teleportation effect to users when browsing the VR environment (Bartosh & Gu 2019). The principle of visual hierarchy is also shown by varying the written text, such as the text font size (Bartosh & Gu 2019; Gordon 2020; Siang 2022). Visual hierarchy is used to divert attention and control users in a VR environment using scale, colour combinations and various other signals (Gordon 2020). Balance is important to ensure the VR design is balanced and attractive which is also implemented in 2D design and it is more emphasised in 3D design. Balance does not necessarily have symmetrical elements but emphasises the layout and proportion of satisfactory elements (Gordon 2020; Setti et al. 2021). Contrast ensures that the UI/UX stands out on the dashboard which is usually associated with the size and colour of the design element or background. Gordon (2020) defined contrast as the principle of the juxtaposition of visually dissimilar elements to convey the fact that these elements are different.

Meanwhile, gestalt refers to how a person can simplify and organise an image consisting of various elements and complex into individual elements. Gestalt has several principles as well, namely 6 (six) main principles are similarity, continuation, closure, proximity, common region, and pragnanz (good figure/ground) (Cherry 2023; Gordon 2020). Table 4.1 is a summary of the parameters found in the key block UI/UX design principles for 2D and 3D.

Table 4.1 Summary of parameters and elements involved in UI/UX design principles

Parameter	Element
Scale	Relative size
Visual hierarchy	Relative importance
Balance	Design evenly
Contrast	Stand out
Gestalt	Similarity, continuation, closure, proximity, common region, pragnaz

4.2.2 Data Extraction

The data extracted or collected is to see and illustrate the previously likely unknown data, and this action will impact a social response; knowledge about something important and principles to understand why it is essential must be co-generated or co-produced. The extracted or collected data will likely involve certain laws and regulations depending on the data collected (Jasanoff 2017). The most recent framework by XR Safety Initiative, 2020; already listed VR data under General Data Protection Regulation of biometric data (Carter & Egliston 2023). Therefore, it is vital to ensure all regulations and laws regarding the data extraction or collection process or the data itself is clear before the data is visualised through the VR dashboard.

The process of data extraction or collection in the design and development of VR dashboards is done with the help of various tools and techniques (e.g., ANOVA, Steichen's study, digital signal processing) and also using specific AI algorithms (e.g., ANN, Expectation-Maximization, Butterworth lowpass filter) to facilitate data classification and decision-making processes. Accurate data extraction using the right tools and algorithms is important to ensure that the visuals displayed on the VR dashboard are useful for users. Data extraction is performed with various methods according to the source of the extracted data. Table 4.2 shows a summary of how data is extracted according to the data source. However, before the data is extracted or gathered, all the rules/laws that abide with data must be obeyed.

Table 4.2 Summary of data extraction process according to the data source tools

Data Source Tools	Data Extraction Process
IoT	1. Setup IoT sensors and cameras, 2. Mapped sensors with appropriate properties, 3. Set platforms/devices to receive data (2D data), 4. Transfer 2D data to 3D platforms/devices, 5. Analyse the data to design the VR space, and 6. Visualise the data on the VR dashboard
Questionnaire	1. Design questions, 2. Distribute the questionnaires, 3. Collect the questionnaires, 4. Analyse the answers gathered from the questionnaires to design the VR space, and

… to be continued

… continuation

	5. Visualised the data on the VR dashboard
GUI	1. Design GUI, 2. User key-in the input through GUI, 3. Analysed user input to design the VR space, and 4. Visualised the data on the VR dashboard
VR equipment	1. Setup VR equipment, 2. Brief the user on how to use the VR equipment, 3. Interview the user after their experience in the VR environment/capture the user’s eye movement, 4. Analyse the data to design the VR space, and 5. Visualised the data on the VR dashboard
Smartphone	1. Transfer 2D data to the appropriate 3D platform/device, 2. Analyse the data to design the VR space, and 3. Visualised the data on the VR dashboard
Heart rate monitor	1. Setup device to track the user's movement, transfer data to the appropriate 3D platform/device, 2. Analyse the data to design the VR space, and 3. Visualised the data on the VR dashboard

4.2.3 Domain Model and Knowledge Representation

Knowledge representation is closely related to ontology which refers to the formal specification of the domain of knowledge or set of concepts and categories in a subject area, in this case, the domain model of VRDDM. Visualise a process or work in the form of a dashboard to help users see more clearly in helping with daily work. However, building a VR dashboard that can interact with users requires a highly structured and semantically rich ontology that links concepts and accurate relationships in the VRDDM knowledge domain Visual Reality Design Development Ontology (VRDDO) is a must. The VRDDO will be discussed in detail in Section 4.2.

Ontology in the VRDDM model domain allows users to identify transparent relationships between different entities in the data. Figure 4.2 illustrates graphical descriptions and definitions between elements and sub-elements of the VRDDM domain model. However, none of the studies in VR dashboard development discusses the importance of ontology in ensuring that an integrated knowledge representation is created.

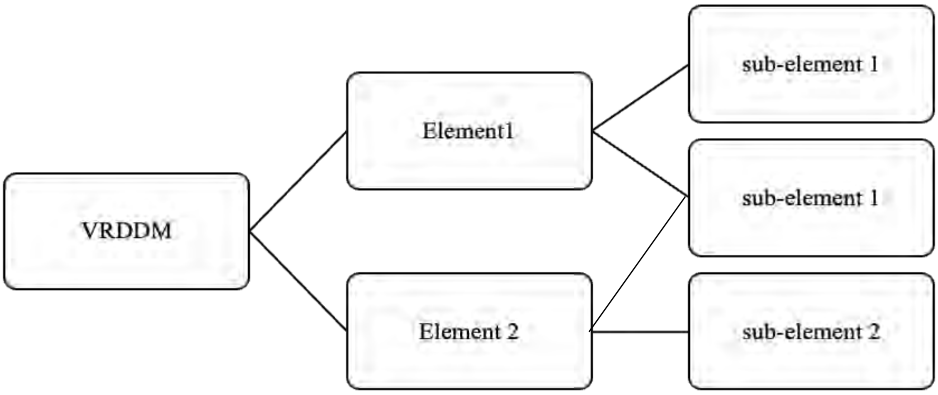


Figure 4.2 Graphical illustration of an element of the ontology of the VRDDM domain model

Figure 4.2 illustrates a single ontological element within the VRDDM domain model and its hierarchical decomposition into Sub-Element 1 and Sub-Element 2. The main element represents a high-level concept such as “VisualizationEntity” or “InteractionAffordance” in the ontology. Sub-Element 1 denotes the attributes or properties that define this entity (for example, colour scheme, position, or data-binding type). Sub-Element 2 represents the relationships connecting this element to other entities (for example, linking a VisualizationEntity to a DataSource or UserAction class).

This layered representation clarifies how each element in the VRDDM is both individually described (through its sub-elements) and semantically linked within the broader VRDDO. The upper node captures the conceptual abstraction, while the lower nodes formalize the implementation logic. In the prototype demonstrations (PoC 1 and PoC 2), these sub-elements were translated into practical parameters—such as visual panels (Sub-Element 1) and interactive sensor connections (Sub-Element 2)—demonstrating how the ontology governs the VR dashboard’s structure and interaction design.

4.2.4 Common Dashboard Design Process

Designing a VR dashboard is a rather complicated process because it involves various gadgets and software and requires 2D data input that needs to be modified according to

3D to be manipulated into the VR dashboard (Arjun et al. 2022; Baltabayev et al. 2018; Bartosh & Gu 2019; Lutters & Damgrave 2019; Mukhopadhyay et al. 2022; Vock et al. 2021; Weidner & Broll 2022; Yoo et al. 2018). However, several steps in the process of building a VR dashboard may differ from one process of building a VR dashboard that requires a framework that all developers can use. Therefore, a standard process must be built to help VR dashboard developers build dashboards more quickly and effectively, mainly using templates. Figure 4.3 illustrates the standard design process of a VR dashboard summarised from a previous study in VR dashboard development which highlighted the steps of VR dashboard design and development in their study (Arjun et al. 2022; Baltabayev et al. 2018; Bartosh & Gu 2019; Millais et al. 2018; Mukhopadhyay et al. 2022; Vock et al. 2021; Weidner & Broll 2022; Yoo et al. 2018).

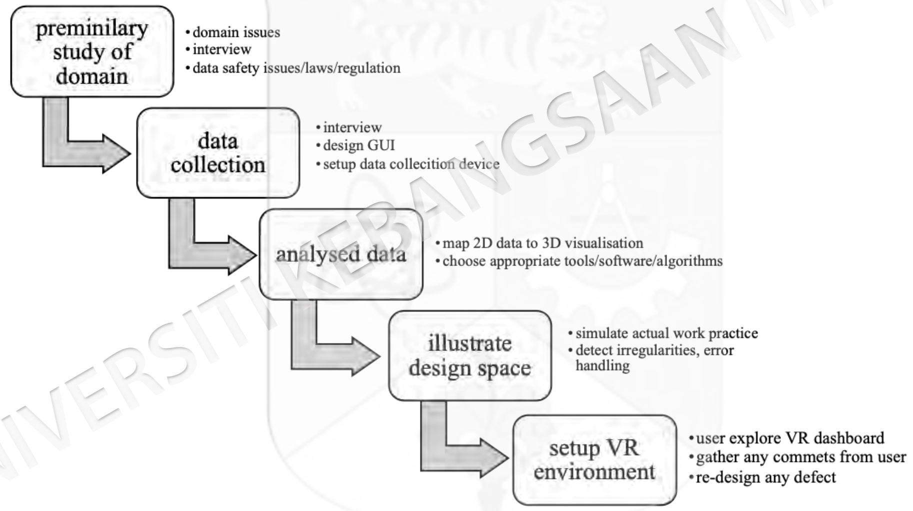


Figure 4.3 Common VR dashboard design process

4.2.5 Templates

The use of design templates provides a structured starting point for developers and researchers to create VR dashboards consistently and efficiently. Templates encode pre-defined layout configurations, visualization types, and interaction patterns derived from the VRDDO concepts. These reusable blueprints accelerate design iterations, reduce cognitive load for new users, and maintain conformity with ontological definitions. Templates can be suitably positioned as a unifying layer between knowledge representation and user interface generation ensuring that every instantiated dashboard adheres to both functional and aesthetic guidelines defined in the VRDDM. Templates can also provide a starting point for building a dashboard by using various types of software to create a unique dashboard. The advantage of using templates in VR dashboard development is that it can help unify the workspace and save time because building a dashboard from scratch is no longer necessary. Templates allow dashboard replication across various collections and workspaces (mondayblog 2022).

4.2.6 Interaction Design Process

Immersiveness in VR is very important; therefore, the designer must get a clear direction of the user's needs and avoid confusion in the development process. Therefore, good interaction with the user in the VR dashboard design process can improve the overall efficiency of the design. Interaction design, known as IxD is synonymous with the world of VR which focuses on user experience. Developers use ixD process to create user-centric solutions related to user needs, goals and behaviour when interacting with products to ensure usability-related issues can be addressed (Gong et al. 2020). Based on the research in the VR dashboard (refer to Table 2.2) and as stated by Interior Design Foundation (2020) it can be concluded that there are five stages involved in the IxD process, namely discovering what users need, analysing user need, designing a potential solution, prototyping and implementing, and deploying (Arjun et al. 2022; Millais et al. 2018; Vock et al. 2021; Weidner & Broll 2022; Yoo et al. 2018). Figure 4.4 illustrates the IxD process.

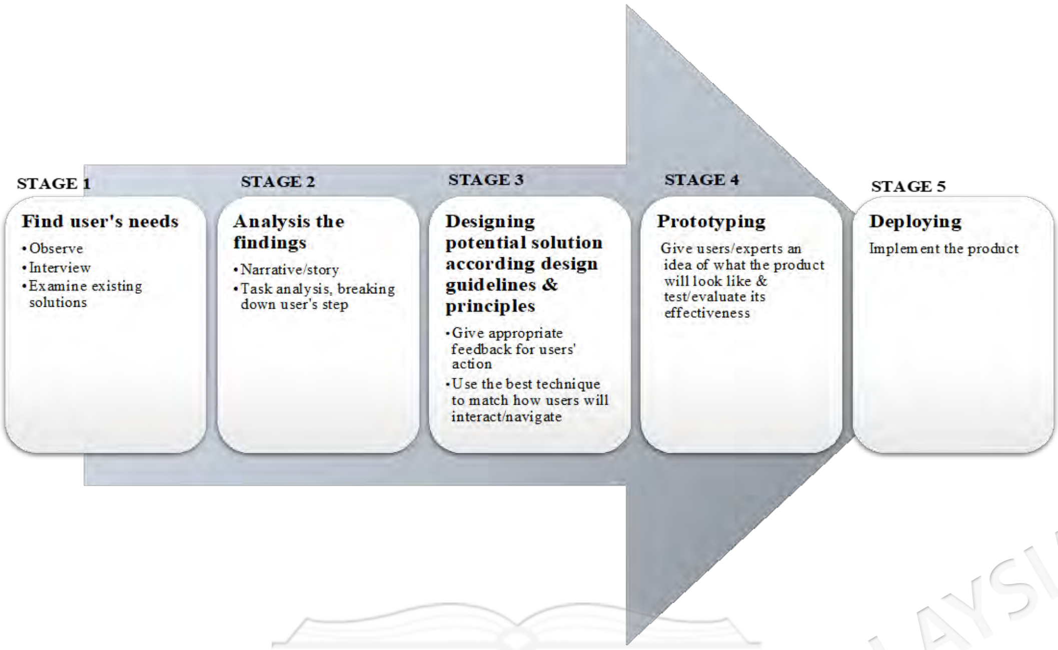


Figure 4.4 Stages in the interaction design process

4.2.7 Data Visualisation and Modelling Tools

Dashboard has gained popularity for data visualization in various fields such as manufacturing, health, smart city and farming (Li et al. 2020; Goap et al. 2018; Shamsuzzoha et al. 2016; Youcef et al. 2021). This data visualisation process involves different types of data, tools and various methods and techniques that require the help of several different tools simultaneously, especially if it involves a VR environment. VR elements include a virtual world, immersion, sensory feedback, and interaction. There are mainly six components in VR systems: i) computing devices, ii) a headset, iii) sensors, iv) input devices, v) audio system, and vi) software. The 3 (three) primary types of VR are: i) non-immersive ii) semi-immersive, iii) fully immersive. 3D is used to create a VR world, but the VR part is slightly different. VR is a levelled-up version of 3D simulation. VR is experienced through a headset that connects to a 3D simulation on a device (often a computer or gaming console). Therefore, data visualisation for the VR dashboard must be facilitated by numerous tools, templates and devices to model and visualise the data in the dashboard.

4.2.8 Immersive Design Guide and Ecological Psychological Perspective

The Immersive Design Guide serves as a practical reference for implementing the affordance and presence principles described in the Ecological Psychology Perspective (EPP). It provides detailed parameters on spatial positioning, interaction feedback, balance, contrast, and visual hierarchy to enhance user engagement and situational awareness. The guide ensures that data visualization in VR not only represents information accurately but also aligns with the perceptual and behavioral expectations of users in a 3D environment.

4.2.9 Storyboarding

Storyboarding is a crucial pre-visualization technique used in various creative fields, including VR dashboard design. In the context of VR data visualization, storyboarding involves creating a sequence of sketches or illustrations that outline the user's journey through the virtual environment and their interactions with the data displays. This process helps designers plan the layout, flow, and key elements of the VR dashboard before investing time and resources into full development. Storyboarding is particularly important in VR dashboard design because it allows designers to anticipate and address potential issues with user experience, spatial arrangement, and information hierarchy in a 3D environment. It helps in crafting a cohesive narrative for data exploration, ensuring that users can navigate and interpret complex information intuitively. By mapping out the user's journey, designers can optimize the placement of data visualizations, control panels, and interactive elements to create a more immersive and efficient data exploration experience.

An example of work incorporating storyboarding in VR dashboard design is the study by Mahmood et al. (2020), titled "Storyboard-Based Immersive Analytics." In this research, the authors propose a storyboard-driven approach to designing immersive analytic systems, including VR dashboards. They demonstrate how storyboarding can be used to plan user interactions, data transformations, and visualization transitions in a virtual environment. The study showcases how this method can lead to more engaging and effective data exploration experiences in VR. Another relevant work is by Chen et al. (2021), who discuss the use of storyboarding in designing a VR-based visual analytics system for urban planning. Their approach emphasizes the importance of storyboarding in creating a narrative flow for complex spatial data analysis in virtual environments. These examples highlight how storyboarding serves as a bridge between conceptual design and final implementation, ensuring that VR dashboards are not only visually appealing but also functionally effective and user-centric. Storyboarding supplements the visual aspects of a VR dashboard allowing information to be presented in an organized manner. In VR environments, a user can experience can be overwhelming due to 360° visual field of view (FoV). Therefore, it is essential that the information presented in VR dashboards to have a flow of structured data presented to user properly while maintaining information clarity and immersion.

4.2.10 Use of AI in Storyboarding

Recent advancements in Artificial Intelligence (AI), particularly Generative AI (GenAI) and large language models (LLMs), have introduced new opportunities for enhancing the storyboarding process in VR dashboard design. Traditionally, storyboarding has been a manual, time-consuming task that requires significant artistic and technical expertise to create detailed sketches and user journey narratives. AI technologies can now automate and augment these processes, offering designers powerful tools to conceptualize and iterate storyboard designs more efficiently and effectively.

One of the key applications of AI in storyboarding is through natural language processing (NLP) and text-to-image generation models. Designers can provide high-level textual descriptions of user interactions or desired VR dashboard features, and AI systems such as OpenAI's DALL·E, MidJourney, or Stable Diffusion can generate corresponding visual storyboard panels. This capability allows rapid prototyping of multiple design scenarios without requiring advanced drawing skills, enabling teams to explore diverse design alternatives early in the development phase. For instance, a designer could input a prompt such as, "A farmer interacts with a 3D soil moisture map in a VR dashboard using hand gestures," and the AI would produce an illustration capturing the envisioned scene. This approach reduces iteration cycles and helps communicate ideas visually to stakeholders or interdisciplinary teams.

AI can also assist in structuring storyboards by analyzing user requirements, domain knowledge, and interaction patterns. Machine learning algorithms can process previous user studies, system logs, and design guidelines to suggest logical sequences of user actions and system responses. Such AI-driven insights can inform storyboard narratives that are more aligned with real-world usage contexts, enhancing the user-centricity of VR dashboard designs. Moreover, AI tools like ChatGPT can generate descriptive narratives for each storyboard frame, outlining user objectives, system feedback, and potential pain points. This textual support complements visual panels, creating a richer and more comprehensive storyboard documentation.

Additionally, AI technologies integrated with motion capture and 3D modeling tools enable the generation of animated storyboard sequences. Instead of static images, designers can work with dynamic prototypes that simulate user interactions within virtual spaces. This capability is particularly valuable in VR, where spatial arrangements, depth perception, and movement play critical roles in user experience. AI-powered systems can suggest optimal placements of data visualizations and interactive elements within a 360° field of view, addressing the challenge of information overload and ensuring clarity in immersive environments.

Another significant advantage of AI-assisted storyboarding is its ability to personalize design workflows. AI systems can adapt storyboards to different user personas, considering factors such as expertise level, cultural preferences, or accessibility needs. For example, an AI tool could generate alternative storyboard versions for novice farmers versus experienced agronomists, ensuring that VR dashboards cater to varying cognitive models and interaction styles.

However, it is essential to recognize the limitations and challenges of integrating AI in storyboarding. While AI can accelerate idea generation and visualization, human oversight remains crucial to ensure relevance, cultural appropriateness, and avoidance of biases inherent in AI training data. Designers must critically evaluate AI-generated outputs and refine them to align with the intended user experience and design goals.

The use of AI in storyboarding represents a paradigm shift for VR dashboard design. By automating visualization, enhancing narrative development, and supporting dynamic prototyping, AI empowers designers to focus on higher-level creative and strategic decisions. This synergy between human creativity and machine intelligence holds the potential to produce more innovative, user-centered, and efficient VR dashboards for complex domains such as smart farming. As VR technologies continue to evolve, AI-assisted storyboarding will likely become an integral part of the design toolkit, bridging the gap between conceptualization and immersive implementation.

4.3 APPLYING ONTOLOGICAL APPROACH

Developing a Virtual Reality (VR) dashboard for smart farming applications involves integrating domain-specific knowledge and ensuring seamless interaction between users and the agricultural environment. One effective approach to achieve this is by leveraging the perdurant ontological approach. In this context, an ontology serves as a structured framework that captures and organizes essential concepts, relationships, and domain-specific semantics.

Applying an ontological approach to the development of VR dashboards involves a systematic and structured framework that leverages key building blocks to create a cohesive and effective virtual environment. The foundation of this approach lies in the incorporation of UI/UX design principles for both 2D and 3D interfaces. By understanding user behaviors and preferences in immersive environments, designers can craft intuitive interfaces that enhance user experience within the virtual realm. These principles extend to the incorporation of immersive design guides, ensuring that the dashboard aligns with the unique characteristics and possibilities of virtual reality.

Data extraction and knowledge representation form the backbone of the ontological approach, enabling the VR dashboard to dynamically source and organize information. Through effective storyboard creation and the utilization of common dashboard design processes, developers can map out user journeys and interactions within the virtual space. Templates serve as a valuable tool for streamlining the development process, providing a consistent structure for UI elements and data visualization. The interaction design process, closely tied to the immersive design guide, focuses on creating natural and intuitive interactions that leverage the capabilities of VR interfaces. Modelling tools play a crucial role in shaping the virtual environment, allowing for the creation of 3D representations of data and interactive elements. The integration of data visualization techniques further enhances the interpretability of information within the VR dashboard.

In the ontological approach, key deliverables are not merely static components but are seen as interconnected entities that contribute to a holistic user experience. The ontology, in this context, serves as the underlying framework that defines the relationships and dependencies between these building blocks. It establishes a structured representation of the VR dashboard's components and their interconnections, enabling developers to understand how each element contributes to the overall functionality and user engagement. The ontological approach thus provides a conceptual roadmap for the design and development of VR dashboards, ensuring coherence, efficiency, and user satisfaction in the immersive virtual environment.

4.3.1 What is an Ontology? Why an Ontology?

An ontology is a formal model that represents concepts and relationships within a specific knowledge domain. Ontologies provide a shared vocabulary and an explicit specification of the meaning of terms and relationships for that domain. In essence, an ontology is a structured representation of knowledge that enables data integration, information search and retrieval, knowledge discovery, and reasoning.

Ontologies are advantageous because they allow both humans and machines to interpret domain information consistently. They support knowledge reuse, sharing and portability across applications and groups. Ontologies also enhance communication between people and organizational systems by establishing common terminology and semantics. This avoids ambiguity by defining a computer-readable dictionary of the concepts and relationships relevant to that domain.

Ontologies play a key role in building virtual reality dashboards because they enable explicit conceptualization of the structure of data being visualized. An ontology represents the hierarchy of core data entities, attributes, and relationships within a domain. This semantic model provides meaning and context for the raw data, allowing it to be logically organized and intelligently displayed to users. Associating real-world data with ontology concepts facilitates automated reasoning and inference, enriching the insights delivered through the VR dashboard.

Overall, ontologies are an essential component of VR dashboards as they lay the knowledge framework to interpret and interact with domain data in context. The shared conceptualization allows the visualization system to present data in meaningful ways based on defined concepts and relations. Ontologies thus enhance the accuracy, utility and interactivity of VR dashboards through structured representation of the relevant knowledge domain. They provide the semantic fabric to transform raw data into actionable VR-enabled models and visualizations.

4.3.2 ODM: A Short Review

Ontological design takes a philosophical approach to understanding the fundamental nature of objects and systems. This design methodology looks beyond superficial aesthetics and functionality to consider how objects exist in relationship to larger ecologies. Grounded in ontology, the study of being, ontological design recognizes that objects do not exist in isolation. It sees them as intrinsically interconnected with and affecting complex systems across scales. This orientation views design itself as a way of shaping realities. Design brings forth ways of knowing and being in the world. In the context of this study, the ontological perspective is embedded within the Virtual Reality Dashboard Design Method (VRDDM) through the integration of the Virtual Reality Dashboard Design Ontology (VRDDO) as its structural and semantic foundation. Each phase of VRDDM from conceptual modelling to interface development and data visualization utilizes ontological classes, relationships, and attributes defined within VRDDO to ensure that dashboard elements are semantically consistent and logically connected. This embedding was concretely realized in the two Proof-of-Concept prototypes (PoC 1 and PoC 2), where the ontology guided the creation of dashboard components, data mapping, and interaction behaviors. PoC 1 implemented the ontological schema for defining data entities and interface structure, while PoC 2 extended it to demonstrate adaptive visualization and interaction, confirming how ontology informs both conceptual coherence and functional implementation within the VRDDM framework.

Ontological design critically examines the ontological implications of design - the effects on worlds, futures, and possibilities. It asks ethical questions about what types of existence design makes viable. This methodology is gaining traction as a way to understand design's role in systemic issues like climate change, inequality, and more. An ontological approach is well-suited for building VR dashboards that expose ecological connections. It recognizes that data visualizations are not neutral representations. They are shaped by choices rooted in sociocultural paradigms about what counts as data. VR ecosystems dashboards grounded in ontological design can shed light on obscured relations and center marginalized perspectives. This allows VR to catalyze new collective ways of seeing and being on our deeply interdependent planet. An ontological orientation helps ensure VR dashboards don't just represent, but transform.

In designing an effective dashboard, utilising ontology driven conceptual modelling (ODCM) can be used. ODCM is a paradigm that involves usage of foundational ontologies for guiding the definition of model concepts, languages and tools. This involves the application of unified foundational ontology (UFO) and OntoUML which a UFO based modelling language. OntoUML is a vast catalogue containing open source, UFO grounded models which can help researchers, developers and modelers to develop ontological design (Sales et al. 2023). This catalogue contains diverse collection of open-source models from various domains created by other ontological modelers in common machine readable formats which are JavaScript Object Notation (JSON) and Turtle. The utilization of this catalogue can enhance the ontological design of the VR dashboard in this study.

The concept of ontologies is systematized through endurants and perdurants, philosophical positions that address how objects persist over time. Endurants, as defined by Huang, 2016 are entities that persist wholly at any specific temporal juncture, such as physical objects. Conversely, perdurants, as described by Huang (2016), are entities that possess temporal segments and persist through a continuum of time, such as events or processes.

The application of endurant and perdurant can impact the development of ontologies (Ahmad et al. 2010; Huang 2016). The significance of perdurant and endurant ontology lies in their ability to categorize entities based on their relationship to time, playing a prominent role in top-level ontologies in information science. The necessity of incorporating both perspectives in an ontology depends on the specific requirements of the domain being modelled (Hales & Johnson 2003).

Despite its significance, there are limitations in the application of endurants and perdurants. Huang (2016) states that the distinction may not be consistently represented linguistically. Additionally, there is a lack of standard tools to develop perdurant ontologies, suggesting that the distinction may not be adequately supported by existing ontological frameworks (Ahmed et al. n.d.). Furthermore, Johansson (2005) argued that robust top-level ontologies classifying particulars may need to rely on taxonomic principles other than the endurant-perdurant distinction.

In conclusion, the distinction between endurantism and perdurantism in ontology provides a valuable framework for understanding the temporal aspects of entities. The use of both perspectives offers advantages in accurate representation, modeling structural and dynamic aspects, and supporting diverse applications. However, challenges such as inconsistent linguistic representation and a lack of standard tools for perdurant ontologies exist. The universal applicability and representation of this distinction in linguistic and ontological systems raise questions, emphasizing the need for careful consideration based on specific domain requirements. The choice between endurantism, perdurantism, or a combination should align with the domain’s needs for effective knowledge representation. These insights can be instrumental in guiding the design and development of future ontologies.

4.4 DESIGN AND DEVELOPMENT

4.4.1 Building VRDDO with Key Blocks

The construction of the Virtual Reality Dashboard Design Ontology (VRDDO) is grounded in an in-depth analysis of key building blocks identified across various Virtual Reality (VR) studies. These key blocks serve as the foundation for establishing a structured and semantically rich ontology capable of supporting the development of VR dashboards in diverse application domains, including smart farming. This section provides a comprehensive explanation of how these key blocks were systematically derived from existing VR-related literature, focusing on the insights gained from twelve prominent studies (VRdash01–VRdash12).

An extensive narrative literature review was conducted to identify recurring design components and methodological practices within prior VR dashboard development studies. This review aimed to map the design space of VR dashboards by analyzing different approaches, tools, and frameworks adopted by researchers across various domains such as healthcare, manufacturing, urban planning, and education. Each study provided insights into essential elements that contribute to the effectiveness and usability of immersive VR dashboards.

A common theme observed across VRdash01 to VRdash12 was the emphasis on user interface (UI) design principles, which are critical in creating intuitive and user-friendly immersive environments. For example, Arjun et al. (2022) in VRdash01 highlighted the role of visual hierarchy, depth cues, and consistent layout arrangements in supporting user navigation and reducing cognitive load within VR dashboards. This principle was echoed in Bartosh and Gu (2019) (VRdash06), where multi-scalar visualizations for smart city exploration required careful alignment of UI components to accommodate varying user perspectives.

Another key block consistently identified was data extraction, which encompasses the methods and technologies for retrieving, processing, and integrating data streams from multiple sources. Studies like Mukhopadhyay et al. (2022) (VRdash02) and Baltabayev et al. (2018) (VRdash09) demonstrated the integration of real-time sensor data and external databases to populate VR environments with dynamic content. These processes are essential for ensuring that dashboards remain current and relevant, particularly in domains requiring rapid decision-making, such as smart farming and emergency response systems.

Knowledge representation emerged as another pivotal component, evident in all 12 studies. Effective representation of domain knowledge allows users to contextualize information and derive meaningful insights. Vock et al. (2021) (VRdash07) and Yoo et al. (2018) (VRdash10) highlighted ontology-based and semantic models as key enablers for structuring complex data relationships and supporting adaptive VR environments.

The interaction design process was highlighted in ten studies as crucial for maintaining user engagement and ensuring accessibility within immersive spaces. Weidner and Broll (2022) (VRdash03) and Arjun et al. (2023) (VRdash11) demonstrated how multimodal interaction methods such as gesture recognition, eye-tracking, and voice commands enhanced user agency and supported diverse user needs. These findings align with the growing emphasis on user-centric design in VR development.

Data visualization techniques were universally present across all reviewed studies. They transformed raw data into comprehensible, actionable insights by leveraging immersive features of VR. Visualization approaches varied from traditional bar and line charts adapted for 3D spaces to more advanced geospatial heatmaps and volumetric representations. These immersive visualizations play a critical role in supporting situational awareness and decision-making processes.

A less frequently discussed yet vital component was storyboarding, noted in studies such as Millais et al. (2018) (VRdash08) and Weidner and Broll (2022) (VRdash03). Storyboarding provided a blueprint for structuring user journeys and defining interaction sequences within VR environments. This practice ensures logical flow and coherence in immersive experiences, reducing design iteration cycles and improving overall usability.

Additionally, several studies introduced modelling tools and immersive design guides as key supports for VR dashboard development. Tools like Unity3D, Unreal Engine, and OntoUML (used for ontological formalization) were frequently cited as enablers for rapid prototyping and visualization. Immersive design guides offered structured recommendations on spatial orientation, depth management, and scale consistency critical factors for minimizing user disorientation in VR settings.

Lastly, key deliverables and common dashboard design processes were identified as integral to project success. Deliverables ranged from functional prototypes and evaluation frameworks to comprehensive design blueprints, as seen in Setti and Csapo (2021) (VRdash04). The presence of these deliverables highlights the importance of clear milestones and systematic methodologies in VR dashboard development projects.

Table 4.3 in the thesis presents a consolidated overview of key blocks identified across twelve major VR studies (VRdash01–VRdash12). Each row corresponds to a study, listing the key blocks involved in their respective development processes. This table illustrates the diversity and frequency of key block usage, highlighting both universal components and domain-specific variations.

For instance, studies such as VRdash02 (Mukhopadhyay et al. 2022) and VRdash07 (Vock et al. 2021) showcase a comprehensive set of key blocks, including immersive design guides and modelling tools, reflecting their complex application domains like healthcare monitoring and multimodal interaction design. In contrast, VRdash05 (Lutters & Damgrave, 2019) and VRdash09 (Baltabayev et al. 2018) focus more narrowly on data visualization and knowledge representation, indicating a streamlined design approach suited to their specific use cases.

The aggregation of these studies in Table 4.3 provides a robust empirical foundation for constructing VRDDO. It demonstrates that while each study tailored its approach to domain needs, there is significant overlap in foundational design elements. These commonalities validate the selection of key blocks and underscore their relevance for a standardized VR dashboard design ontology capable of supporting diverse application scenarios.

Table 4.3 Keyblocks appearing in other VR application studies

References & Acronym	Keyblocks Involved in Development
Arjun et al. (2022) VRdash01	1) UI Design principles 2) Data extraction 3) Knowledge representation 4) Interaction design process 5) Data visualization
Mukhopadhyay et al. (2022) VRdash02	1) UI Design principles 2) Data extraction 3) Knowledge representation 4) Interaction design process 5) Data visualization 6) Immersive design guide 7) Modelling tools 8) Key deliverables
Weidner and Broll (2022) VRdash03	1) UI Design principles 2) Data extraction 3) Knowledge representation 4) Interaction design process 5) Data visualization 6) Storyboarding 7) Common dashboard design process
Setti and Csapo (2021) VRdash04	1) Data visualization 2) Knowledge representation 3) Templates
Lutters and Damgrave (2019) VRdash05	1) Data visualization 2) Knowledge representation 3) Templates
Bartosh and Gu (2019) VRdash06	1) UI design principles 2) Templates 3) Knowledge representation 4) Interaction design process 5) Data visualization 6) Modelling tools 7) Key deliverables
Vock et al. (2021) VRdash07	1) UI design principles 2) Data extraction 3) Common dashboard design process 4) Templates 5) Storyboarding 6) Knowledge representation 7) Interaction design process 8) Data visualization

… to be continued

… continuation

	9) Immersive design guide 10) Modelling tools 11) Key deliverables
Millais et al. (2018) VRdash08	1) Templates 2) Storyboarding 3) Knowledge representation 4) Modelling tools 5) Key deliverables 6) Data extraction 7) Immersive design guide
Baltabayev et al. (2018) VRdash09	1) Data extraction 2) Knowledge representation 3) Data visualization
Yoo et al.(2018) VRdash10	1) Data extraction 2) Templates 3) Storyboarding 4) Knowledge representation 5) Data visualization 6) Key deliverables
Arjun, et al. (2023) VRdash 11	1) UI design principles 2) Data extraction 3) Common dashboard design process 4) Templates 5) Storyboarding 6) Knowledge representation 7) Interaction design process 8) Data visualization 9) Modelling tools 10) Key deliverables
Lei et al. (2022) VRdash 12	1) Data extraction 2) Knowledge representation 3) Data visualization

Table 4.4 presents a quantitative analysis of the frequency with which specific key blocks appear across the 12 VR-related studies (VRdash01–VRdash12) reviewed in this research. By aggregating these occurrences, the table highlights the degree of commonality among the identified key blocks, offering insights into their relative importance and prevalence in the design and development of VR dashboards. This systematic evaluation reveals that certain key blocks are universally acknowledged in VR literature, while others appear more selectively based on domain-specific requirements or project objectives. The count of appearances provides empirical validation for including these elements in the Virtual Reality Dashboard Design Ontology (VRDDO).

A closer examination of Table 4.4 shows that UI Design Principles, Data Visualization, Knowledge Representation, and Interaction Design Process are the most frequently appearing key blocks, each cited in 10 to 12 of the reviewed studies. This finding underscores their central role in VR dashboard development. For instance, the prominence of UI Design Principles reflects the need for intuitive and consistent interfaces that can guide users effectively in immersive environments, minimizing cognitive overload. Similarly, the widespread focus on Data Visualization emphasizes the importance of translating complex data sets into meaningful 3D representations, a cornerstone of immersive analytics. Knowledge Representation also ranks highly due to its critical function in structuring domain-specific knowledge for seamless integration into VR systems, enabling adaptive and context-aware dashboards. The Interaction Design Process, consistently discussed across studies, further highlights the necessity of multimodal interaction techniques such as gesture control, voice commands, and eye tracking that enhance user engagement and accessibility.

In contrast, key blocks such as Storyboarding, Immersive Design Guides, and Modelling Tools appear less frequently, typically in five to eight studies. While these components are not as universally applied, their significance lies in specific design contexts. Storyboarding, for example, plays a pivotal role in structuring user flows and ensuring coherence in narrative-driven VR applications, as observed in VRdash03 and VRdash07. Similarly, Immersive Design Guides provide crucial recommendations on scale, depth, and spatial orientation, which are particularly vital in applications where user immersion and spatial accuracy are paramount. Modelling Tools are indispensable in cases where rapid prototyping and iterative testing are required, as demonstrated in studies utilizing Unity3D, Unreal Engine, or OntoUML. The relatively lower occurrence of these blocks does not diminish their value; rather, it suggests their role as situational enhancers tailored to specific project needs.

The synthesis of these findings provides a hierarchical perspective on key block relevance. High-frequency blocks establish the core structure of VRDDO, ensuring broad applicability across diverse domains, while medium- and low-frequency blocks offer flexibility for domain-specific customization. This layered approach allows VRDDO to function as both a standardized framework and a modular toolkit, adaptable to varying requirements. Table 4.4 thus serves as an empirical anchor for the ontology's development, confirming that its components are derived from observed patterns in the literature rather than theoretical abstraction alone. By grounding VRDDO in these shared elements, the framework gains credibility and practical utility for guiding future VR dashboard design efforts.

Table 4.4 Keyblocks commonality in VR studies

Keyblock	Count
Knowledge representation	12
Data Visualization	11
Data Extraction	8
Templates	7
UI Design principles	6
Interaction design process	6
Key deliverables	6
Modelling tools	5
Storyboarding	5
Immersive design guide	3
Common Dashboard design process	3
Data extraction	1

By synthesizing these findings, the research identified all the core key blocks that are essential for VR dashboard design:

1. UI Design Principles
2. Data Extraction
3. Knowledge Representation
4. Interaction Design Process
5. Data Visualization
6. Storyboarding
7. Modelling Tools
8. Immersive Design Guide
9. Templates

10. Common Dashboard Design Process
11. Key Deliverables

These key blocks formed the conceptual backbone of the VRDDO, providing a modular structure that accommodates domain-specific requirements while maintaining generalizability across VR applications.

The analysis of Table 4.3 and Table 4.4 provides a robust foundation for the development of the Virtual Reality Dashboard Design Ontology (VRDDO). Table 4.3 offers a comprehensive mapping of key blocks identified across twelve seminal VR studies (VRdash01–VRdash12), revealing the design elements and methodologies employed in diverse application domains. This qualitative synthesis demonstrates how each study incorporates specific components, from UI Design Principles and Data Visualization to Knowledge Representation and Interaction Design Processes, underscoring their critical roles in immersive dashboard development. Complementing this, Table 4.4 quantifies the frequency of key block appearances, highlighting patterns of commonality that validate the selection of essential components for VRDDO. High-frequency blocks such as UI Design Principles and Data Visualization form the core of the ontology, ensuring relevance and applicability across domains, while medium- and low-frequency blocks like Storyboarding and Immersive Design Guides provide flexibility for domain-specific customization. Together, these tables establish an empirical basis for the ontology's structure, ensuring that VRDDO is both theoretically grounded and practically informed. By synthesizing these insights, the framework aligns with best practices observed in existing literature, offering a modular and adaptive approach to designing VR dashboards that meet the complex demands of real-world applications such as smart farming.

4.4.2 Overview of Several ODMs

There are several ODMs available, each with its unique approach to ontology development. An overview of eight commonly used ODMs namely Ontology Development 101 (OD101), OntoSpec, Upon Lite, Methontology, NeON methodology, Uschold and King Methodology and the recently developed ODMs, Linked Open

Terms (LOT) Methodology and Agile Ontology Engineering Methodology (AgiSCont) will be briefly discussed in this Section.

1. *Ontology Development 101 (OD101)*: Ontology Development 101 (OD101), introduced by Noy et al., 2001 serves as a fundamental guide for novice ontology designers embarking on their first ontology creation. It provides basic-level information on the terms and concepts in a domain by using wine classification as an example. The method employs an iterative approach, beginning with an initial rough draft of the ontology, followed by subsequent revisions and refinements. OD101 as outlined by Noy et al. (2001) comprises three key steps: 1) Defining concepts in the domain (classes): This involves identifying the key concepts or classes that are relevant to the domain of interest. 2) Arranging the concepts in a hierarchy (subclass-superclass hierarchy): This key step involves organizing the identified concepts or classes into a hierarchical structure, often in the form of a subclass-superclass hierarchy. 3) Defining which attributes and properties (slots) classes can have and constraints on their values: In this step, the attributes and properties that each class can have are defined, along with any constraints on their values. However, Nie et al. (2023) pointed out a limitation of OD101. While it provides a basic guide for creating initial ontologies, it may not offer a comprehensive overview of diverse domains, which is essential for comparing and benchmarking different environments. OD101 primarily considers two similar environments, leading to a lack of definition that allows for comparison and benchmarking against each other. Despite this, OD101 remains important for creating ontologies, which are widely used across various application domains such as biomedical (Bright et al. 2012) and natural disaster management (Chou et al. 2011).

2. *OntoSpec:* According to Kassel (2005), OntoSpec is a micro-level Ontology Development Methodology (ODM) that emphasizes formalization aspects. It utilizes highly structured natural language as a specification mode, aiding the builder with the ontological knowledge modelling step, upstream of the formal representation and knowledge implementation steps. Similar to Ontology Development 101 (OD101), OntoSpec involves an iterative process comprising

four key steps: 1) Identifying the entities (concepts and relations), 2) Modelling the properties characterizing the entities through successive refinements, 3) Formalizing the ontology using a formal representation language, and 4) Evaluating and validating the ontology. OntoSpec provides a modelling framework that allows ontology builders to define conceptual entities (concepts and relations) composing the ontology through successive refinements. The general principle of OntoSpec involves identifying ever more precise roles defined in a generalization/specialization taxonomy, while considering the structure of the properties in question. OntoSpec is independent of formal representation languages, which makes its definitions universally understandable. This allows domain experts and future users of the ontology to collaborate with the builder in evaluating the modelling choices and the quality of the resulting definitions. However, OntoSpec's use of semi-informal language may limit its applicability in contexts that require strict formalization or the use of specific formal representation languages (Kassel 2005). It focuses on the details of formalization rather than the broader process of ontology development (Nicola et al. 2016). Despite this, OntoSpec remains a valuable ODM widely used across various application domains such as neurology (Gibaud 2011) and business process (Turki et al. 2016).

3. *UPON Lite:* UPON Lite, as described by Nicola et al. (2016) is a methodology for rapid ontology engineering, derived from the Unified Process for Ontology building (UPON). It is designed to be accessible to domain experts, with minimal intervention from ontology engineers, and focuses on delivering formal ontology. As noted by Lille et al. (2021), this method consists of key steps: 1) Building the domain terminology lexicon, 2) Associating domain terms with descriptions and possible synonyms, 3) Organizing the domain terms in an ISA hierarchy, and 4) Producing a formally encoded ontology that contains conceptual knowledge collected in the previous steps. UPON Lite's main advantage according to Nicola et al. (2016) is its ability to allow a wide base of users, typically domain experts, to construct an ontology largely without the help of ontology engineers. Only in the last step, after domain content is elicited, organized, and validated, the ontology engineers intervene is needed to deliver

a final ontology formalization before releasing it to users. This approach provides a well-defined enrichment to each preceding step and disintermediates ontology engineers, making it easier and faster for end-users to create usable ontologies with more efficient collaboration between domain experts and ontology engineers. However, UPON Lite does have some limitations. Lille et al. (2021) highlighted that one of the key limitations is that it may not offer a comprehensive overview of diverse domains, which is essential for comparing and benchmarking different environments. UPON Lite primarily considers two similar environments, leading to a lack of definition that allows for comparison and benchmarking against each other. Another limitation underscored by Lille et al. (2021) is that despite the existing scientific literature reports on practical applications of UPON Lite in several domains, the detailed elaboration of the development process is limited. This could potentially limit its reproducibility in an actual business context. Despite these limitations, UPON Lite continues to be relevant for Ontology Engineering, particularly for domain experts due to its ease of use and reduced dependence on ontology engineers. It is used across various application domains such as smart building (Koh 2020) and social networks (Sebei et al. 2020).

4. *Methontology*: According to Fernandez Lopez et al. (1997), Methontology an ODM that stresses the importance of reusing and reengineering existing ontologies and knowledge resources. Methontology provides a systematic approach to ontology development, which lead to the creation of more effective and easier to maintain over time ontologies. Fernandez Lopez et al. (1997) state that this ODM proposes a set of guidelines and best practices for identifying and evaluating existing ontologies, determining how they can be reused or reengineered to meet the needs of a new ontology development project. Fernandez Lopez et al. (1997) outline the best practices in Methontology include reusing existing ontologies, carefully capturing domain concepts and relationships, using formal language, evaluating the ontology's quality, and thorough documentation. The six key steps in Methontology include: 1) Identifying the purpose of the ontology and its intended uses, 2) Capturing and building the ontology, 3) Implementing and testing the ontology, 4) Evaluating

the ontology, 5) Documenting the ontology after each phase and 6) Maintaining and evolving the ontology. Fernandez Lopez et al. (1997) highlight that these steps are not necessarily sequential and can occur concurrently or iteratively. Evaluations should occur throughout the process to ensure continuous improvement of the ontology (Lopez 1999). Due to its comprehensive and systematic approach to ontology development, which includes various phases such as requirements elicitation and analysis, conceptualization, integration, implementation, and maintenance, Methontology, therefore, is often used for developing heavyweight ontology (Gokhale et al. 2011; Keet 2020). Fernandez Lopez et al. (1997) argue that the comprehensive approach of Methontology leads to high-quality ontologies that are well-aligned with the needs of the intended users and easier to maintain over time. Nonetheless, despite its breadth, Methontology has limitations. It necessitates more time and effort than other, less comprehensive ODMs (Keet 2020; Lopez 1997; Lopez 1999). Nevertheless, Methontology continues to be a well-established and influential ODM. It has been successfully utilized in diverse fields, including chemistry (Lopez 1997) and legal (Corcho et al. 2005).

5. *NeOn Methodology:* The NeOn Methodology, as explained by Suárez-Figueroa et al. (2012) and Suarez (2015), is a scenario-based ODM that focuses on the construction of ontology networks. It promotes collaborative ontology development and emphasizes the reuse and re-engineering of knowledge resources. Unlike other methodologies that enforce a strict workflow, NeOn offers flexibility, accommodating a range of scenarios including reengineering, alignment, modularization, localization, and integration with non-ontological resources (Suarez 2012). According to Suárez-Figueroa et al. (2012), the NeOn Methodology framework is built upon four pillars: The NeOn Glossary, ontology-building scenarios, methodological guidelines, and guidelines for ontology evaluation and evolution. It involves six main steps: 1) Ontology requirements specification, 2) Ontology analysis, 3) Ontology design, 4) Ontology development, 5) Ontology evaluation, and 6) Ontology evolution. These steps are scenario-driven and can be customized to meet the specific characteristics and requirements of each scenario (Suarez 2015). Interestingly,

the NeOn Methodology framework is flexible and customizable based on the specific needs of ontology engineers and software developers for different scenarios. This adaptability as noted by Suárez-Figueroa et al. (2015) is a key strength of the NeOn Methodology, making it suitable for a wide range of ontology engineering contexts. However, Suárez-Figueroa et al. (2015) highlighted that a limitation of this methodology is that it does not explicitly state all the steps to be performed, and its application can be time-consuming. Despite this, the NeOn Methodology has been flexibly applied in various domains such as education (Clemente et al. 2010) and tourism (Lamsfus et al. 2009).

6. *Uschold and King Methodology:* The Uschold and King Methodology developed by Uschold et al. (1995) is an ODM that emphasizes the systematic development of ontologies which includes identifying the appropriate content, relationships, and structuring for the ontology, as well as establishing a process for ontology development and evaluation (Uschold & Gruninger 1996). The methodology is centered on four distinct steps: 1) Identifying the purpose, 2) Building the ontology, 3) Evaluating the ontology, and 4) Documenting the ontology. It provides a set of techniques, methods, and principles for each phase to produce high-quality ontologies (Uschold & Gruninger 1996). Uschold et al. (1996) outlined the key steps in this ODM which include identifying the purpose and scope of the ontology, building the ontology, evaluating the ontology's quality, consistency, and completeness, and documenting the ontology. This ODM involves a comprehensive and systematic approach, making it particularly suitable for complex domains where precision and detail are required (Bravo et al. 2019; Keet 2020). However, despite its comprehensive nature, it lacking in terms of the need for motivating scenarios to guide the construction process, limited user engagement throughout the ontology creation process, and potential inadaptability to all ontology development requirements (Bravo et al. 2019; Keet 2020). Nonetheless, this ODM remains a valuable tool for Ontology Engineering, particularly for domain experts, due to its ease of use and reduced dependence on ontology engineers. It has been successfully applied in various

domains, including e-government (Fonou-Dombeu et al. 2011) and education (Abed et al. 2014).

7. *LOT (Linked Open Terms) Methodology:* The LOT (Linked Open Terms) Methodology, as described by Poveda-Villalón et al. (2022) is a method for developing ontologies and vocabularies focusing on industry projects. It emphasizes alignment with software development, integrating ontology development into the software industry to promote interoperability between different systems by providing well-documented and consistent standards for information exchange and reuse (Poveda-Villalón et al. 2022). Unlike other methodologies that enforce a strict workflow, LOT allows for the adoption of the method in different contexts and needs, offering flexibility, and accommodating a range of scenarios including requirements specification, ontology implementation, ontology publication, and ontology maintenance. According to Poveda-Villalón et al. (2022), the LOT Methodology framework is built upon four pillars: 1) The LOT Glossary, 2) Ontology-building scenarios, methodological guidelines, and 3) Guidelines for ontology evaluation and evolution. It involves four main steps: 1) Ontology requirements specification, 2) Ontology implementation, 3) Ontology publication, and 4) Ontology maintenance. These steps are scenario-driven and can be customized to meet the specific characteristics and requirements of each scenario. Interestingly, the LOT Methodology framework is flexible and customizable based on the specific needs of ontology engineers and software developers for different scenarios. This adaptability as noted by Poveda-Villalón et al. (2022) is a key strength of the LOT Methodology, making it suitable for a wide range of ontology engineering contexts and aims to serve as a reference framework that can be tailored to meet the specific needs of each project and context. This methodology however does not explicitly state all the steps to be performed, and its application can be time-consuming. According to Poveda-Villalón et al. (2022), this, limitation is inherent in any methodology that aims to be flexible and adaptable to different contexts. Despite this limitation, the LOT Methodology has been flexibly applied in various domains such as VICINITY,

DELTA, BIMERR, and Ciudades Abiertas, demonstrating its potential for use in various contexts.

8. *Agile Ontology Engineering Methodology (AgiSCOnt):* The Agile Ontology Engineering Methodology (AgiSCOnt), as explained by Spoladore et al. (2023) is a novel approach that supports organizations in collaborative ontology development. It is a recent ODM developed to support ontologists, especially novices, through the ontology development workflow in an iterative, customizable, and flexible manner while promoting collaboration with domain experts (Spoladore et al. 2023). Similar to LOT, AgiSCOnt is designed to accommodate differing levels of technical expertise among ontology engineers and it is highly iterative, customizable, and flexible, allowing ontologists to tailor the approach to their particular needs and contexts (Spoladore et al. 2023). There are five main steps involved in AgisCOnt: 1) Defining the scope and objectives of the ontology, 2) Selecting the ontological language and expressivity, 3) Identifying the most appropriate Ontology Design Patterns (ODPs) for the domain, 4) Building the ontology iteratively and, 5) Evaluating the ontology against use case scenarios. The possible limitation of AgiSCOnt is that some of the steps are not comprehensively described, resulting in some level of subjectivity in the implementation of the methodology, which can potentially lead to inconsistencies. However, due to its adaptability and flexibility, this method has been applied favorably across domains of knowledge.

The UOA is derived by combining the common characteristics and key steps of various ODMs, aiming to streamline the ontology development process and enhance its effectiveness. Through an extensive analysis of existing methodologies, this research contributes to the field by offering a consolidated perspective on ODMs. The study findings shed light on the strengths and weaknesses of different approaches, facilitating informed decision-making for ontology developers. A Unified Ontological Approach (UOA) should strive to strike a balance between common elements and adaptability.

9. *Other ODMs:* In addition to the above-established and new ODMs, there are also studies on ontology development using a customized ODM. Youcef et al. (2021) introduced an ODM founded on two philosophically grounded foundational ontologies, UFO (Engelberg et al. 2022; Guizzardi et al. 2021) and DEMO (Dietz & Mulder 2020) to offer a clear and consistent representation of domain knowledge for virtual reality training in ophthalmology known as OntoPhaco. This ODM spans crucial phases to create reusable, localized, and shareable ontologies for the domain through IWs. There are five key steps involved: 1) Pre-conceptualization – select domain, scope, and range, 2) Conceptualization – analyze and construct classes, relationships, and axioms, 3) Implementation – encode ontology in a knowledge representation language, 4) Ontology evaluation – assess suitability for intended use, 5) Ontology maintenance – review and improve the structure, expand the scope, and refine documentation. Based on the comprehensiveness of OntoPhaco developed using this ODM, its application demands significant expertise and effort and may not be well-suited for less-defined or dynamic domains.

    In contrast, Sattar et al. (2021) advocate for an enhanced ODM rooted in the Design Science Research Methodology (DSRM), comprising six steps: 1) Requirement identification, 2) Conceptualization, 3) Implementation, 4) Evaluation, 5) Documentation, and 6) Maintenance. This improved ODM underscores collaborative ontology development practices, aligns ontologies with business goals, and integrates agile development principles. It applies to any domain involving IWs. Both ODMs share heavyweight characteristics, embodying a rigorous and comprehensive approach, as suggested by Aminu et al. (2020), rendering them more suitable for the development of intricate ontologies.

4.4.3 Implementing UOA as ODM for Building VRDDO

The Unified Ontological Approach (UOA) is a framework for ontology development that synthesizes the strengths of various Ontology Development Methods (ODMs) and draws inspiration from successful ontologies like the Business Model Ontology (BMO).

This approach aims to streamline the ontology development process by integrating common characteristics and key steps found across different methodologies. The UOA emphasizes iterative development, consistent notation, flexible formalization, reusability, scenario-driven customization, and comprehensive structural representation (Ahadi et al. 2024).

The development of the UOA was facilitated through a Narrative Literature Review (NLR) method. This approach allowed for a comprehensive and interpretative synthesis of existing literature related to ODMs. The NLR method is particularly well-suited for addressing complex and emerging fields, enabling researchers to explore topics in broader ways. Through this method, researchers identified common steps and practices across different ODMs, cross-referenced these findings with the principles of successful ontologies like the BMO, and integrated these insights to create the UOA framework.

The UOA is particularly suitable for building the Virtual Reality Dashboard Design Ontology (VRDDO) due to several key factors. First, its emphasis on scenario-driven development aligns well with the diverse use cases and applications of VR dashboards across different domains. This approach ensures that the VRDDO will be relevant and applicable in real-world contexts. Second, the flexible formalization approach allows for the VRDDO to adapt to the rapidly evolving field of VR technology and dashboard design principles. Third, the focus on reusability and reengineering enables the VRDDO to leverage existing knowledge in related fields, such as information visualization and human-computer interaction, while still allowing for VR-specific adaptations.

Furthermore, the UOA's comprehensive structural representation ensures that the VRDDO can capture both the structural and dynamic aspects of VR dashboard design, which is crucial given the interactive and immersive nature of VR environments. The iterative process embedded in the UOA also allows for continuous refinement of the VRDDO, ensuring it remains up-to-date with advancements in VR technology and design practices. By adopting the UOA for the development of the VRDDO, researchers can create a robust, flexible, and comprehensive ontology that effectively captures the complexities of VR dashboard design while ensuring its applicability and adaptability across various domains and use cases.

4.4.4 Ecological Psychology Perspective and BMO Theory for Establishing Key Blocks in UOA

In developing the VRDDO, this study adopts Kernel theory pragmatist perspective by implementing two theories suited for the ontological design of VR. The theories are based on business model ontology (BMO) design for the development of business model canvas (BMC) (Osterwalder 2004). The Business Model Ontology (BMO), developed by Alexander Osterwalder, provides a structured framework for representing, understanding, communicating, and analyzing business models. It addresses the challenge of defining business models by offering a common language and conceptual structure. The BMO served as the foundation for the widely adopted Business Model Canvas (BMC), a visual tool for describing, designing, and innovating business models. In the context of the Virtual Reality Dashboard Design Ontology (VRDDO), the BMO's approach to structuring complex business concepts has inspired a similar ontological approach to VR dashboard design.

As one of the grounding theories for VRDDO, the BMO demonstrates the power of ontologies in creating standardized frameworks for complex domains, guiding the development of a comprehensive and adaptable structure for VR dashboard design principles.

In designing the BMC, key blocks are established based on the common characteristics/elements that exists from other business models (Osterwalder 2004), (Chungyalpa et al. 2016). Semantics that relate each of the key blocks help to establish the concepts well in developing the ontology of a business model. Therefore, this approach will also serve as one of the grounded theories within this work in developing VRDDO.

Another major grounding theory that was applied to this study for VRDDO development is the theory of ecological psychological perspective (EPP) (Gibson

1986). The theory emphasizes direct perception of environmental affordances - features suggesting how to interact with objects. This active perception model views senses as interconnected, information-seeking mechanisms. In Virtual Reality Dashboard Design Ontology (VRDDO) development, EPP provides crucial insights into user perception and interaction within virtual environments. Combined with the Business Model Ontology (BMO), EPP informs the design of intuitive, exploration-friendly VR dashboards. By considering affordances in virtual spaces, VRDDO can create more natural and meaningful interactions, enhancing user engagement and information comprehension. This synthesis enables a comprehensive approach to VR dashboard design, grounded in both perceptual psychology and structured business concepts.

4.4.5 Relationships and Semantics

The Virtual Reality Dashboard Design Ontology (VRDDO) is structured around 12 key blocks, each serving as a fundamental concept in the design and development of VR dashboards. These blocks collectively form a comprehensive framework that guides the creation of effective and user-centric VR dashboards. Explanation of each block and its role as a concept in the VRDDO as below:

UI/UX Design Principles for 2D and 3D: This block emphasizes the importance of user interface and user experience design in both 2D and 3D environments. It incorporates five main principles: scale, visual hierarchy, balance, contrast, and gestalt. These principles ensure that the VR dashboard is not only visually appealing but also intuitive and easy to navigate (Siang 2022). As a concept in the VRDDO, this block provides guidelines for creating immersive and user-friendly interfaces that leverage the unique capabilities of VR environments. In the VRDDO, this concept influences immersive design guide.

Common Dashboard Design Process and Templates: This block outlines a standardized process for designing VR dashboards, including steps like requirements gathering, data processing, UI/UX design, and implementation. It also emphasizes the use of templates to streamline the design process and ensure consistency across different dashboard projects. Thus templates as a concept facilitates the design process in providing structured approach towards VR dashboard development.

Data Extraction/Data Collection: This block focuses on the methods and processes of gathering and extracting data for visualization in the VR dashboard. It covers various data sources such as IoT devices, questionnaires, GUI inputs, VR equipment, smartphones, and sensors. The concept emphasizes the importance of adhering to data protection regulations and using appropriate tools and algorithms for accurate data extraction and classification where applicable.

Domain Model and Knowledge Representation: This block introduces the concept of ontology in the context of VR dashboard design. It highlights the need for a structured and semantically rich representation of the knowledge domain, which is crucial for creating interactive and meaningful VR dashboards. The VRDDO itself is a manifestation of this concept, providing a formal specification of the concepts and relationships within the VR dashboard design domain.

Interaction Design (IxD) Process: This block focuses on the user-centric design approach, emphasizing the importance of understanding user needs and behaviors when interacting with VR dashboards. The five stages of the IxD process (discovering user needs, analyzing, designing solutions, prototyping, and deploying) form a crucial concept in the VRDDO, ensuring that the resulting dashboards are highly usable and meet user requirements (Gong et al. 2020).

Data Visualization and Modelling Tools: This block covers the various tools and techniques used for visualizing and modelling data in VR environments. It acknowledges the complexity of VR systems, including hardware components and software requirements. As a concept in the VRDDO, this block guides developers in selecting and utilizing appropriate tools for creating effective data visualizations in VR.

Storyboarding: This block emphasizes the importance of pre-visualization techniques in VR dashboard design. Storyboarding helps in planning the user's journey through the virtual environment and their interactions with data displays (Walker et al.

2013). As a concept in the VRDDO, storyboarding serves as a crucial step in crafting a cohesive narrative for data exploration and optimizing the user experience. Table 4.5 summarizes all the concepts and their relationships in the VRDDO.

Table 4.5 Summary of concepts and their relationships in VRDDO

Concept	Relationship	Related Concept	Description
UI/UX Design Principles for 2D & 3D	Influences	Immersive Design Guide	The design principles of UI/UX design for 2D & 3D will influence the immersive design guide. Creates immersive and user-friendly interfaces that leverage the unique capabilities of VR environments.
UI/UX Design Principles for 2D & 3D	Incorporates	Common Dashboard Design Process	The design principles of UI/UX design for 2D & 3D will incorporate common dashboard design processes. outlines a standardized process for designing VR dashboards, including steps like requirements gathering, data processing, UI/UX design, and implementation.
Common Dashboard Design Process	Influenced by	Modelling Tools	Common Dashboard Design Process will be influenced by modelling tools available. Guides developers in selecting and utilizing appropriate tools for creating effective data visualizations in VR.
Common Dashboard Design Process	Facilitates	Templates	Common Dashboard Design Process will facilitate what suitable templates to be used.
Modelling Tools	Incorporates	Templates	Modelling Tools will incorporate suitable templates. Ensure consistency across different dashboard projects.
Data Extraction	Guided by	Key deliverables	Data Extraction process will be guided by the key deliverables. Considers various data sources such as IoT devices, questionnaires, GUI inputs, VR equipment, smartphones, and sensors.
Data Extraction	Shapes	Data visualization	Data Extraction will shape the Data Visualization. focuses on the methods and processes of gathering and extracting data for visualization in the VR dashboard.
Data Visualization	Influenced by	Immersive Design Guide	Data Visualization will be influenced by the Immersive Design Guide. Focusing on added immersion features allowing good and intuitive data visualization for users.
Templates	Ensures	Storyboarding	Templates will ensure proper Storyboarding. Storyboarding helps in planning the user's journey through the virtual environment and their interactions with data displays.
Data Visualisation	Ensures	Knowledge	Data Visualization will ensure proper Knowledge Representation. It highlights the need

… to be continued

… continuation

		Representation	for a structured and semantically rich representation of the knowledge domain.
Knowledge Representation	Ensures	Key Deliverables	Knowledge Representation will ensure meeting the Key Deliverables which are the main data to be displayed to users.
Interaction Design Process	Influenced by	Data Visualization	Interaction Design Process will be influenced by Data Visualization.
Interaction Design Process	Shapes	Storyboarding	Interaction Design Process will shape the Storyboarding.
Interaction Design Process	Influenced by	Immersive design guide	Interaction Design Process will be influenced by the Immersive Design Guide.
Storyboarding	Facilitates	Knowledge Representation	Storyboarding will facilitate proper Knowledge Representation.
Storyboarding	Ensures	Key deliverables	Storyboarding will ensure meeting the Key Deliverables.
Affordance	Influenced by	Environmental Interactivity	Affordance of an object will be influenced by environmental interactivity within the VR dashboard.
Affordance	Shapes	Interaction Design Process	Affordance help shape the interaction design process.

4.4.6 Initial Proposed VRDDO

The Virtual Reality Dashboard Design Ontology (VRDDO) shown in Figure 4.5 is considered as the 'backbone' of the Virtual Reality Dashboard Design Method (VRDDM), which aims to address the lack of standardized approaches in designing VR information dashboards, particularly in the context of smart farm monitoring. Developed using a Unified Ontological Approach (UOA), the VRDDO serves as a structured framework to encapsulate commonalities identified across various dashboard design-related works. This ontology forms the theoretical foundation of the VRDDM, providing a systematic and standardized method for creating immersive monitoring, where effective visualization and data presentation are crucial for decision-making and maintaining high-quality agricultural production. The ontology not only facilitates the design process but also promotes knowledge sharing and reuse, potentially eliminating ad-hoc practices in VR dashboard development. While the current focus of the VRDDO is on smart farm monitoring, its structured approach VR information dashboards can effectively tackle monitoring challenges in smart farming and potentially other domains.

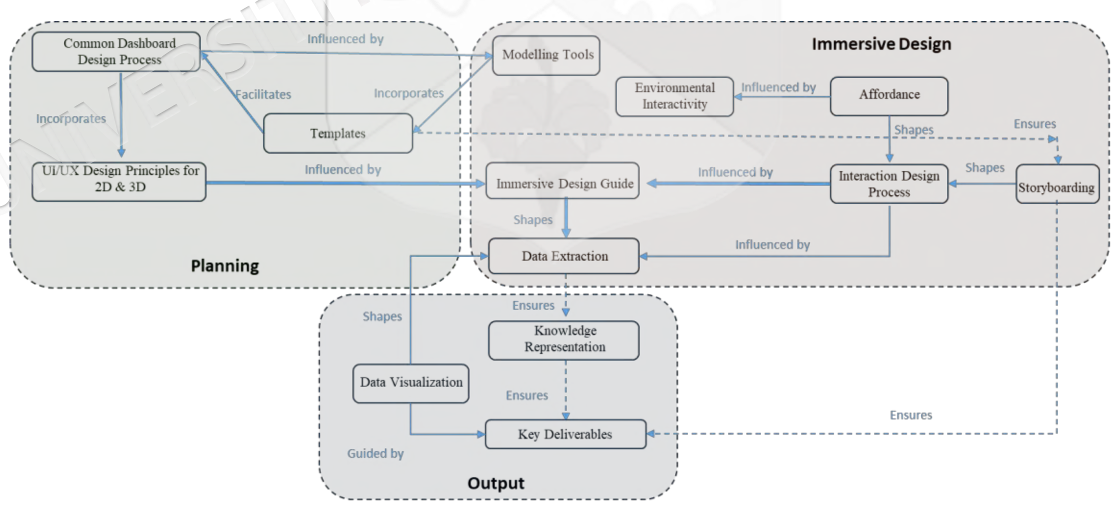


Figure 4.5 Proposed VRDDO with concepts derived from key blocks

Source: Leong et al. 2024

The VRDDO is developed through a comprehensive process that begins with a narrative review of existing literature to identify common elements and best practices in dashboard design. These commonalities which are considered as key blocks of VR dashboard designs are then formalized using the UOA, which allows for a systematic organization of concepts, relationships, and design principles specific to VR dashboard creation. By incorporating insights from various sources and methodologies, the VRDDO aims to create a robust and flexible framework that can guide the design and development of VR dashboards across different applications. This standardized approach offered by the VRDDO is particularly significant in the context of smart farm monitoring, where effective visualization and data presentation are crucial for decision-making and maintaining high-quality agricultural production. The ontology not only facilitates the design process but also promotes knowledge sharing and reuse, potentially eliminating ad-hoc practices in VR dashboard development. While the current focus of the VRDDO is on smart farm monitoring, its structured approach and foundation in common design principles suggest potential for adaptation and application in other domains, opening avenues for future research to explore its versatility and robustness across various fields requiring immersive data visualization and monitoring solutions.

4.4.7 Final VRDDO

a. Restructuring under UFO

The development of the VRDDO employed the Unified Ontological Approach (UOA), as proposed by Ahadi et al. (2024), as the primary Ontology Development Method (ODM). The UOA was specifically chosen for its ability to integrate various ontology development approaches while maintaining flexibility for domain-specific adaptations. This structured approach facilitates the systematic progression from problem identification to ontology implementation and validation, ensuring both theoretical rigor and practical applicability.

The UOA framework comprises nine iterative steps: (1) Identifying the scope and purpose, (2) Defining and identifying concepts, (3) Organizing concepts, (4) Defining properties and constraints, (5) Formalizing the ontology, (6) Implementing and testing, (7) Evaluating the ontology, (8) Documenting the ontology, and (9) Maintaining and evolving the ontology. These steps enable the iterative refinement of the ontology throughout its lifecycle, ensuring that the resulting framework aligns with its intended purpose and can adapt to future changes. Figure 4.6 illustrates the UOA framework, which serves as the foundation for VRDDO development.

The implementation process utilized UML for initial conceptual modeling, followed by OntoUML for ontological formalization. This combination provided the necessary rigor for developing a semantically rich and well-founded ontology while maintaining practical applicability. OntoUML, an extension of UML enriched with ontological principles from the Unified Foundational Ontology (UFO), was chosen for its ability to enhance the ontological adequacy of conceptual models (Guizzardi 2005). The formalization process included syntactical validation using the OntoUML Plugin in Visual Paradigm, ensuring that the IDDO framework was free of errors and adhered to formal modeling principles.

b. Redraw of VRDDO Using VP

After the implementation of UFO in the preliminary VRDDO, relationship between concepts are clarified further. The redraw of the Virtual Reality Dashboard Design Ontology (VRDDO) using Visual Paradigm (VP) represents a critical refinement step that significantly advances the semantic precision and structural coherence of the framework. This iteration, depicted in Figure 4.6 – VRDDO iteration with implementation of UFO, leverages the Unified Foundational Ontology (UFO) to enhance the ontological rigor and alignment of the conceptual model. The integration of UFO principles ensures that the VRDDO not only captures domain knowledge effectively but also adheres to foundational ontological commitments, making it more robust, reusable, and adaptable across diverse application contexts. This process underscores the study’s commitment to both theoretical soundness and practical applicability, bridging the gap between abstract conceptualization and real-world implementation in VR dashboard design for smart farming.

The updated VRDDO places strong emphasis on clarifying relationships between key concepts derived from earlier stages of literature synthesis and thematic analysis of VRdash01–VRdash12 studies. The application of UFO within VP provided a formal framework for representing entities, their roles, and relationships at a higher semantic level. For example, abstract classes like <<Kind>> and <<Role>> were introduced to categorize key elements such as "User Action Possibility" and "User Information Pickup" with greater ontological precision. The <<Kind>> classification ensures that core concepts are treated as essential, universal categories within the VR dashboard domain, while <<Role>> captures context-dependent properties of entities that emerge during user interaction in immersive environments. This distinction is crucial because it aligns with ecological psychology principles, emphasizing affordance and the dynamic interplay between users and virtual objects.

The implementation of UFO within Visual Paradigm also facilitated syntactic validation of the ontology. By employing OntoUML, the team ensured that the VRDDO met rigorous formal modelling standards, reducing ambiguity and ensuring consistency across concept definitions and relationships. OntoUML's extensions to UML allowed the representation of temporality, object composition, and existential dependencies elements that are especially relevant in modelling the dynamic nature of VR dashboards, where data streams, user interactions, and system states are constantly evolving. The syntactic validation process used VP's OntoUML plugin to detect potential errors, redundancies, or inconsistencies in the model, resulting in a refined ontology ready for application in practical VR dashboard design scenarios.

Beyond structural refinements, the redraw also strengthens the VRDDO's adaptability for future developments in immersive technologies. By formalizing key blocks as reusable ontological constructs, the VRDDO becomes a foundational framework that can extend beyond smart farming applications into other sectors requiring immersive monitoring solutions, such as healthcare, urban planning, or disaster management. The clear categorization of concepts into foundational (e.g., Data Visualization, Interaction Design Process) and domain-specific (e.g., Environmental Data Sensors, Farm Operations Data) components enhances modularity and scalability. As new technologies and interaction modalities emerge such as haptic feedback or AI-driven predictive analytics the VRDDO's structure can accommodate these innovations without necessitating a complete redesign.

In summary, the redraw of VRDDO using VP and UFO represents a pivotal evolution from a preliminary conceptual model to a robust, semantically grounded framework capable of supporting diverse design requirements. It advances the theoretical underpinnings of the ontology by embedding foundational ontological commitments while simultaneously ensuring its practical relevance for immersive VR dashboard development. Figure 4.6 – VRDDO iteration with implementation of UFO captures this transformation, illustrating how theoretical refinement translates into actionable design insights. This iteration not only resolves ambiguities in earlier versions but also positions the VRDDO as a versatile and enduring artefact within the broader landscape of design science research.

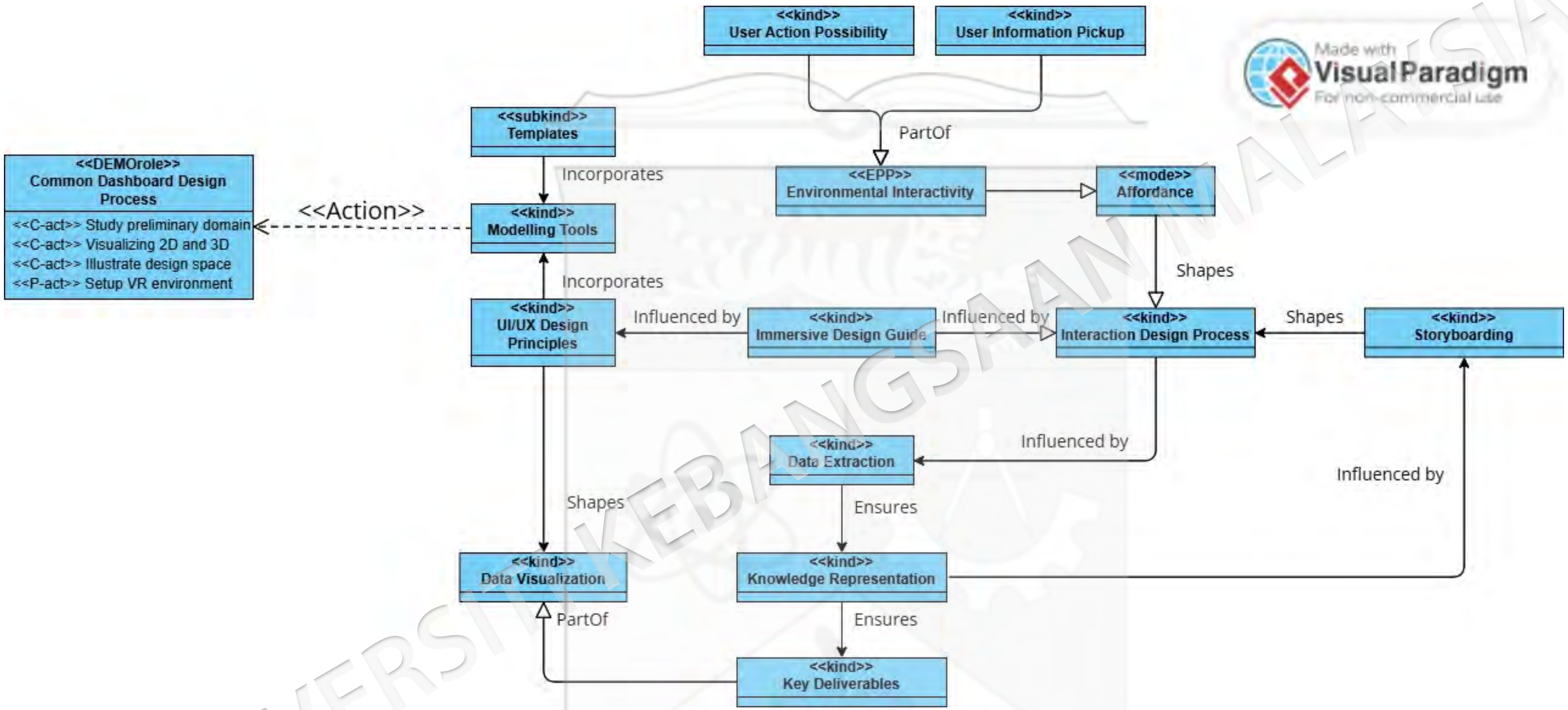


Figure 4.6 VRDDO iteration with implementation of UFO

Source: Leong et al. 2023

c. Introduction of Two (2) Additional Concepts

The VRDDO with the implementation of UFO prompts the introduction of two new concepts. These concepts further define the Ecological Psychological Perspective (EPP) Theory and how it will be part of the VRDDO to contribute towards achieving affordance and shapes the interaction design process. The two concepts are both classified as <<kind>>. One concept, which is User action possibility refers to what are possible actions or gestures that the user can do to interact with object within the 3D VR dashboard. Another concept is known as User information pickup. This concept refers to how can the user know that an object within the VR environment can be interacted. The concept emphasizes the need for VR dashboard designers and developers to incorporate a self-explanatory design for objects such as information windows within the VR environment for users. Therefore, with the implementation of the EPP theory, it is known that to achieve greater immersion, designers will have to design interactable objects that is both self-explanatory and offers freedom of interaction between users and the VR dashboard. Immersion can achieve greater information delivery and clarity for users especially with dense amount of information to display within a VR environment.

The Virtual Reality-Driven Design Objective (VRDDO), with the integration of Unified Formal Ontology (UFO), introduces two innovative concepts that deepen the application of the Ecological Psychological Perspective (EPP) Theory in virtual reality (VR) environments. These concepts are critical to achieving affordance, a central tenet of EPP, and to shaping the interaction design process in immersive VR systems. By focusing on the dynamic interplay between users and virtual objects, the VRDDO leverages these concepts to enhance usability and immersion. The first concept, User Action Possibility, explores the spectrum of actions or gestures users can perform to interact with objects within a 3D VR dashboard. This notion underscores the importance of designing intuitive and versatile interaction methods, from touch-based gestures to voice commands, that align with users' natural behaviors. The second concept, User Information Pickup, addresses the mechanisms through which users recognize that an object within the VR environment is interactable. This concept stresses the importance of self-explanatory design principles, ensuring that elements like interactive information windows intuitively communicate their purpose and functionality. These advancements align with contemporary research emphasizing the importance of seamless interaction and intuitive affordances in enhancing VR user experience (Bowman et al. 2023).

By embedding EPP theory into VR design, VRDDO establishes a framework that bridges cognitive science with cutting-edge technological applications. In the context of VR, affordance refers not only to the inherent possibilities an environment provides but also to how these possibilities are perceived by users. The User Action Possibility concept ensures that virtual objects accommodate a broad range of interactions while respecting the principles of ergonomic and cognitive accessibility. For instance, interactive dashboards can be designed to allow users to manipulate data points with simple gestures, such as pinching, swiping, or voice commands, creating a natural and engaging experience. Simultaneously, the User Information Pickup concept emphasizes visual and auditory cues, such as glowing borders, animations, or sound effects, to signal interactivity. Research has shown that such self-explanatory design elements can significantly enhance user engagement and task performance in VR settings (Park & Lee 2024). Consequently, VR developers must prioritize these concepts to create environments that are not only functional but also intuitive and immersive.

The implementation of these concepts within the VRDDO framework has far-reaching implications for the future of interaction design. As VR environments grow more complex, the ability to display dense information while maintaining user clarity and immersion becomes paramount. Incorporating EPP-driven principles enables designers to craft interactable objects that balance freedom of interaction with clarity of purpose. This balance is particularly critical in applications such as education, healthcare, and data visualization, where the delivery of accurate and easily interpretable information is essential. For example, in medical training simulations, VR dashboards equipped with self-explanatory interactive elements can enhance the learning experience by providing real-time feedback and reducing cognitive overload. Similarly, in business analytics, immersive dashboards can facilitate better decision-making by allowing users to intuitively explore large datasets. These advances contribute to achieving higher levels of immersion, which research identifies as a key factor in improving information retention and user satisfaction in VR environments (Smith et al. 2025). Ultimately, the VRDDO's integration of EPP Theory with the UFO approach paves the way for a new era of human-centered VR design, where interactivity and intuitiveness coalesce to deliver transformative user experiences.

The DEMO Theory of Dietz (2006), this theory has been developed and refined over many years as a tool for information systems design. In particular, the central concept in the theory is that the stable elements in the description of an organization are the speech acts that organization performs. This ties back to the ontological need to have something the same when an organization reengineers its business processes, described above. DEMO is not a new theory, but has not had wide acceptance in the Information Systems community. This may be because taking an ontological view of actions is fairly new. But the theory is so well suited to our purpose here to represent "action" knowledge in endurant ontology DEMO recognizes that a speech act performed as an item of business is generally a complex action. A business act is a type of speech act called a production act or P-act. This is the ontologically stable aspect of the organization. A P-act is generally performed as the result of a conversation among several parties. Each step in the conversation is another type of speech act called a coordination act or C-act. The C-acts making up a P-act are packaged in a transaction. The P-act is made only if the transaction completes. The C-acts are subject to change, even though the P-act remains stable. In VRDDO, we capture action knowledge as UML profile <<DEMOrole>> and capture all relevant C-acts and P-acts are relevant to VRDDO endurant system.gy of VRDDO system.

Table 4.6 Concepts with implemented upper ontologies

Concepts	Upper Ontology	Rationale
Common Dashboard Design Process	<<DEMOrole>>	Emphasizes the progressive, temporal nature of the design process with distinct stages of development.
Modelling Tools	<<kind>>	Defines the fundamental structures for representing VR dashboard elements, ensuring consistency in visualization and

… to be continued

… continuation

		interaction modeling.
Templates	<<subkind>>	Acts as pre-designed frameworks that align with standardized dashboard layouts, aiding in efficient UI/UX development.
UI/UX Design Principles for 2D & 3D	<<kind>>	Guides the visual and interactive elements by leveraging VR affordances to create an intuitive and immersive user experience.
Environmental Interactivity	<<EPP>>	Describes how the dashboard allows dynamic engagement with virtual elements, ensuring real-time feedback and adaptability in VR environments.
Affordance	<<mode>>	Refers to the perceived action possibilities within the VR interface, shaping user expectations and interactions in the system.
Immersive Design Guide	<<kind>>	Provides structured methodologies for designing VR dashboards, ensuring users are effectively engaged within the virtual environment.
Data Extraction	<<kind>>	Focuses on gathering and structuring relevant data for visualization and interaction, crucial for informed decision-making in VR dashboards.
Interaction Design Process	<<kind>>	Defines the workflow of user interactions with the VR dashboard.
Storyboarding	<<kind>>	Facilitates the planning of dashboard workflows by visually representing interaction sequences and possible user journeys.
Knowledge Representation	<<kind>>	Encapsulates how domain knowledge, actions, and entities are structured within the VR dashboard ontology, ensuring meaningful data organization.
Data Visualization	<<kind>>	Translates complex data into graphical representations that enhance user comprehension and decision-making within the VR space.
Key Deliverables	<<kind>>	Outlines the critical outcomes expected from the VRDDO framework, aligning with both technical and design perspectives.

4.5 FROM VRDDO TO VRDDM

Upon successful completion of VRDDO with its upper ontologies implementation, VRDDM was constructed and ready to be tested for developing a VR dashboard. The demonstration stage of this study involves development of VR dashboard according to the smart farming use case and analyzing the response feedback from developers on how well the VRDDM performs in VR dashboard design.

From the establishment of the VRDDO, a clearer and more user-friendly canvas is designed. This canvas shown in Figure 4.7 which is known as the VRDDM contains all the relevant concepts derived from the VRDDO, literature study and underpinning theories. The VRDDM helps to tabulate important concepts in building and designing VR dashboards that can be tailored to various use case scenarios. The concepts are arranged in three main groups that are considered as phases in the VR dashboard design process. The first group is Planning which revolves around design principles, modelling tools, selecting common design processes and templates. Some of the concept boxes are merged with other concept boxes. This signifies the close relevancy of each concept with each other. For example, UI/UX Design Principles for 2D & 3D concept and modelling tools concept is related closely together in a sense that suitable modelling tools should be chosen to help achieve good scale, visual hierarchy, balance and contrast of the UI/UX design within the planning phase.

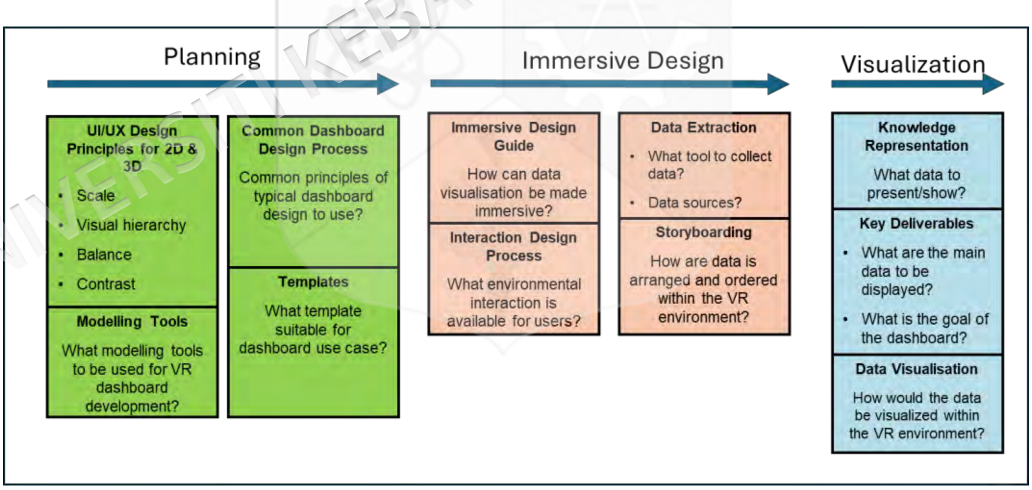


Figure 4.7 Proposed VRDDM established from VRDDO

Similar to how the Business Model Canvas (BMC) is used to develop a business model, the VRDDM Canvas is intended to produce a complete VR Dashboard Design Blueprint (DDB) for a single dashboard. Each VRDDM concept block results in a tailored DDB that captures the unique requirements and design specifications of a specific VR dashboard, providing a comprehensive guide for its development. The transition from the Virtual Reality Dashboard Design Ontology (VRDDO) to the

Virtual Reality Dashboard Design Method (VRDDM) represents a pivotal evolution in this study's methodology, solidifying the theoretical constructs into a tangible, user-friendly framework for practical application. While VRDDO serves as the ontological backbone, capturing the essential knowledge elements, relationships, and design principles necessary for immersive dashboard creation, VRDDM operationalizes these insights into a systematic, step-by-step approach. This transformation is crucial as it bridges the gap between abstract theory and actionable design strategies, ensuring that VR developers and designers can readily apply the framework in diverse real-world scenarios. By leveraging VRDDM, stakeholders are equipped not only with a conceptual foundation but also with a structured workflow that accommodates the complexities of VR environments and user-centric design requirements.

A key aspect of this transformation lies in the reorganization and contextual alignment of concepts derived from VRDDO. The VRDDM Canvas arranges these concepts into three main phases: Planning, Design, and Development. Each phase integrates related key blocks to guide practitioners through the iterative design process. For instance, the Planning phase brings together UI/UX Design Principles for 2D & 3D, Modelling Tools, Common Design Processes, and Templates, highlighting their interdependencies in ensuring effective spatial layout and interaction design. By presenting these elements as interconnected blocks within a single canvas, VRDDM promotes a holistic view of design considerations, avoiding the pitfalls of fragmented or siloed approaches. Furthermore, this structured arrangement aids in storytelling and scenario planning, enabling designers to map user journeys and information flows with clarity and precision.

The VRDDM's visual resemblance to tools like the Business Model Canvas (BMC) is deliberate, as it provides an intuitive template for translating theoretical constructs into practical deliverables. Each block within the VRDDM Canvas results in a tailored Dashboard Design Blueprint (DDB), which encapsulates all critical elements for a specific VR dashboard project. This DDB functions as a communication artifact between designers and developers, ensuring that design intent is faithfully executed in development. Moreover, the VRDDM accommodates iterative refinements by supporting feedback loops between phases, allowing teams to adapt designs dynamically based on user testing, technical constraints, or evolving requirements. This iterative capability reinforces the method's robustness and adaptability, making it suitable for both exploratory prototypes and production-level implementations.

Another significant enhancement in VRDDM over VRDDO is its explicit integration of modern tools and technologies, including Generative AI for rapid prototyping and storyboarding. While VRDDO establishes foundational relationships between concepts, VRDDM situates these within a practical workflow that leverages AI to augment human creativity and efficiency. This synergy ensures that VR dashboard designs are not only theoretically sound but also contemporary, aligning with emerging trends in immersive technologies. As such, the VRDDM embodies a pragmatic evolution of its ontological predecessor, positioning itself as a comprehensive and scalable solution for immersive system design across multiple domains.

4.5.1 What is VRDDM?

The VRDDM is a canvas for aiding VR designers and developers to design a VR dashboard. Built from the VRDDO, the VRDDM consists of all the related outlined concepts that emphasized efficient VR dashboard design. The implementation of grounding theory of BMO and EPP allows proper construction of the VRDDO which is the backbone of VRDDM. The 11 blocks contained in the VRDDM are the result of literature study on VR design, implementation of grounding theories and the utilization of UFO in establishing relationships between each concept. The 11 blocks are as follows:

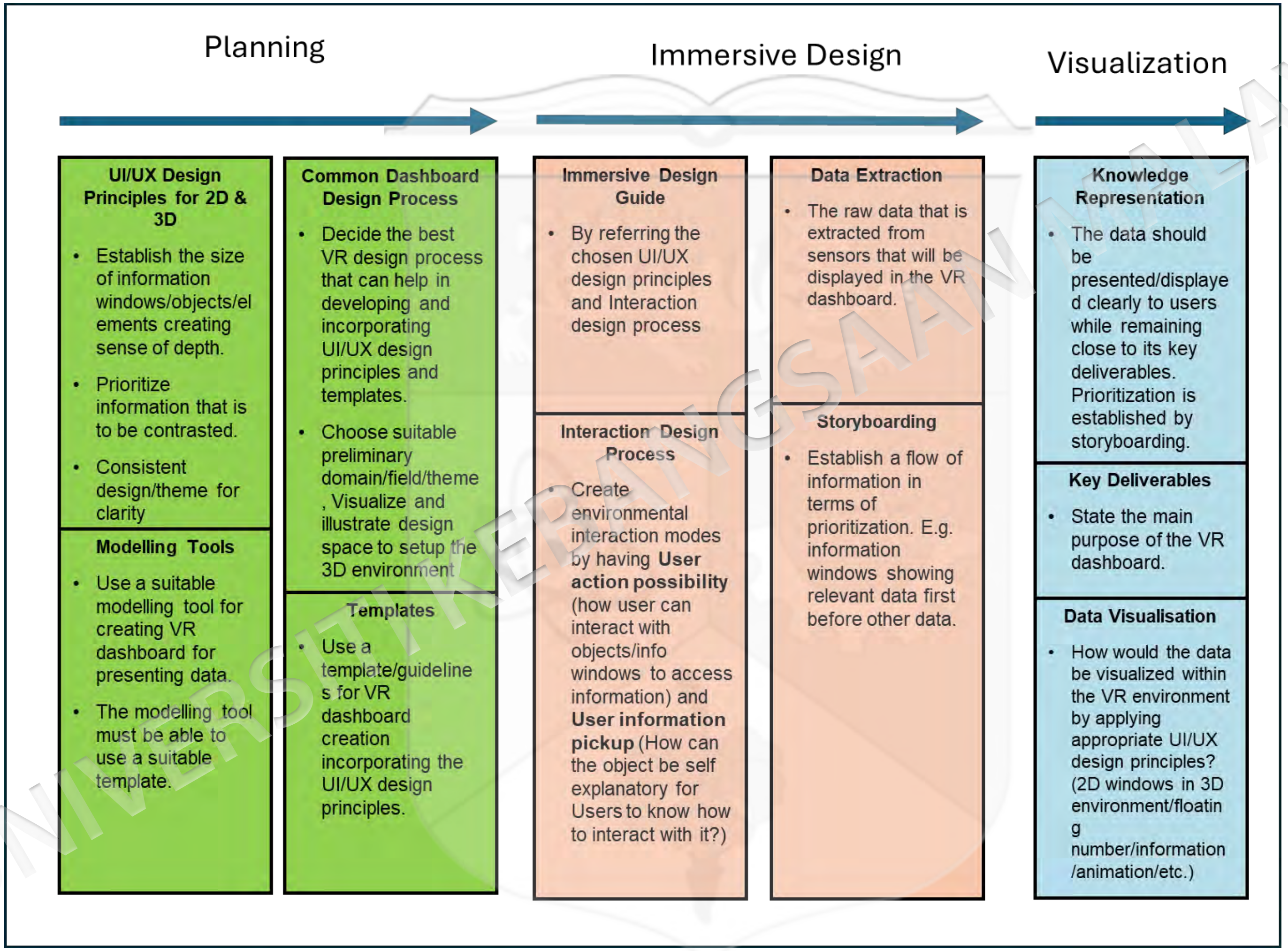


Figure 4.8 VRDDM with detail explanation for each concept block

Virtual reality (VR) dashboard design is a multi-faceted process that requires developers to integrate key principles of UI/UX design while leveraging advanced technologies to ensure an optimal user experience. At the core of this process are the foundational UI/UX design principles for 2D and 3D environments. Developers must establish the size of information windows, objects, or elements to create a sense of depth and immersion. This ensures that users perceive spatial relationships accurately, a critical requirement in VR environments. Furthermore, prioritization of key information is paramount; elements requiring immediate attention should stand out using contrast techniques. Consistency in themes and designs is also essential, as it enhances the clarity of the user interface and reduces cognitive load. Developers should employ suitable modelling tools capable of generating VR-compatible dashboards and ensure that the tools support templates that align with UI/UX design principles. These foundational steps provide a robust starting point for creating VR dashboards that are functional, intuitive, and visually coherent.

The next step in the VR dashboard design process involves adopting a structured design framework that guides developers through conceptualization to implementation. A common dashboard design process emphasizes the selection of the best VR design approach that incorporates UI/UX principles seamlessly. Developers must select a suitable domain or field to establish a contextual foundation for their designs. For example, a healthcare VR dashboard would require a thematic emphasis on precision and clarity, while a gaming VR dashboard might prioritize dynamic visuals. Visualization and illustration of the design space are integral to setting up the 3D environment. Here, templates and guidelines play a pivotal role in ensuring uniformity and alignment with best practices. The use of standardized templates helps in integrating the UI/UX design principles into the VR space efficiently, reducing the margin for error and ensuring a streamlined workflow. By adhering to these steps, developers can build a foundation that aligns with both user needs and domain-specific requirements.

To enhance the user experience, the design process must incorporate immersive design principles and interaction design strategies. Immersive design focuses on creating a VR environment that is both engaging and functional. By referring to UI/UX principles and incorporating interaction design elements, developers can ensure that the VR dashboard meets user expectations. Interaction design is centered on two critical aspects: user action possibilities and user information pickup. User action possibilities refer to how users interact with objects or information windows to access data. For example, this could involve clicking, grabbing, or other intuitive actions within the VR space. User information pickup, on the other hand, deals with how objects can be designed to communicate their purpose or function clearly to the user. This includes using visual cues, tooltips, or animations to make interactions self-explanatory. When executed effectively, these principles contribute to a seamless user experience, ensuring that users can navigate the dashboard effortlessly and interact with data in meaningful ways.

Data extraction and organization are crucial components of VR dashboard design, as they underpin the accuracy and relevance of the information presented. Developers must ensure that raw data extracted from sensors or other input sources is processed and displayed effectively within the VR environment. This requires a structured approach to data prioritization, which can be achieved through storyboarding techniques. Storyboarding establishes a logical flow of information, ensuring that the most relevant data is presented first. For example, a VR dashboard in an industrial setting might prioritize real-time equipment status over historical data to facilitate immediate decision-making. Effective storyboarding also ensures that users do not experience information overload, which can detract from the overall usability of the dashboard. By focusing on clear and structured data presentation, developers can enhance the utility and user experience of the VR dashboard, making it a powerful tool for visualization and decision-making.

Finally, knowledge representation, key deliverables, and data visualization are essential considerations for VR dashboard design. Knowledge representation involves presenting data in a manner that is both clear and closely aligned with the key deliverables of the dashboard. Developers should prioritize clarity and ensure that data presentation aligns with the main purpose of the VR dashboard. For instance, a VR dashboard designed for financial analysis should emphasize trends, forecasts, and actionable insights over less critical information. Data visualization techniques should be tailored to the VR environment, leveraging unique capabilities such as 2D windows within 3D spaces, floating numbers, animations, or interactive elements. These techniques not only enhance user engagement but also facilitate deeper understanding and analysis. By integrating advanced visualization methods and aligning them with the core objectives of the dashboard, developers can create VR solutions that are not only functional but also transformative, delivering value across diverse applications and domains.

4.5.2 Case Study: The Tok Dor, Besut

The VRDDM established from VRDDO was put to the test through several practical scenarios within the realm of smart farm monitoring. Smart farming, being a data-intensive domain, presents numerous opportunities to showcase the utility of VRDDM in crafting effective VR dashboards. Based on the Research Strategy Diagram illustrated in Figure 1.2 of Chapter 1, real-world scenario is selected to demonstrate the VRDDM's implementation and capability in producing VR dashboard proof of concepts. Leveraging the 3D nature of VR environments and the inherent flexibility of VRDDM's concepts, the method enables the generation of multiple dashboard designs from a single execution. This underscores the adaptability and robustness of VRDDM in catering to diverse use cases within a singular methodological framework.

The chosen scenario involves smart farm at the Tok Dor Rock melon farm. The farm specializes in growing high grade Terengganu Musk Melon (MMT) within several green houses. Within a greenhouse camp, growth parameters are strictly monitored to ensure growth of the produce is up to standards for local and international distributions. Each greenhouse contains 60 planted MMTs, each grown with specialized seeds. Each MMT plant will only bear one fruit to optimize its quality in terms of sweetness (Brix scale). MMTs are known to have delicate growing procedures and must be nurtured within a proper environment. Therefore, soil pH sensors, humidity sensors, temperature sensors, and chemical sensors are installed for each MMT plant. The raw data obtained from the sensors are collected via the system control and displayed through a 2D dashboard as shown in Figure 4.9. The 2D dashboard displays the location of each soil sensor within a green house and brief information on the soil condition only. Figure

4.10 is an overview of all parameters within a greenhouse including temperature, atmospheric pressure and humidity sensor.

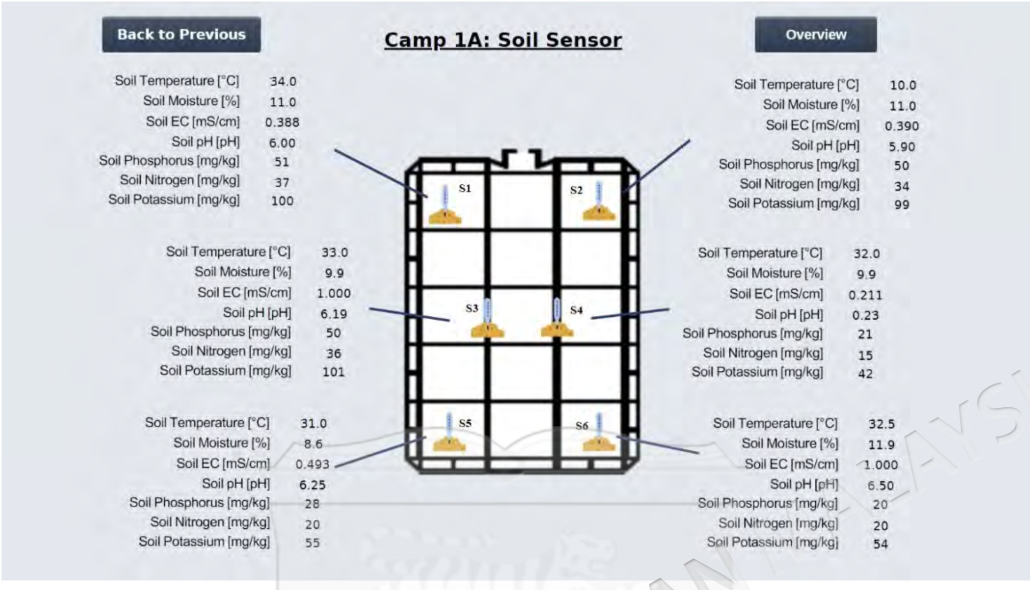


Figure 4.9 Displayed sensor data for a selected greenhouse camp

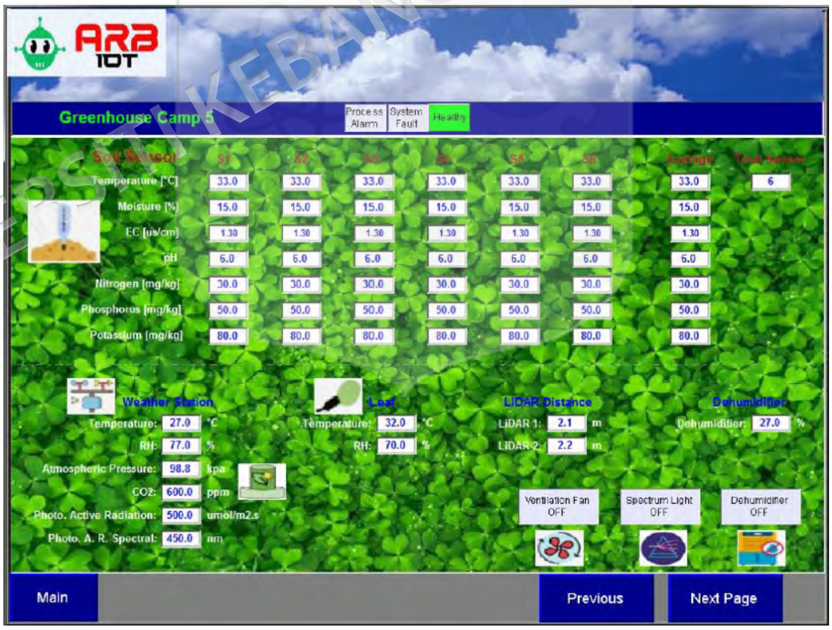


Figure 4.10 2D soil sensors of a smart farm plot. Overview dashboard

4.5.3 Proof of Concept I (PoC1)

The use of VRDDM will reflect on the proof of concept 1 (PoC1) when each of the elements within the VRDDM is established by the VR designer. The established elements will allow a clearer understanding, vision and creation of a storyboard of which a VR developer can understand. In putting the VRDDM to work, Figure 4.11 shows the illustrated flow of concept proving to generate PoCs. A scenario/use case was selected which was on the rock melon farm monitoring. The VRDDM was put to use by identifying and establishing all the 11 blocks. Upon the completion of the VRDDM, a designer should be able to implement all the elements in the blocks into a storyboard. The produced storyboard will give clarity to VR dashboard developers to develop a VR dashboard (termed PoC1).

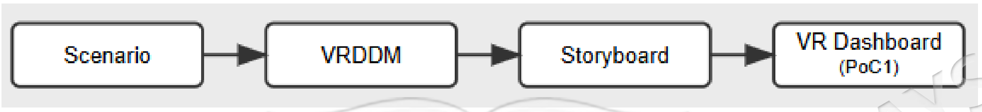


Figure 4.11 Flow of proof of concept

For PoC1, the use case scenario would be converting a 2D overview soil data dashboard (as in Figure 4.9) in the form of 3D VR dashboard. The 3D VR dashboard will view all soil data from one greenhouse from the obtained sensors S1-S6 simultaneously. With this scenario, the VRDDM was executed to identify all the components within each block that will help in the making of a storyboard. A storyboard allows clear visualization of each of the components in VRDDM and serves as an information delivery medium to a VR developer. In other words, the VR developers will only receive a storyboard that contains visual details established from the VRDDM. Therefore, the components in the VRDDM will influence how the storyboard will be made before it is sent to VR developers to produce the VR dashboard. For this chosen scenario, the VRDDM is displayed in Figure 4.12.

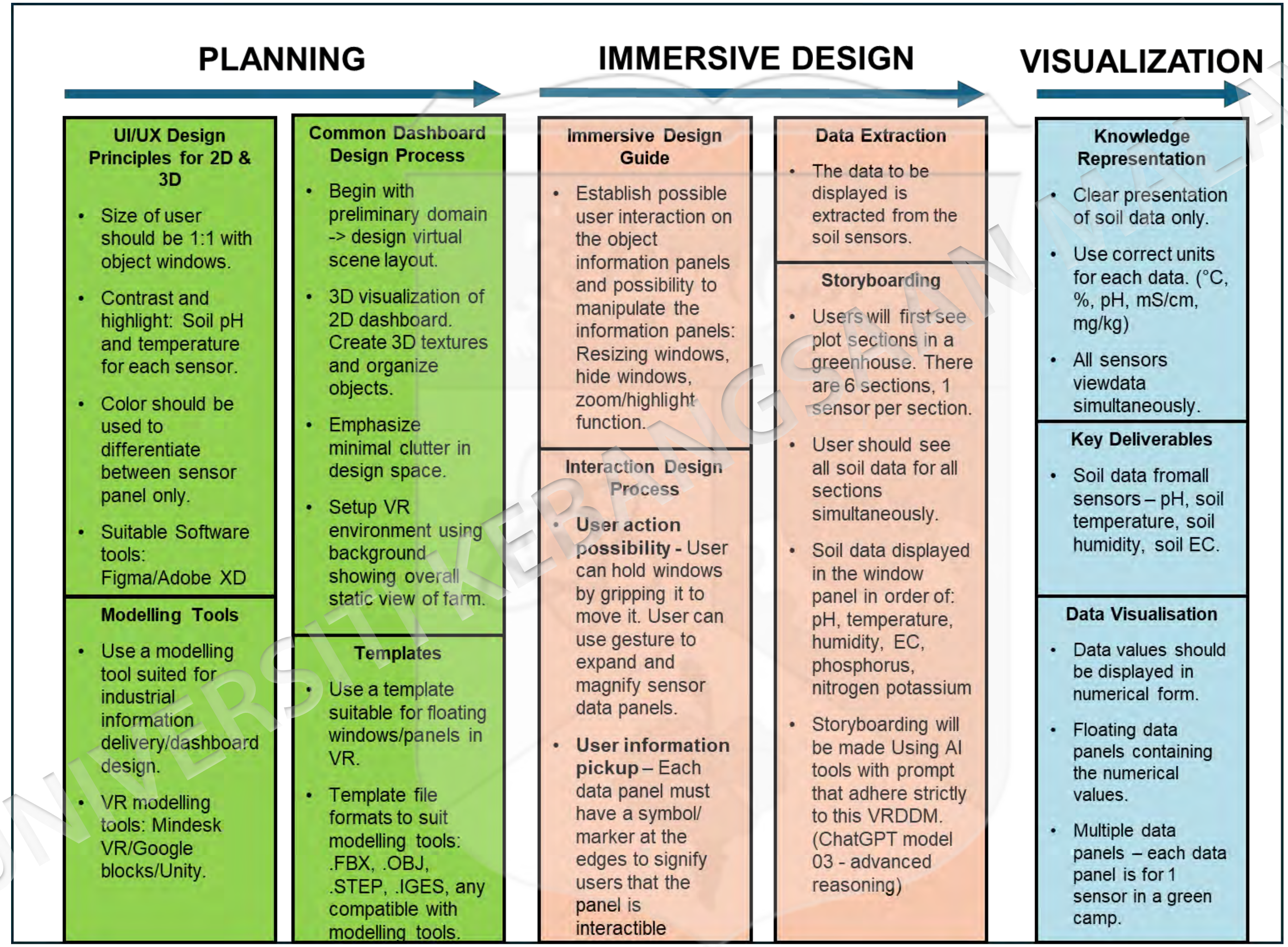


Figure 4.12 PoC1, a 2D overview dashboard converted into 3D VR dashboard (all soil data for all plots)

In the planning phase of developing a 2D overview dashboard into a 3D VR dashboard for soil data visualization, several critical components demand meticulous attention. The UI/UX design principles for both 2D and 3D environments establish fundamental guidelines that emphasize the importance of maintaining precise dimensional relationships between user interfaces and object windows at a 1:1 ratio. This architectural decision ensures optimal visual coherence and interaction accessibility. The design methodology incorporates strategic contrast and highlighting mechanisms, particularly for crucial soil parameters such as pH and temperature readings from individual sensors. The implementation of a sophisticated color differentiation scheme serves to delineate distinct sensor panels, enhancing information clarity and user comprehension. The modelling tools section prescribes the utilization of specialized industrial information delivery and dashboard design software, specifically recommending VR modelling platforms such as Mindesk VR, Google Blocks, and Unity. These tools have been selected for their robust capabilities in handling complex three-dimensional data visualization requirements and their compatibility with various template formats, including FBX, OBJ, STEP, and IGES, ensuring seamless integration with existing modelling infrastructures.

The common dashboard design process delineates a systematic approach to virtual environment creation, beginning with the preliminary domain analysis that informs the virtual scene layout. This process encompasses the intricate transformation of 2D dashboard elements into three-dimensional visualizations, necessitating the creation and organization of 3D textures that effectively represent soil data parameters. The methodology emphasizes the importance of maintaining minimal clutter in the design space, promoting clarity and user focus. A significant aspect of this process involves the establishment of the VR environment using a plain grey background devoid of moving patterns, which serves to minimize visual distraction and cognitive load. The template selection process is particularly crucial, as it must accommodate floating windows and panels in 3D space while ensuring compatibility with various modelling tools and their respective file formats. This comprehensive approach to dashboard design ensures that the final product maintains both functionality and aesthetic coherence while facilitating intuitive user interaction.

The immersive design phase encompasses two primary components: the immersive design guide and the data extraction process, coupled with detailed storyboarding considerations. The immersive design guide establishes protocols for user interaction with object information panels, incorporating sophisticated functionality for window manipulation, including resizing, hiding, zooming, and highlighting capabilities. The interaction design process introduces advanced user possibilities, enabling intuitive window manipulation through gripping gestures and implementing gesture-based controls for panel expansion and magnification of sensor data displays. User information pickup mechanisms are implemented through strategic placement of symbols or markers at panel edges, serving as visual indicators of interactive elements. The data extraction process focuses specifically on soil sensor data acquisition, while the storyboarding component outlines a structured approach to information presentation. Users are initially presented with plot sections within a greenhouse environment, comprising six distinct sections with individual sensors. The system architecture allows users to select specific sensors (S1-S6), triggering popup windows that display comprehensive soil data for the selected sensor, including parameters such as pH, temperature, humidity, EC, phosphorus, and nitrogen potassium levels.

The visualization component of the system emphasizes knowledge representation and data visualization strategies through several sophisticated approaches. The knowledge representation framework prioritizes clarity in soil data presentation, implementing strict adherence to standardized units for various parameters (°C, %, pH, mS/cm, mg/kg). This framework ensures that only selected sensors display their recorded soil data, maintaining information relevance and preventing cognitive overload. The key deliverables encompass comprehensive soil data measurements from multiple sensors, including critical parameters such as pH, soil temperature, soil humidity, and soil EC. The data visualization methodology stipulates that all values must be presented in numerical form, utilizing floating data panels to display these numerical values effectively. The system architecture supports multiple data panels, with each panel dedicated to representing data from a single plot within the greencamp environment. This structured approach to data visualization ensures that complex soil data is presented in an accessible and comprehensible manner while maintaining scientific rigor and accuracy in data representation. The holistic integration of these components creates a sophisticated VR dashboard that effectively transforms 2D soil data visualization into an immersive 3D experience, facilitating enhanced understanding and analysis of complex soil parameters across multiple plots.

Upon outlining and populating each of the key concept blocks in Figure 4.12, the VRDDM is sent to a generative pre-trained transformer AI (GPT) AI (ChatGPT model O1 with Dall-E engine) to visualize a storyboard. The VRDDM is attached to the ChatGPT and is prompted. By using a prompt ‘’Visualize this attached VRDDM in the form of a storyboard’’. This resulted in a singular condensed form of storyboard image.

Figure 4.13 Visualization of PoC1 storyboard

Figure 4.13 of the VRDDM storyboard highlights the importance of precise data visualization in a smart farming VR dashboard by showcasing multiple floating data panels displaying real-time soil parameters, including pH, temperature, humidity, EC, phosphorus, nitrogen, and potassium levels. To ensure clarity, data panels should be semi-transparent with a high-contrast color scheme such as dark backgrounds with bright, readable text in white, cyan, or neon green (hex codes: #FFFFFF, #00FFFF, #32CD32). Each panel should be sized at approximately 40x25 cm in virtual space and positioned at an optimal height (120-140 cm from the virtual ground) to ensure accessibility. Text elements should use sans-serif fonts like Roboto or Open Sans, with numeric values in 32–40pt font size and labels in 24pt for easy readability. To further enhance comprehension, panels should include dynamic highlights, such as color-coded warnings (e.g., red for critical values, yellow for suboptimal conditions) and subtle glowing edges for active selections. Users should be able to zoom in on specific data points via intuitive gesture controls or gaze-based selection, ensuring smooth interactivity.

Table 4.7 Storyboard elements from the VRDDM for PoC1

Item No.	Storyboard Item/Element Displayed	Related VRDDM blocks	Description
1	Floating Data Panels	UI/UX Design Principles for 2D & 3D and Data Visualisation	Multiple floating panels display key soil parameters for smart farming. All sensors are shown simultaneously.
2	Real-Time Soil Parameters	Data Extraction, Key deliverables and Data Visualisation	Panels show real-time data for pH, temperature, humidity, EC, phosphorus, nitrogen, and potassium levels.
3	Data Panel Design	Common Dashboard Design Process	Semi-transparent panels with high-contrast colors (dark background, bright text in white, cyan, or neon green).
4	Size of Data Panels	Common Dashboard Design Process & Immersive Design Guide	Each panel is sized approximately 40x25 cm in virtual space.
5	Positioning of Panels	Immersive Design Guide	Panels are positioned at an optimal height of 120-140 cm from the virtual ground for accessibility.
6	Font and Readability	Modelling tools and Templates	Text elements use sans-serif fonts like Roboto or Open Sans, with numeric values in 32-40pt font size and labels in 24pt.
7	Dynamic Highlights	Interaction Design Process (User Information Pickup)	Panels feature color-coded warnings (red for critical values, yellow for suboptimal conditions).
8	Interaction Controls	Interaction Design Process (User action possibility)	Users can zoom in on specific data points using intuitive gesture controls or gaze-based selection.
9	Color Scheme	UI/UX Design Principles for 2D & 3D	Hex codes used: #FFFFFF (white), #00FFFF (cyan), #32CD32 (neon green) for high

… to be continued

… continuation

			contrast.
10	Glowing Edge Effect	UI/UX Design Principles for 2D & 3D	Panels have a subtle glowing edge to indicate active selections.

Table 4.7 shows a table constructed based on the considered elements of the storyboard. These elements were the factors decided based on the VRDDM as shown previously. Figure 4.14 shows the illustrated storyboard for satisfying item no. 1 and 2.

Figure 4.14 Illustrated storyboard for satisfying item no. 1 and 2

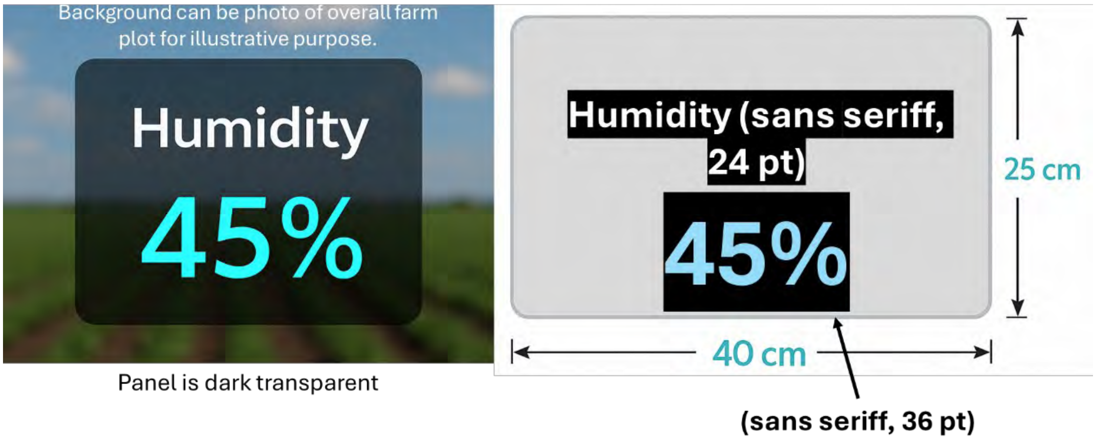


Figure 4.15 Illustrated storyboard for item no. 3, 4, 6

In Figure 4.15 and Figure 4.16, the panel's translucency lets some background through, but the white and neon text (pH, temperature, humidity) remain highly legible. This design demonstrates the recommended approach of using white or bright-colored text on a dark translucent background for AR/VR panels. The dark, semi-transparent panel (gray with ~70% opacity) reduces background distraction while preserving context (you can faintly see the horizon through it). The text colors (white labels and cyan values) provide a strong contrast ratio for readability his panel design follows VR UI best practices: clear text, a muted backdrop, and a slight transparency that gives a modern "glass" effect without sacrificing legibility. A rectangular panel is shown with dimension arrows indicating 40 cm width and 25 cm height. In the VR field, these panels are rendered to appear about the size of a small monitor or tablet. 40 × 25 cm is a comfortable size that's large enough to read at a distance but not so large as to overwhelm the field of view. Developers would set the World Space UI scale accordingly so that, at the typical interaction distance (~1–2 m), the panel subtends an angle making text readable. Keeping panels consistent at real-world scale helps users intuitively understand and interact with them, as objects in VR matching familiar physical dimensions contribute to a sense of presence.

a) color-coded warnings to draw attention to out-of-range values

b) Glowing edges - indicating the panel is active/selected

Figure 4.16 Dynamic highlights and active panel style that satisfies item No. 7 and 10

Table 4.8 Value thresholds

Parameter	Optimal Range	Alert Threshold (Too Low / Too High)
Soil pH	6.0 – 6.8	<5.8 (Acidic) / >7.2 (Alkaline)
Temperature	22°C – 30°C	<18°C / >35°C
Soil Moisture	60% – 80% (relative)	<50% (Dry) / >90% (Waterlogged)
EC (Salinity)	1.5 – 2.5 dS/m	<1.0 (Deficiency) / >3.0 (Salt stress)
Nitrogen (N)	150 – 250 ppm	<100 ppm / >300 ppm
Phosphorus (P)	50 – 100 ppm	<30 ppm / >120 ppm
Potassium (K)	200 – 300 ppm	<150 ppm / >400 ppm

The data values displayed uses 36 pt font, while the label is 24 pt. The dashboard uses a clean sans-serif font (e.g., Roboto or Open Sans) for high legibility, avoiding any ornate or serifed typefaces. As per VR readability guidelines, larger font sizes are used for critical values here the numeric data is significantly larger than the label key readings (numbers) are set at about 32–40 pt for visibility at a distance, while labels are around 24 pt, creating a clear visual hierarchy. The font weight is regular or medium (avoiding very thin lines that could shimmer or vanish in VR). This treatment ensures that even in the somewhat lower resolution of VR displays, text remains crisp and easy to read. Developers should also maintain a consistent typographic hierarchy across panels (e.g., all sensor values use the same size), so users quickly learn to recognize data points by text size and position. The VR dashboard uses color-coded warnings to draw attention to out-of-range values. Red typically indicates a critical condition or error, while yellow denotes a warning or suboptimal range. For example, if soil temperature exceeds a threshold, its display turns red as an alert. If moisture is slightly low, it might turn yellow. The thresholds are shown in Table 4.8. These highlights update in real-time, allowing users to identify issues at a glance without reading every number. By adhering to established color conventions (red = danger, yellow = caution, green/cyan = normal) developers ensure the alerts are intuitive. In implementation, this could be done by applying conditional formatting to the text or panel element (e.g., toggling classes or materials when values cross thresholds). Such dynamic visual feedback is vital in a smart farming context, where immediate attention to anomalies (e.g., extreme pH or nutrient deficiency) can prompt quick corrective action.

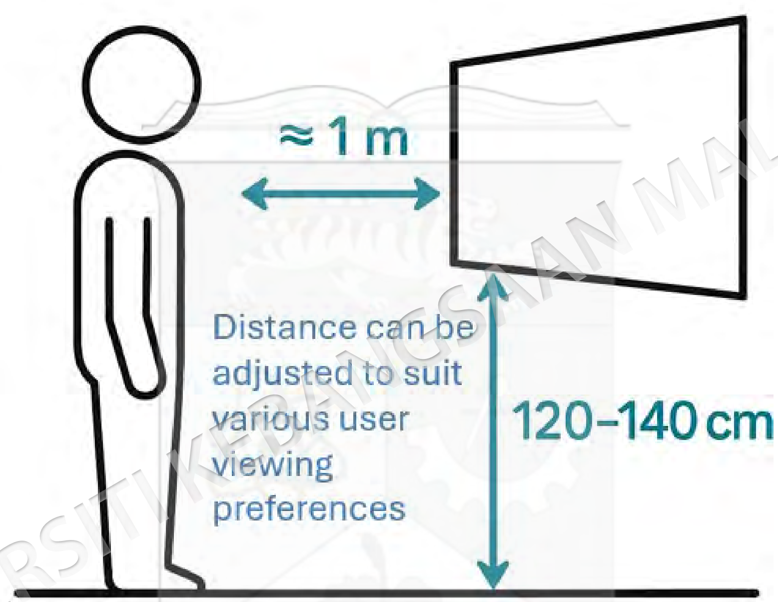


Figure 4.17 Side view illustrating panel height placement relative to a standing user. This satisfies item no. 5.

As shown in Figure 4.17, The panel is around 1.2–1.4 m above the ground, roughly at the user's chest/eye level (indicated by the red double-arrow). This placement aligns with ergonomic recommendations to position frequently viewed UI elements between desk height and eye level. In practice, developers position the VR dashboard panels so that a standing user sees them near eye height without looking up or down too much. 120–140 cm from the ground ensures the user's gaze falls naturally on the data when looking forward. This reduces neck strain and keeps the information in a comfortable viewing zone (within about ±15° of horizontal line-of-sight). It also matches how one would place a physical display for easy reading, reinforcing intuitiveness in the virtual space.

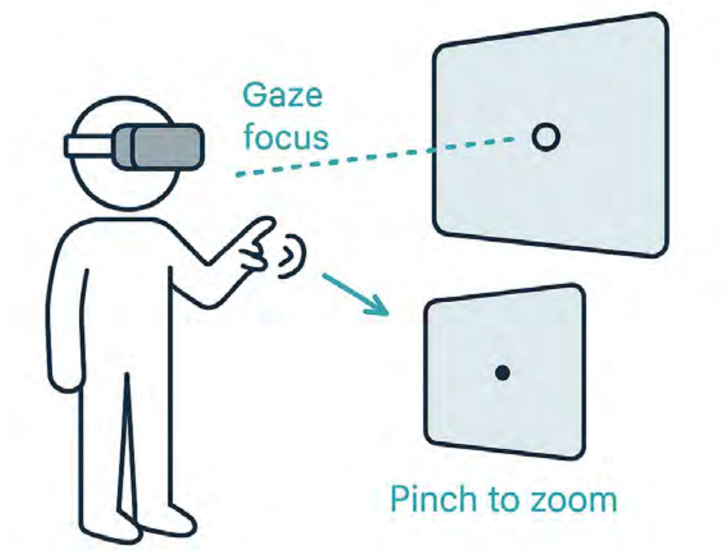


Figure 4.18 Illustration of user interaction methods. A VR user's hand (left side) is depicted reaching out, and a red ray/cursor indicates pointing at a panel (right side). The red dot on the panel represents a gaze focus or cursor, and the arrow suggests a "select" gesture (like a pinch or click) being performed. This satisfies item no. 8.

Users can interact with these floating panels via hand gestures or gaze-based controls instead of a mouse. In VR, two primary interaction techniques are common: direct touch (using hand tracking or controllers to virtually "tap" the panel) and distant pointing (using a ray-cast or gaze to select). For example, with hand-tracking enabled, a user might reach out and pinch or poke a panel to bring up more details (zooming into a chart, for instance). Alternatively, gaze-based interaction allows the user to simply look at a panel to focus it (often indicated by a small cursor in the center of the view), and then perform a click by a hand gesture (pinch or air-tap) or controller button. Developers should implement whichever interaction paradigm fits the hardware: e.g., on HoloLens or Quest with hand tracking, one might use the gaze + pinch method (look at the panel and pinch to select). The storyboard in Figure 4.18 highlights that an interactive VR dashboard is not static; users can point, select, or zoom into these panels for more information. For instance, pinching while gazing at a panel could enlarge it for closer inspection. This natural interaction model makes the dashboard truly immersive and usable without traditional UI devices. Overall storyboard image built from VRDDM for PoC1 is shown in Figure 4.19 giving much clearer overall perspective of how Table 4.7 built from the VRDDM.

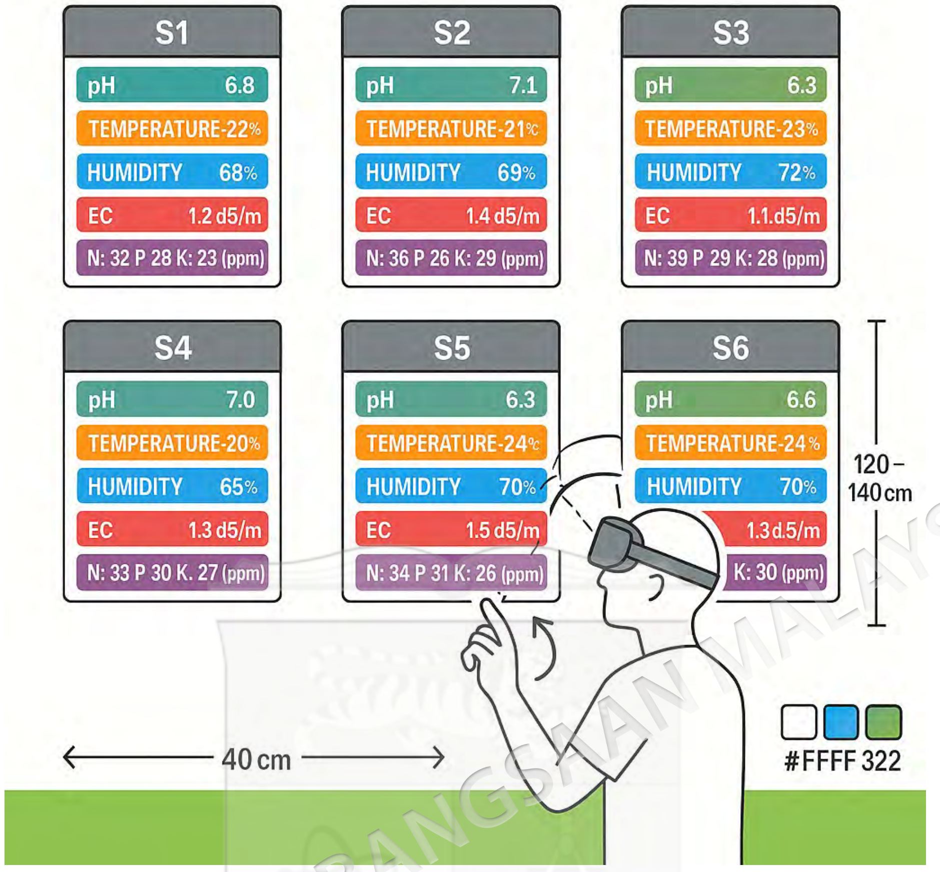


Figure 4.19 All elements of PoC1 are incorporated into a single storyboard image

4.5.4 Proof of Concept II (PoC2)

The PoC focuses on a more granular approach to data visualization by enabling users to view partial data selectively. Unlike PoC1, which provides a holistic view of all sensors within a greenhouse at one time, PoC2 (Proof of Concept 2) centers on user interaction and customization. In this scenario, users can select a specific sensor situated within a greenhouse to access detailed soil data for that particular portion in the greenhouse. For instance, by interacting with a virtual model of the farm, users can click on a sensor plot to retrieve real-time data on soil pH, temperature, and other parameters relevant to that plot. This selective approach not only reduces cognitive load of users (overwhelming data) but also allows users to focus on areas requiring immediate attention or intervention. PoC2 exemplifies the versatility of VRDDM in adapting dashboard designs to meet specific user needs, demonstrating its capability to balance comprehensive and targeted data presentations within the same methodological framework. Figure 4.20 is another instance of VRDDM conducted and later is prompted into advanced reasoning ChatGPT AI for building storyboard elements, Table 4.9.

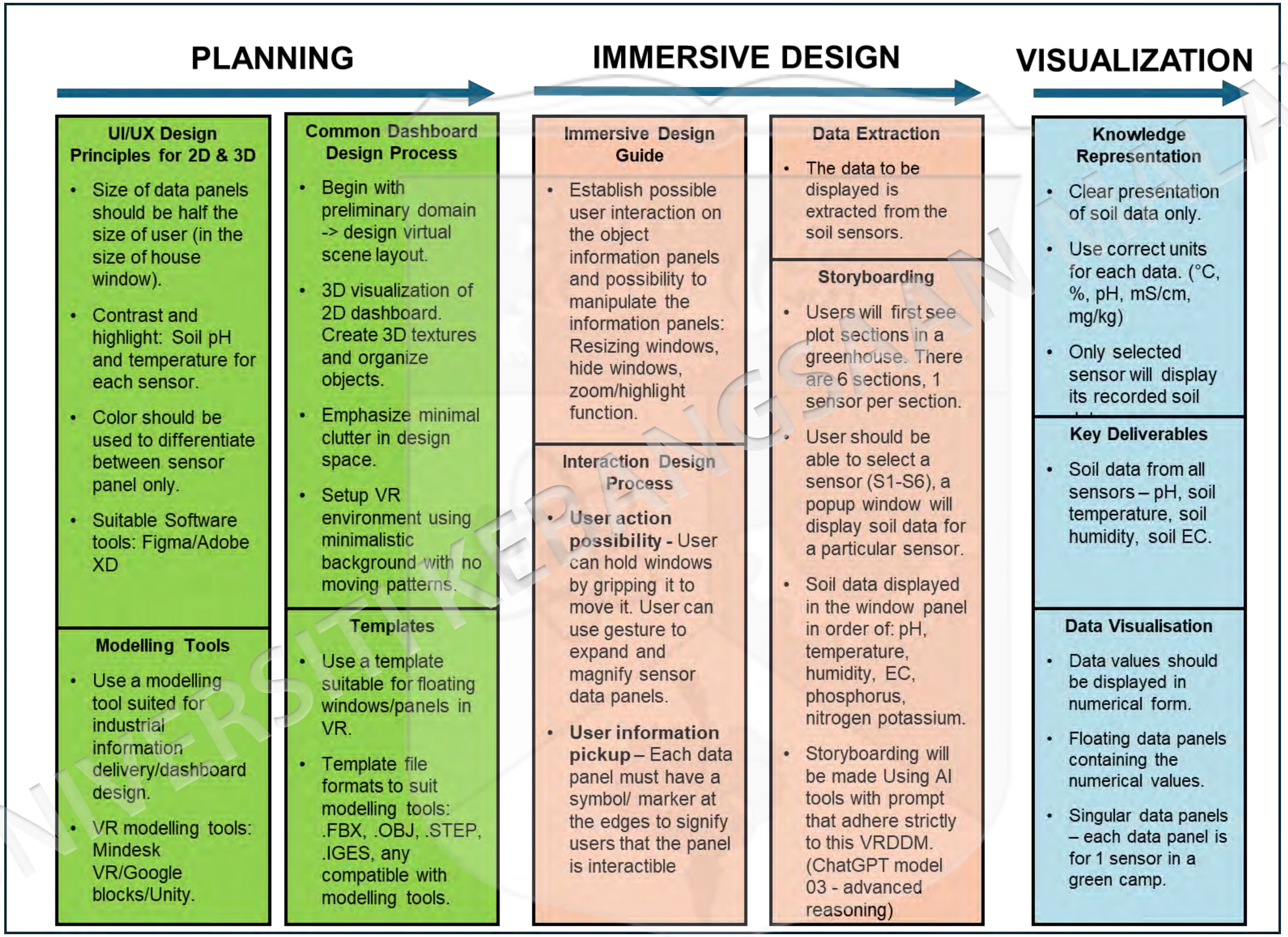


Figure 4.20 PoC2, a 2D overview dashboard converted into 3D VR dashboard (separate windows for each section of greenhouse)

Table 4.9 Storyboard elements from the VRDDM for PoC2

Item No.	Storyboard Item/Element Displayed	Related VRDDM blocks	Description
1	Floating Data Panels	UI/UX Design Principles for 2D & 3D and Data Visualisation	Multiple floating panels display key soil parameters for smart farming. Soil data from 1 sensor is shown when selected.
2	Real-Time Soil Parameters	Data Extraction, Key deliverables and Data Visualisation	One Panel show real-time data for pH, temperature, humidity, EC, phosphorus, nitrogen, and potassium levels. for 1 sensor only when selected.
3	Data Panel Design	Common Dashboard Design Process	Semi-transparent panels with high-contrast colors (dark background, bright text in white, cyan, or neon green).
4	Size of Data Panels	Common Dashboard Design Process & Immersive Design Guide	Each panel is sized approximately 40x25 cm in virtual space.
5	Positioning of Panels	Immersive Design Guide	Panels are positioned at an optimal height of 120-140 cm from the virtual ground for accessibility.
6	Font and Readability	Modelling tools and Templates	Text elements use sans-serif fonts like Sans serif, with numeric values in 32-40pt font size and labels in 24pt.
7	Dynamic Highlights	Interaction Design Process (User Information Pickup)	Panels feature color-coded warnings (red for critical values, yellow for suboptimal conditions).
8	Interaction Controls	Interaction Design Process (User action possibility)	Users can zoom in on specific data points using intuitive gesture controls or gaze-based selection.
9	Color Scheme	UI/UX Design Principles for 2D & 3D	Hex codes used: #FFFFFF (white), #00FFFF (cyan), #32CD32 (neon green) for high contrast.
10	Glowing Edge Effect	UI/UX Design Principles for 2D & 3D	Panels have a subtle glowing edge to indicate active panel selections. This applies to the selected sensors.

While the storyboard structure in both tables is consistent, the new table pivots the VR dashboard from a holistic, all-sensors display (Table 4.7, PoC1) to a selective, sensor-specific view (Table 4.9, PoC2). In PoC 1, multiple floating panels were permanently visible, each streaming real-time data from every section of the greenhouse, giving users an instantaneous, system-wide snapshot. By contrast, PoC2 retains the same floating-panel framework but constrains it to one panel that appears only when a particular sensor pin is selected, thereby decluttering the scene and lowering cognitive load. The "Floating Data Panels" and "Real-Time Soil Parameters" rows explicitly note that a single panel is spawned per sensor, and all subsequent design choices panel size, positioning, font hierarchy, colour scheme, dynamic highlights, and glowing edge effect, now serve to reinforce focus on that isolated data source. Interaction controls emphasise zooming or gaze selection of a targeted plot, rather than navigating a fixed wall of panels, and colour-coded alerts apply only to the active sensor, preventing warning overload. Hence, whereas Table 4.7 illustrated VRDDM's capacity to visualise comprehensive greenhouse data simultaneously, this revised table demonstrates VRDDM's flexibility in presenting granular data on demand, allowing users to investigate individual plots without sacrificing the familiar visual language established in PoC1.

For Floating Data Panels and Real-Time Soil Parameters (Item no. 1 and 2 respectively) are items to be displayed and are derived from the VRDDM key block of UI/UX Design Principles for 2D & 3D, Key deliverables and Data Visualisation. The illustrated storyboard for these items is shown in Figure 4.20. The panels within the visual cone of the user are purposefully arranged to support efficient data recognition and cognitive processing based on established human factors engineering principles. Multiple rectangular data panels float in the VR space, arranged in a semi-circular layout around the user. Each panel displays key soil metrics. The center panel shows temperature and humidity, the left panel shows pH and electrical conductivity (EC), and the right panel shows nutrient levels (N, P, K). Panels are positioned to surround the user's viewpoint, enabling quick glances to each metric without turning too far. This semi-circular arrangement leverages the 3D space to present multiple data points simultaneously, a common VR dashboard pattern. The panels appear to "hover" in mid-air, giving a holographic dashboard feel suited for a smart farming VR environment. Each floating panel displays a discrete environmental variable moisture, pH level, temperature, nutrient composition and electrical conductivity presented in distinct colors to enhance data segmentation and minimize cognitive overload. The soil parameter values are obtained via the separate sensor modules installed in the farming plot.

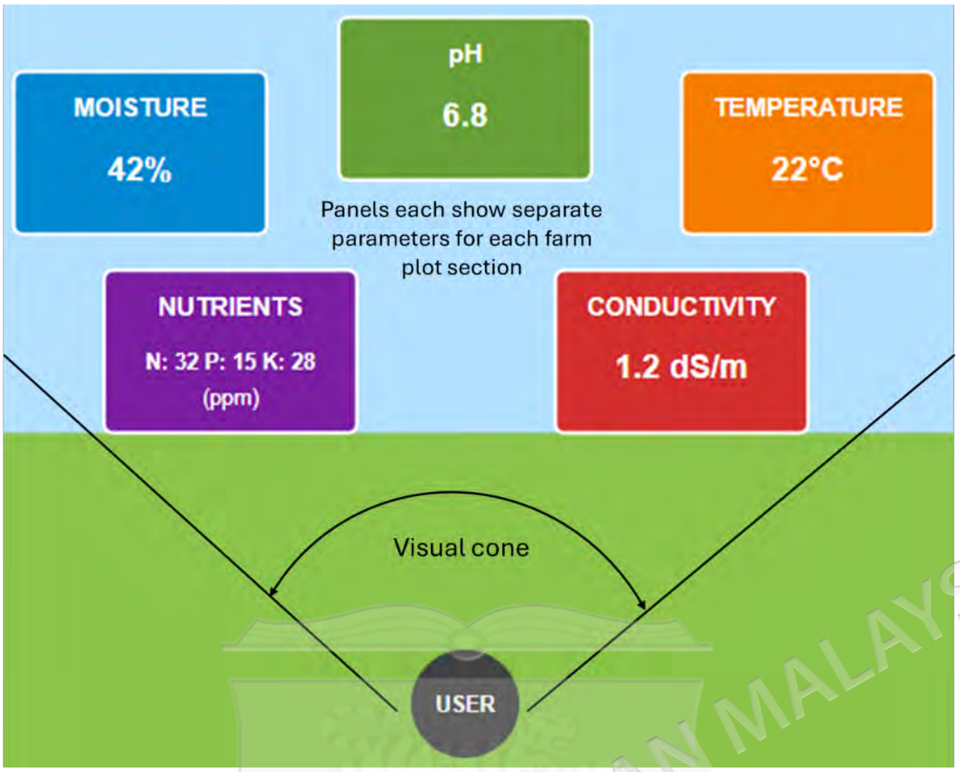


Figure 4.21 Illustrated storyboard for satisfying item no. 1 and 2 of the Table 4.9 (PoC2 storyboard elements)

The distinction of PoC2 compared to PoC1 can be seen via Figure 4.21. Rather than displaying simultaneously the data of all six sensors in a greenhouse, PoC2 sets to only show selected sensors and brings about multiple panels each displaying comprehensive soil health metrics in a color-coded, user-friendly format. Each panel contains crucial parameters: pH levels, temperature readings, humidity percentages, electrical conductivity measurements, and detailed nutrient profiles (nitrogen, phosphorus, and potassium). One parameter per panel only. The design employs a visual hierarchy with dedicated color schemes for each parameter category green for pH, orange for temperature, blue for humidity, red for conductivity, and purple for nutrients ensuring at-a-glance data interpretation. The dashboard floats within a virtual environment featuring a calm blue sky above and fertile green soil below, reinforcing its agricultural context. The user avatar, positioned centrally at the bottom, serves as an anchor point for VR interaction, allowing farmers and agronomists to navigate between monitoring stations with natural hand gestures. This immersive visualization transforms complex soil analysis into an accessible spatial experience, enabling users to make informed decisions about irrigation, fertilization, and crop management while physically situated within their virtual farm ecosystem. Figure 4.22 shows all elements incorporated.

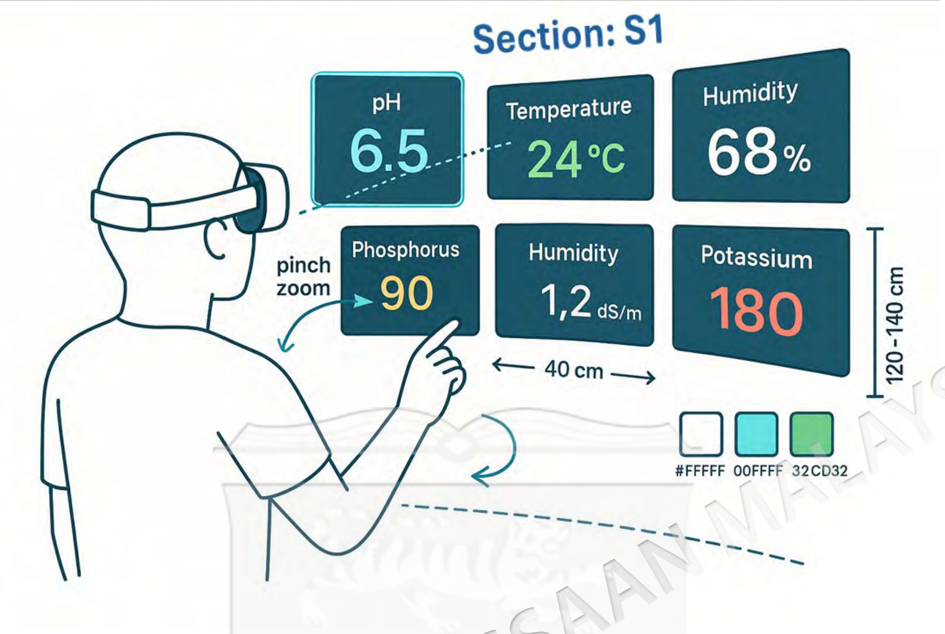


Figure 4.22 All elements of PoC2 are incorporated into a single storyboard image. The user is currently selecting section S1, he is presented with multiple windows each showing separate soil parameters

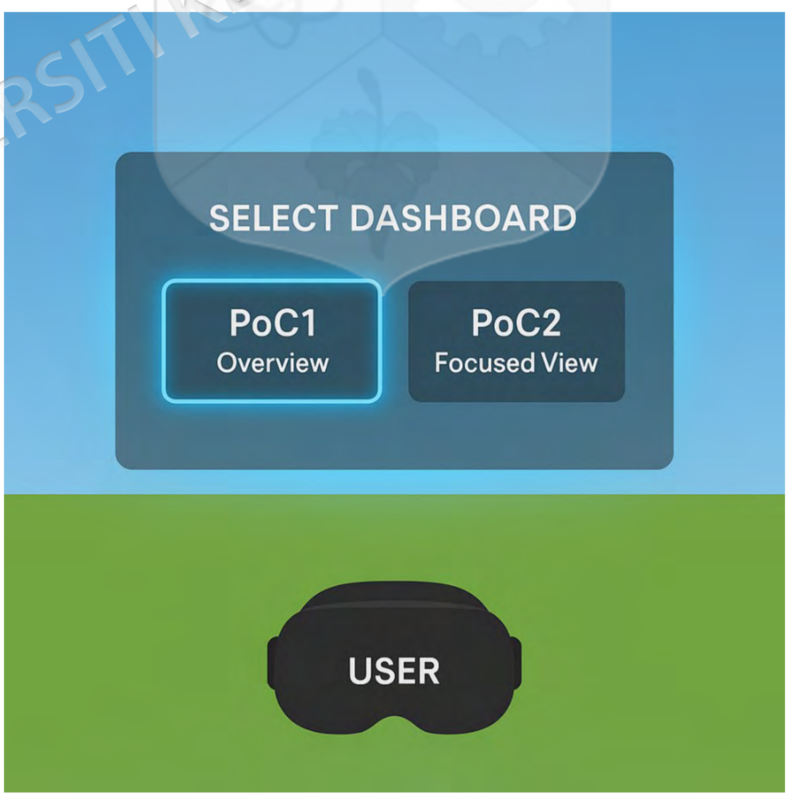


Figure 4.23 User preferences to use either PoC1 and PoC2

Additionally, it is desirable for the Virtual Reality (VR) dashboards developed in Proof of Concept 1 (PoC1) and Proof of Concept 2 (PoC2) to offer users the ability to select their preferred dashboard interface, enabling a more tailored and user-centric experience. This functionality depicted in Figure 4.23 would empower users to choose between the distinct design philosophies, layouts, and interaction flows of PoC1 and PoC2 based on their individual preferences, work habits, or specific task requirements. By supporting such customization, the system aligns with adaptive user interface (UI) principles, which emphasize flexibility and responsiveness to diverse user needs. This adaptability is particularly crucial in smart farming applications, where users may range from experienced agronomists seeking data-dense visualizations to field workers requiring simplified, action-oriented interfaces. Allowing users to switch between PoC1 and PoC2 not only accommodates varying cognitive styles and information processing preferences but also addresses use-case priorities such as monitoring, analysis, or intervention planning. Moreover, this feature supports task-specific needs by enabling users to select the dashboard most suitable for their current operational context, whether real-time monitoring during critical growing phases or in-depth analytics for long-term decision-making. Such a user-centric approach enhances engagement, improves usability, and promotes broader adoption of the VRDDM framework in agricultural settings.

4.5.5 Evaluation of PoCs – Findings from Interview

The evaluation phase within the Design Science Research Methodology (DSRM) plays a pivotal role in determining the overall utility, completeness, and usability of the VRDDM canvas as a functional design artifact. Following its initial demonstration through mock-up development, this phase offers a more rigorous assessment of the framework's effectiveness in guiding dashboard design processes. While earlier sections demonstrated the feasibility of using the VRDDM Canvas across various dashboard implementation contexts, this part of the study shifts focus towards understanding how well the framework supports real-world application from the standpoint of its target users and stakeholders.

To ensure a structured yet flexible evaluation process, a semi-structured interview approach was adopted, guided by a carefully developed interview protocol. This protocol was informed by established best practices in qualitative research design (Kallio et al. 2016), ensuring consistency in data collection while also allowing interviewers the freedom to probe deeper into participants' experiences and perspectives. The guide includes questions that address essential aspects of the VRDDM framework's relevance, ease of use, and applicability, grounded in recognized criteria for evaluating design science artifacts (Venable et al. 2016).

The application of a semi-structured interview guide is especially valuable in exploratory research contexts such as this, as it strikes a balance between maintaining alignment with research goals and uncovering unanticipated yet meaningful insights (Longhurst 2003). This approach enables evaluators to capture both broad and nuanced feedback from participants directly involved in dashboard design or familiar with its intended domain. The insights derived from this qualitative evaluation provide a rich foundation for refining the VRDDM canvas, ensuring its continued relevance and effectiveness as a design aid for user-centric dashboard development.

4.5.6 Evaluation of PoCs – Interview Method

To facilitate a rigorous and contextually grounded evaluation of the VRDDM framework, a qualitative research design was employed, leveraging semi-structured interviews as the principal data collection method. This approach was deemed appropriate due to its capacity to elicit rich, experiential data and uncover nuanced perspectives regarding the framework's usability, effectiveness, and applicability within the domain of dashboard design (Kallio et al. 2016). The semi-structured format offers a methodologically robust balance ensuring consistency in the core themes explored across participants while preserving flexibility to probe emergent issues and contextual insights. Given the complexity and iterative nature of design artefacts in Design Science Research, this approach aligns well with the need for deep interpretive understanding, particularly in evaluating artefacts situated in practice-based environments (Longhurst 2003).

The evaluation process was conducted with two purposively selected participant groups: dashboard designer who were directly involved in the demonstration phase, and a VR developer with substantial experience in visual analytics and dashboard implementation. The purposive sampling strategy ensured that feedback was grounded in practical engagement with the VRDDM, thereby enhancing the relevance and credibility of the evaluation findings. An interview guide was developed to support the inquiry process, comprising open-ended questions strategically aligned with established criteria for evaluating DSR artefacts namely, utility, usability, completeness, and potential for improvement (Venable et al. 2016). Additional prompts were embedded to uncover contextual challenges, implementation barriers, and constructive feedback for refinement, thereby enabling a multidimensional evaluation of the framework's performance.

All interviews were conducted via Google Meet to accommodate remote participation and to ensure accessibility across geographic locations. The platform's integrated recording and transcription functionalities facilitated detailed documentation of each session. However, due to the occasional inaccuracy of automated transcripts, all transcripts were subjected to rigorous manual review to ensure fidelity of the data. A member-checking process was then implemented whereby participants were provided with cleaned transcripts for validation. This step not only upheld ethical standards ensuring participants' informed consent regarding the use of their responses but also contributed to the trustworthiness and authenticity of the qualitative data, enhancing its credibility as evidence for evaluating the artefact.

In optimizing the quality and depth of the responses, all participants were provided with the full set of interview questions in advance. This preparatory step allowed participants adequate time to reflect on their experiences and formulate considered responses, resulting in more insightful and coherent data collection during the interview sessions. The interviews, consequently, yielded a comprehensive set of qualitative insights encompassing both the strengths and limitations of the VRDDM framework. This methodological approach characterized by rigorous sampling, structured yet flexible instrumentation, ethical validation procedures, and participant preparedness ensures the robustness of the evaluation and positions the findings as a meaningful contribution to the broader discourse on artefact evaluation in design science research.

Following the completion and verification of interview transcripts, the data were systematically examined using Braun and Clarke's (2006) six-phase thematic analysis approach. This method enabled the identification of key patterns and insights by progressing through a structured process: becoming familiar with the data, generating initial codes, identifying potential themes, reviewing and refining these themes, defining and naming them, and finally synthesising the findings into a coherent report. This analytical framework provided a rigorous and transparent means of interpreting participants' perspectives, ensuring that emergent themes were grounded in the data and reflective of the overall research objectives.

The structured yet adaptable nature of the chosen evaluation method proved valuable in uncovering consistent patterns across participant responses, which were then synthesized into meaningful themes. These themes provided insight into both the strengths and limitations of the VRDDM, reflecting its practical application and user experience. The thematic analysis process, grounded in systematic coding and interpretation, facilitated a comprehensive understanding of how the framework performs in real-world scenarios and highlighted opportunities for further refinement.

From a methodological standpoint, this approach is consistent with established practices in design science and information systems research (Baskerville et al. 2018). The integration of semi-structured interviews with Braun and Clarke's thematic analysis enabled a robust, multi-dimensional examination of the VRDDM. Rather than focusing solely on outcome metrics, the evaluation emphasized in-depth qualitative understanding capturing not only how the framework functions, but also how it is perceived and experienced by its users.

Although the evaluation involved only two participants, each was selected through purposive sampling based on their direct involvement with the VRDDM. This included dashboard developers and a domain expert working within the smart waste management context. Such a sampling strategy is widely endorsed in Design Science

Research (DSR), particularly during formative evaluation stages where depth of insight is prioritized over breadth. The intention was not statistical generalization, but rather informed reflection drawn from those with practical familiarity and expertise.

Accordingly, the evaluation was interpretive and exploratory in nature. Its primary aim was to gather experience-rich feedback that could inform ongoing improvement of the VRDDM canvas (Gregor & Hevner 2013; Iivari 2007). This aligns with the broader goals of the evaluation phase within the Design Science Research Methodology (DSRM), where artefacts are iteratively assessed and refined through real-world engagement and reflective inquiry (Sonnenberg & vom Brocke 2012).

Although the sample size was limited, the data gathered provided valuable and in-depth insights, offering well-grounded feedback on the VRDDM's usability, structural coherence, and relevance to its intended domain. Participants' reflections revealed recurring thematic patterns, which emerged organically and validated the suitability of the chosen analytical method (Braun & Clarke 2006). Within the context of Design Science Research, such a depth-oriented approach is often considered appropriate particularly during the initial stages of artefact validation where the goal is to refine the design through experiential input rather than generalize findings (Baskerville et al. 2018). A summary of the evaluation methodology is presented in Table 4.10.

Table 4.10 Summary of VRDDM evaluation methodology

Aspect	Description
Methodology	Qualitative research using semi-structured interviews to obtain in-depth insights into the application and perceived utility of the VRDDM canvas.
Participant selection	The evaluation involved one VR dashboard designer and one VR developer. The designers were selected for their hands-on experience in creating VR mock-up dashboards, ensuring they could offer practical insights into its implementation. The inclusion of a VR developer, with expertise in both the domain and information systems, added a valuable external perspective. This combination of participants allowed for a balanced evaluation, incorporating both design-focused and domain-specific viewpoints to assess the framework's applicability and effectiveness across technical and contextual dimensions.

… to be continued

… continuation

Data collection method	Semi-structured interviews supported by open-ended interview questions aligned to core evaluation dimensions.
Interview focus	Evaluation of the VRDDM'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 via google meet with consent and subsequently transcribed for analysis.
Analysis method	Thematic analysis conducted using the six-phase process proposed by Braun and Clarke (2006), allowing for the identification and interpretation of recurring themes in participant responses.

Having established the evaluation methodology, the subsequent subsections delve deeper into the design of the evaluation process. They present a detailed account of the participant selection criteria, the structure and content of the semi-structured interview guide, and the analytical approach employed for interpreting the qualitative data. This comprehensive explanation ensures transparency in how the evaluation was conducted and provides context for understanding the findings. By outlining these elements, the study demonstrates a systematic and reflective approach to assessing the VRDDM framework, aligning with best practices in qualitative and design science research.

a. Respondent Profiles

To ensure the evaluation of the VR Dashboard Design Method (VRDDM) reflected both technical expertise and practical design perspectives, two respondents were purposively selected based on their direct involvement in the development and demonstration phases and their specialized knowledge in virtual reality systems. This combination of roles was chosen to provide a balanced and holistic assessment of the VRDDM's usability, design relevance, and applicability to real-world dashboard development in immersive environments. Both respondents contributed unique insights from their respective professional backgrounds, ensuring that the evaluation captured the nuances of both creative design thinking and technical implementation challenges.

The first respondent was a VR designer (VRD1) with extensive experience in user interface (UI) and user experience (UX) design for immersive applications. His portfolio includes designing interactive 3D environments for training simulators and healthcare visualization tools, equipping him with a deep understanding of how visual elements and user flows influence perception and usability in virtual spaces. Throughout the evaluation, VRD1 provided critical feedback on the structural aspects of VRDDM, particularly its support for narrative-driven storyboarding, spatial arrangement of data visualizations, and adherence to UX best practices in VR contexts. His insights were invaluable in assessing how effectively VRDDM guides designers in creating user-centric dashboards that balance visual appeal with functional clarity in complex 360° environments.

The second respondent was a VR developer (VRDev1) specializing in implementing VR applications using platforms such as Unity3D and Unreal Engine. With a strong technical background in programming, 3D modelling integration, and VR hardware optimization, he focused on evaluating VRDDM from a development feasibility and implementation perspective. VRDev1 assessed the method's capacity to support technical workflows, its alignment with current VR development tools, and its effectiveness in managing system performance constraints common to immersive applications. His feedback highlighted the practicality of VRDDM in guiding the integration of ontological frameworks, dynamic data visualizations, and user interaction mechanisms within VR dashboards. Together, the complementary perspectives of the VR designer and VR developer ensured a comprehensive evaluation of VRDDM, validating its potential as a robust framework for guiding both conceptual design and technical realization of VR dashboards in smart farming and other domains.

Table 4.11 Profiles of the respondents

Respondent	Role	Expertise	Focus in Evaluation
VRD1	VR Designer	UI/UX design for immersive 3D environments; experience in training simulators and healthcare visualization tools.	Evaluated VRDDM's support for narrative storyboarding, spatial arrangement of data visualizations, and adherence to UX best practices in VR.
VRDev1	VR Developer	Technical development of VR applications using Unity3D and Unreal Engine; expertise in 3D modeling integration and hardware optimization.	Assessed VRDDM's alignment with VR development tools, technical feasibility, and ability to manage performance constraints in immersive systems.

Table 4.11 provides an overview of the profiles of the two respondents involved in the evaluation of the VR Dashboard Design Method (VRDDM). The inclusion of these respondents was strategically planned to capture diverse yet complementary perspectives essential for assessing the framework's practicality and effectiveness. By selecting a VR designer and a VR developer, the evaluation integrates insights from both conceptual and technical dimensions of VR dashboard development. The VR designer contributed expertise in user interface (UI) and user experience (UX) design, offering critical feedback on how well VRDDM supports immersive storytelling, spatial organization, and user-centric design principles. Meanwhile, the VR developer brought a technical perspective, assessing the feasibility of implementing VRDDM using contemporary development platforms such as Unity3D and Unreal Engine, and evaluating the method's ability to accommodate hardware and performance constraints typical in VR systems. Together, their combined expertise ensured a holistic evaluation of the framework, addressing not only the visual and interactive qualities of VR dashboards but also the backend technical considerations necessary for successful deployment. This table serves to contextualize their roles, areas of expertise, and specific focus during the evaluation, highlighting how their feedback shaped the refinement and validation of VRDDM in this study.

b. Interview Questions

The interview process was designed to gather in-depth qualitative insights from two key stakeholders: a VR dashboard designer and a VR dashboard developer who were directly involved in the evaluation of the VR Dashboard Design Method (VRDDM) and its associated artefacts. The structured interviews aimed to assess multiple dimensions of the VRDDM, including its usability, effectiveness, completeness, adaptability, and alignment with industry practices. By focusing on these areas, the interviews provided a rich understanding of how the framework performed in real-world contexts and identified opportunities for refinement and future enhancements.

The interview questions were divided into thematic sections tailored to each respondent's role, ensuring relevance and maximizing the depth of responses. For the VR dashboard designer, the questions emphasized user experience, methodology flow, and practical design support. For the VR developer, the focus was on technical feasibility, integration potential, and domain-specific applicability.

c. Interview Questions for VR Dashboard Designer

The interview with the VR dashboard designer was organized into seven thematic sections: Usability, Effectiveness, Completeness, Impact, Challenges & Limitations, Suggested Improvements, and Overall Assessment

In Section A: Usability, the questions probed the designer's ease of understanding and applying the VRDDM Canvas during their workflow. They were asked: "How easy was it to understand and apply the VRDDM Canvas in your dashboard design process?" and "Did the concepts within the VRDDM Canvas feel comprehensive and relevant to your needs?" These questions aimed to assess how intuitive the framework was for practitioners and whether the structure of the canvas facilitated seamless adoption.

Section B: Effectiveness focused on the practical value of the VRDDM in supporting design decisions and enhancing user outcomes. The designer was asked to reflect on how the method helped address the specific needs of their intended dashboard users, guided data selection and visualization choices, and improved the overall quality and purposefulness of the final product. For instance, the question "Did the VRDDM improve the overall quality and purposefulness of your final VR dashboard?" provided insights into the framework's impact on design outcomes.

In Section C: Completeness, the interview explored potential gaps in the VRDDM's coverage of critical design aspects. Questions like "Were there any important aspects of dashboard design that the VRDDM did not cover adequately?" and "Did any part of the method feel redundant or unnecessary in your workflow?" elicited feedback on the framework's comprehensiveness and relevance. Another important question, "How well were ecological psychological perspective theories incorporated in the VRDDM?", assessed the integration of theoretical underpinnings into practical design guidelines.

Section D: Impact assessed how the VRDDM influenced the designer's workflow and decision-making compared to their previous approaches. Questions such as "How did using the VRDDM compare to your previous dashboard design approaches?" and "Would you consider using the VRDDM methodology again for other projects?" provided insights into long-term adoption potential and perceived value.

The designer was also encouraged to discuss practical challenges in Section E: Challenges and Limitations, with questions like "What were the main challenges or difficulties you encountered while applying the VRDDM?" and "Did any platform-specific or project-related limitations affect your experience?" This section aimed to uncover technical or process-related constraints that could inform future iterations of the methodology.

Section F: Suggested Improvements gave the designer a platform to propose refinements to the framework. Questions such as "What suggestions do you have to improve the VRDDM framework?" and "Are there any additional features, sections, or tools you would like to see included?" encouraged creative and constructive feedback.

Finally, in Section G: Overall Assessment, the designer provided a holistic evaluation of the VRDDM, rating its usefulness on a scale of 1–10 and offering their perspective on whether they would recommend it to other professionals. The question "Would you recommend this method to other dashboard designers? Why or why not?" aimed to assess broader applicability within the design community.

d. Interview Questions for VR Dashboard Developer

The VR dashboard developer's interview mirrored a similarly structured approach but focused on technical aspects, domain relevance, and integration potential.

The questions were grouped into five thematic sections: Dashboard Relevance and Utility, Domain-Specific Metrics, Interpretability and Clarity, Adoption and Integration, and Overall Assessment.

In Section A: Dashboard Relevance and Utility, the developer was asked to evaluate how well the PoCs reflected operational and strategic information needs, with questions like “How well do the VR dashboards reflect the operational and strategic information?” and “Which VR dashboard features do you find most helpful for guidance towards developing a VR dashboard?” This section gauged the artefact’s practical utility from a technical perspective.

Section B: Domain-Specific Metrics examined whether the dashboards adequately incorporated key indicators used in VR development. Questions such as “Do the dashboards include key indicators that are commonly used in VR dashboard development?” and “How reliable or trustworthy do you find the way these metrics are visualized?” focused on data integrity and relevance. The question “Are there any critical domain-specific metrics that are missing or underrepresented?” provided insights into potential content gaps.

In Section C: Interpretability and Clarity, the developer was asked to reflect on the ease of understanding the dashboard structures. Questions included “Is the VR dashboard easy to interpret for developers at different levels or fields?” and “Would this VR dashboard canvas support rapid understanding or require training for proper interpretation?” This section helped assess the framework’s accessibility to diverse technical audiences.

Section D: Adoption and Integration addressed organizational considerations. Questions like “How likely is it that this VR dashboard design method could be adopted by any organization?” and “What factors would support or hinder the integration of these VR dashboard methods into existing development operations?” explored real-world feasibility and alignment with existing workflows and systems.

Section E: Overall Assessment invited a holistic evaluation. Questions such as “How would you rate the VR dashboard design method overall in terms of usefulness and alignment with industry needs?” and “Would you recommend them for wider use across the smart farming sector?” sought to capture the developer’s overall impression and perceived value of the framework.

This structured and role-specific approach to interviews allowed for a comprehensive evaluation of the VRDDM from both creative and technical standpoints. The designer's feedback emphasized usability and design support, while the developer's responses focused on technical integration and operational relevance. Together, these perspectives provide a nuanced understanding of the VRDDM's strengths, limitations, and potential for adoption in diverse VR development contexts. Table 4.12 shows the summary of interview sections and question focus areas.

Table 4.12 Summary of Interview Sections and Question Focus Areas

Respondent	Section	Focus Area
VR Dashboard Designer	A. Usability	Ease of understanding and applying the VRDDM Canvas; relevance of concepts to design workflow.
	B. Effectiveness	Support for design decisions, user-centric outcomes, and quality improvements in final dashboards.
	C. Completeness	Coverage of critical design aspects, gaps, redundancies, and integration of theoretical underpinnings.
	D. Impact	Influence on workflow compared to previous approaches; potential for future adoption.
	E. Challenges & Limitations	Practical and platform-specific challenges encountered during application of VRDDM.
	F. Suggested Improvements	Recommendations for refining the framework and adding new features or tools.
	G. Overall Assessment	Holistic evaluation of usefulness, rating, and likelihood of recommending to other designers.
VR Dashboard Developer	H. Dashboard Relevance and Utility	Alignment with operational and strategic needs; helpfulness of specific features for development guidance.
	I. Domain-Specific Metrics	Adequacy and reliability of key indicators used in VR dashboard development; identification of gaps.
	J. Interpretability and Clarity	Ease of understanding for technical audiences; need for training or support for adoption.
	K. Adoption and Integration	Feasibility of integrating the method into existing workflows; organizational adoption potential.
	L. Overall Assessment	General usefulness, alignment with industry needs, and recommendation for wider use.

e. Interview Responses from VR Dashboard Designer and Developer

The evaluation of the Proof of Concepts (PoC1 and PoC2) under the VRDDM framework was informed by in-depth interviews with two key respondents: a VR Dashboard Designer (VRD1) and a VR Dashboard Developer (VRDev1). Their responses, documented in Appendix B and Appendix C, provide a comprehensive view of the framework's effectiveness from both creative and technical perspectives. The interviews explored seven thematic areas: Usability, Effectiveness, Completeness, Impact, Challenges and Limitations, Suggested Improvements, and Overall Assessment. Insights drawn from their feedback not only validate the VRDDM's core strengths but also offer constructive directions for refinement.

i. Insights from the VR Dashboard Designer (VRD1)

During the interview on July 8, 2025, at 10:00 a.m., VRD1 reflected extensively on his experience using the VRDDM Canvas to design mock-up dashboards.

In terms of usability, VRD1 highlighted how the canvas provided an accessible and logical workflow. He noted, "Initially, I found the VRDDM Canvas quite intuitive. At first glance, the structure might seem a little dense, but it quickly became clear how each section guides you through the design process" (10:12 a.m., Appendix B). He described how the key blocks acted like "reminders of best practices," creating a roadmap for tackling complex design tasks.

When asked about the relevance of the concepts in the canvas, VRD1 emphasized their applicability: "The framework covered a wide range of considerations user interaction, data visualization, even storyboarding which really aligned with the challenges we face in VR design" (10:19 a.m., Appendix B). He found that the integration of ecological psychological perspectives was particularly beneficial for immersive environments, allowing him to design for more natural user interactions.

On effectiveness, VRD1 commented on how the VRDDM influenced his data visualization choices: "The method encouraged me to think about the story the data needed to tell. Instead of defaulting to familiar 2D charts, I explored volumetric and interactive 3D visualizations that fit the VR context better" (10:36 a.m., Appendix B). He acknowledged that the framework shifted his approach from one focused on aesthetics to one emphasizing user-centric storytelling.

Regarding completeness, VRD1 identified accessibility as a gap: "While comprehensive, I felt the VRDDM could strengthen its focus on accessibility design considerations like accommodating color blindness or motion sensitivity in VR" (10:49 a.m., Appendix B). He also suggested providing practical examples of how theoretical principles apply in VR-specific contexts.

When discussing impact, VRD1 observed a significant improvement in his workflow: "It felt more structured and deliberate. Previously, I relied a lot on intuition and past experiences, but the VRDDM forced me to step back and analyze the 'why' and 'who' before diving into 'what' and 'how'" (11:06 a.m., Appendix B). This shift resulted in designs that were more purposeful and aligned with user needs.

Among the challenges, VRD1 mentioned the effort required to translate ontological concepts into practical design tasks: "The main challenge was understanding and translating the ontological concepts into actionable design steps during the early stages" (11:22 a.m., Appendix B).

For suggested improvements, VRD1 proposed an interactive digital version of the canvas: "An interactive digital version of the canvas would be great, allowing designers to drag-and-drop components and see a live preview of layouts" (11:45 a.m., Appendix B).

In his overall assessment, he rated the framework highly: "I'd rate it an 8. It's a solid framework that brings structure and theoretical depth" (11:51 a.m., Appendix B). He added, "I would recommend it to other dashboard designers, especially for complex, user-centered VR projects" (11:55 a.m., Appendix B).

VRD1 emphasized the VRDDM's strength in guiding narrative-driven design and maintaining spatial coherence in immersive environments. He noted that the structured flow of the framework facilitated his design process, allowing him to focus on user-centric storytelling while addressing complex 360° data visualizations. Particularly, VRD1 appreciated how the VRDDM incorporated elements of ecological psychology, supporting more natural user interactions within the VR dashboards. He commented that the framework's emphasis on user analysis and task flows significantly improved his ability to prioritize and arrange dashboard elements, resulting in a more intuitive user experience. Challenges identified included the need for more explicit prompts about iterative design feedback loops and clearer guidelines for integrating information governance principles in practical design stages. Despite these, he acknowledged the VRDDM as a valuable asset for fostering deliberate and thoughtful dashboard designs that transcend visual aesthetics to focus on functional clarity and user engagement.

ii. Insights from the VR Dashboard Developer (VRDev1)

In his interview on July 9, 2025, at 2:30 p.m., VRDev1 offered technical perspectives on implementing the VRDDM and developing the PoCs.

On dashboard relevance and utility, VRDev1 remarked on the practical alignment of the dashboards: "They do quite well overall. The dashboards provide a good balance of high-level strategic overviews and detailed operational data" (2:41 p.m., Appendix C). He praised specific features like dynamic threshold warnings and interactive panels, calling them "particularly effective in identifying out-of-range values" (2:47 p.m., Appendix C).

For domain-specific metrics, VRDev1 appreciated the inclusion of common indicators but pointed out gaps: "In the context of smart farming, I'd say predictive analytics indicators could be more prominent" (3:03 p.m., Appendix C). He also suggested enhancing temporal trend visualizations to support forecasting.

When asked about interpretability and clarity, VRDev1 said, "The canvas provides a structured way for even less experienced developers to understand the system's architecture" (3:14 p.m., Appendix C). However, he noted that "a brief orientation to VRDDM's terminology and workflow might benefit teams unfamiliar with ontological design concepts" (3:23 p.m., Appendix C).

In terms of adoption and integration, VRDev1 was optimistic: "The framework integrates well with standard VR development pipelines and can adapt to existing data systems" (3:32 p.m., Appendix C). He highlighted modularity as a strength but cautioned about potential hindrances like hardware constraints and resource requirements.

His overall assessment rated the method highly: "I'd rate it an 8. It provides a strong foundation for building immersive dashboards and aligns well with industry needs" (3:43 p.m., Appendix C). He recommended the framework for broader use: "It's practical, scalable, and supports the type of data visualization needed in smart farming" (3:47 p.m., Appendix C).

VRDev1's feedback focused on technical feasibility and implementation considerations. He found the VRDDM's artefacts to align well with modern development platforms like Unity3D and Unreal Engine, highlighting its potential for cross-platform adaptability. The framework's modular approach enabled easier integration of ontological structures and dynamic data visualization techniques. However, VRDev1 also pointed out certain limitations, such as performance constraints when deploying high-fidelity VR dashboards on resource-limited hardware. He suggested expanding the framework to include more detailed guidelines on optimizing graphical assets and data processing pipelines to accommodate real-time rendering requirements. Furthermore, VRDev1 valued the VRDDM's guidance on prioritizing data relevance for immersive contexts, which he found essential in avoiding cognitive overload for end users. His feedback underscored how the framework could serve as a blueprint for translating conceptual designs into technically robust, scalable VR solutions.

Both respondents acknowledged the dual Proof of Concepts (PoC1 and PoC2) as vital demonstrations of VRDDM's versatility. VRD1 preferred PoC2 for its focus on granular, task-specific data visualization that supported precision farming workflows, while VRDev1 highlighted PoC1's holistic representation of operational data as an effective example of integrating high-level monitoring in VR. Their combined feedback validated the framework's ability to cater to diverse user needs and technical requirements, reinforcing its relevance in real-world smart farming scenarios.

The thematic analysis of their responses revealed recurring strengths of the VRDDM: structured guidance, user-centered focus, technical adaptability, and a clear methodological flow. Equally, it identified areas for enhancement, such as improved support for iterative refinement and platform-specific optimization practices. Together, these insights inform a well-rounded understanding of the framework's performance and its potential for broader application in the VR design and development ecosystem. This multidimensional evaluation reflects how the VRDDM bridges the gap between design creativity and technical feasibility, supporting a comprehensive workflow from ideation to deployment.

4.6 SUMMARY

Both scenarios underline the transformative potential of VRDDM in enhancing data visualization and user experience in smart farming. By transitioning from a static 2D dashboard to dynamic VR environments, VRDDM enables the creation of dashboards that are not only visually engaging but also functionally superior. In PoC1, the ability to visualize soil conditions across the entire farm simultaneously empowers users to make informed decisions regarding resource allocation and crop management. On the other hand, PoC2's interactive design caters to precision farming practices by providing users with the tools to monitor and address issues at a granular level. These scenarios showcase the scalability and adaptability of VRDDM, affirming its value as a methodological framework for VR dashboard design.

Furthermore, the execution of VRDDM in these scenarios highlights its potential to address real-world challenges in data-intensive industries beyond smart farming. The principles of UI/UX design, immersive interaction, and knowledge representation embedded in VRDDM ensure that dashboards are not only visually appealing but also user-centric and purpose-driven. By integrating advanced visualization techniques and interactive features, VRDDM offers a structured approach to designing VR dashboards that cater to diverse application domains, from agriculture to industrial monitoring and healthcare.

The application of VRDDM in developing PoC1 and PoC2 underscores its efficacy as a design methodology for VR dashboards. The flexibility to generate multiple artifacts from a single execution, as demonstrated in these scenarios, reflects the adaptability and robustness of VRDDM. By transforming static 2D data into immersive 3D visualizations, VRDDM not only enhances data interpretation but also facilitates better decision-making. These proof-of-concept implementations serve as starting point for evaluating the effectiveness of VRDDM in assisting VR designers to design VR dashboard.

CHAPTER V

CONCLUSION

5.1 INTRODUCTION

This final chapter concludes the research by reflecting on the principal achievements, consolidating both the theoretical and practical contributions, and proposing directions for future research. The study was initiated in response to a critical gap in the literature namely, the absence of a standardized and ontologically grounded method for designing virtual reality (VR) dashboards, particularly within the domain of smart farming. While VR technology has been increasingly adopted across sectors for immersive data interaction, its application in dashboard design remains fragmented and largely ad hoc, lacking a unified framework or methodological consistency.

To address this challenge, the research adopted the Design Science Research Methodology (DSRM) as outlined by Peffers et al. (2008) as its central methodological approach. Through iterative cycles of problem identification, design, development, demonstration, and evaluation, the study led to the formulation of the Virtual Reality Dashboard Design Method (VRDDM). This artefact was supported by the development of the Virtual Reality Dashboard Design Ontology (VRDDO), which provides a formalized structure for guiding dashboard creation based on ontological principles. The integration of Business Model Ontology (BMO) and the Ecological Psychology Perspective (EPP) further contributed to the theoretical robustness of the framework.

This chapter begins by revisiting the research objectives and summarizing how each has been fulfilled throughout the study. It then presents the research contributions through the lens of the Design Science Research Knowledge Contribution Framework (Gregor & Hevner 2013), highlighting the novel artefacts and methodological insights derived. Special attention is given to the primary contribution, the VRDDM, alongside its supporting components such as VRDDO, prototype dashboards, and interview insights. The chapter concludes with critical reflections and identifies several avenues for future research, particularly in extending the VRDDM framework to other domains and refining its implementation based on broader empirical validation.

5.2 RESEARCH ACHIEVEMENTS

The achievements of this study are best reflected through the systematic fulfilment 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.

5.2.1 Achievement of Research Objective 1

The first research objective was to identify the fundamental knowledge domains essential for developing a method for designing functional Virtual Reality (VR) dashboards. This objective was addressed through a comprehensive narrative literature review, as detailed in Chapter 2, which examined thirteen relevant studies across various VR dashboard implementations. The review investigated multiple dimensions, including domain of application, methodological structure, visualization strategies, interface interaction, tools and algorithms used, design processes, and theoretical underpinnings such as UI/UX principles.

The analysis yielded several important insights. First, while VR dashboards have been explored across diverse fields such as manufacturing, health, urban planning, and data analytics, there was no evidence of a unified or standardised design method being adopted. Most studies emphasized the benefits of immersive visualization and interaction but lacked a consistent structure or framework for guiding the development process. Second, although common practices such as the use of Unity3D, digital twins, or user-centered interaction models were frequently observed, these elements were applied in an ad-hoc manner. Crucially, none of the reviewed studies applied an ontological lens to organise the design knowledge systematically, nor did they consider the ecological psychology perspective to inform user-system interaction.

These findings confirmed the existence of a methodological gap in VR dashboard design, particularly in the context of data-intensive environments such as smart farming. The absence of a structured, theoretically grounded, and reusable approach to dashboard design reinforced the need for a comprehensive framework. This recognition validated the direction of the study and laid the foundation for the development of the Virtual Reality Dashboard Design Method (VRDDM), which aims to offer an ontologically structured and conceptually coherent method for VR dashboard creation.

5.2.2 Achievement of Research Objective 2

The second objective aimed to propose an ontological framework that systematically organises the knowledge domains required to design functional Virtual Reality dashboards. This objective was addressed through the construction of the Virtual Reality Dashboard Design Ontology (VRDDO), as detailed in Chapter 4. The process was guided by the Design Science Research Methodology (DSRM) and grounded in both theoretical and empirical foundations. The VRDDO was conceptualised to serve as the backbone of the broader Virtual Reality Dashboard Design Method (VRDDM), ensuring that the method is not only structured but also semantically coherent and reusable across different domains.

The development process began with identifying a set of key building blocks that are commonly cited in dashboard design practices. These included elements related to UI/UX design principles for 2D and 3D environments, data extraction and processing, knowledge representation, interaction design, and visualisation modelling tools. Drawing inspiration from prior ontological design practices, these components were translated into formal entities and relationships within the VRDDO structure. Special attention was given to ensuring that the ontology could accommodate domain-specific knowledge, particularly in the context of smart farming, where environmental data, crop behaviour, and sensor outputs are key informational inputs.

To provide a rigorous foundation, the VRDDO was developed using the Unified Ontological Approach (UOA), supported by the Unified Foundational Ontology (UFO) as its upper ontology. This ensured the philosophical robustness and semantic clarity of the conceptual model. The ontology was further enriched by integrating theoretical constructs from the Ecological Psychology Perspective (EPP) and Business Model Ontology (BMO), which helped define the affordances and relationships between user actions, system feedback, and contextual goals in the dashboard environment. These theoretical components strengthened the internal coherence of the model while anchoring it in established interdisciplinary knowledge.

The final VRDDO was validated through iterative refinement, using case-based scenarios and feedback from practitioners involved in the field. The structured representation of concepts within the ontology facilitated the creation of a coherent semantic backbone for the VRDDM framework. This achievement directly addresses the second research objective by providing a robust ontological infrastructure for dashboard design in VR contexts. It lays the groundwork for a methodologically sound and theoretically grounded dashboard design method that can be reused, adapted, and extended across different application domains beyond smart farming.

5.2.3 Achievement of Research Objective 3

The third research objective focused on applying the proposed design method Virtual Reality Dashboard Design Method (VRDDM) to develop functional VR dashboards that enable monitoring and visualisation of precision agriculture data. Smart farming was selected as the primary domain of application, given its growing importance in addressing agricultural sustainability, food security, and productivity challenges, particularly in developing countries. Rather than concentrating on high-level automation or drone-based decision systems, the study focused on the field-level monitoring process, which remains a crucial gap in operational farm management. This scope allowed for the demonstration of VRDDM's practical utility in visualising environmental and crop-related data for more informed farming decisions.

The implementation phase was conducted through the development of a VR-based dashboard prototype tailored to a real-world case study in Tok Dor, Besut. Two proof-of-concept (PoC) prototypes were developed using Unity3D, integrating simulated IoT data to represent field conditions such as soil moisture, humidity, temperature, and crop health. These prototypes applied key elements from the VRDDO and followed the step-by-step design structure outlined in the VRDDM framework. By using immersive interaction and spatial data visualisation, the dashboard offered users an intuitive method of navigating through field data and identifying anomalies, trends, or areas requiring intervention capabilities that traditional dashboards typically struggle to deliver effectively.

To evaluate the applicability and completeness of the method, semi-structured interviews were conducted with key stakeholders including software developers, VR designers, and agricultural practitioners. Thematic analysis of the feedback revealed several important themes: the intuitive nature of VR interfaces for non-technical users, the practicality of applying ontological guidance during design, the benefits of immersive data visualisation, and the importance of aligning interaction design with ecological psychology principles. Several constructive suggestions were also offered, particularly regarding improving multi-user collaboration in VR, refining spatial layout techniques, and expanding the dashboard's metrics to support more diverse farming operations.

In addition to validating the utility of the VRDDM framework in a live domain, this implementation also exposed areas for future improvement. Key areas identified include enhancing the adaptability of the method for different VR hardware environments, developing clearer UI/UX templates for novice designers, and exploring the integration of AI-driven analytics for predictive insights. The findings also underscored the importance of domain-specific tailoring and suggested the creation of modular extensions of VRDDM for broader agricultural use cases such as livestock monitoring and greenhouse automation.

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 5.1 below consolidates these achievements for clarity.

Table 5.1 Research objectives and achievements

Research Objective	Focus	Achievement
RO1	To identify the fundamental knowledge domains essential for developing an adequate method for designing functional virtual reality (VR) dashboards.	Addressed through an extensive narrative literature review of thirteen studies on VR dashboards across multiple domains. Revealed significant gaps, including the absence of a standardised design method, lack of ontological grounding, and no structured approach applied in the context of smart farming. These findings validated the need for a formalised design methodology.
RO2	To propose an ontological framework that systematises the knowledge required for designing VR dashboards.	Achieved through the development of the Virtual Reality Dashboard Design Ontology (VRDDO), guided by the Unified Ontological Approach (UOA) and grounded in the Unified Foundational Ontology (UFO). The framework integrated elements such as UI/UX principles, domain knowledge, and ecological psychology perspective, providing a structured semantic base for the overall VRDDM.
RO3	To apply a design method for creating VR dashboards that functionally monitor and visualise precision agriculture data.	Demonstrated through two proof-of-concept (PoC) implementations based on a smart farming case study in Tok Dor, Besut. The dashboard prototypes developed using Unity3D validated the method's applicability. Evaluated through stakeholder interviews, the VRDDM was found to be practical, immersive, and adaptable, while also highlighting potential improvements in metrics coverage, layout, and multi-user support.

The successful completion of all three research objectives establishes a strong foundation for positioning this study within the domain of design science research. From identifying the lack of a standardised method for designing VR dashboards in smart farming, to developing the ontologically grounded VR Dashboard Design Ontology (VRDDO), and validating its practical applicability through immersive prototype implementation, each phase of the research has contributed significantly to both theoretical advancement and real-world relevance. The next section builds upon these achievements by articulating the study's contributions through the lens of the Design Science Research Knowledge Contribution Framework. Particular attention is given to the core artefacts VRDDO and VRDDM and how they extend current knowledge in virtual reality design, ontology-driven methodologies, and the agricultural technology domain.

5.3 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 Design Science Research (DSR) frameworks. Specifically, the discussion draws on the widely recognised model by Gregor and Hevner (2013).

The Virtual Reality Dashboard Design Method (VRDDM) is the main artefact of this study, which is an ontologically grounded, stepwise methodology for designing and implementing VR dashboards in data-intensive domains. The sub-artefacts are: (i) the Virtual Reality Dashboard Design Ontology (VRDDO), which acts as the semantic backbone that formalises concepts and relationships used throughout the method; and (ii) the VR dashboard prototypes (PoC1 and PoC2), which instantiate and validate the method in practice through storyboarded, ontology-driven designs and interactions (see Tables 4.7 and 4.9; storyboard figures in Figures 4.12– Figure 4.22).

Regarding AI/ML usage, Chapter 4 demonstrates AI-assisted storyboard generation (to accelerate design exploration and enforce consistency with the method's phases and building blocks) and rule/threshold-based adaptive visual cues during prototyping. These become part of the Chapter 5 contribution narrative as concrete evidence of methodological utility and extensibility i.e., AI supports design knowledge reuse and iteration. In Chapter 5's contribution models (see Figure 5.2 and surrounding discussion), this triad: VRDDO → VRDDM → PoCs positions the ontology as a conceptual invention, the method as an exaptation of known principles into a novel VR-dashboard context, and the prototypes as improvement artefacts that operationalise and validate the approach.

5.3.1 Design Science Research Contribution Framework

To systematically position the knowledge contributions of this study, an established framework within the Design Science Research (DSR) paradigm is adopted: the DSR Knowledge Contribution Matrix proposed by Gregor and Hevner (2013). This framework offers a robust lens through which to evaluate the novelty, relevance, and theoretical significance of artefacts developed in DSR studies. By mapping contributions against two key dimensions problem maturity and solution maturity the matrix enables researchers to articulate where their work resides in the landscape of design science contributions. Importantly, this approach helps to distinguish whether a study introduces entirely new constructs, adapts existing solutions to novel problems, or incrementally improves established practices within familiar domains. For this thesis, the matrix provides a structured means to evaluate the Virtual Reality Dashboard Design Method (VRDDM), the Virtual Reality Dashboard Design Ontology (VRDDO), and their associated Proof-of-Concept implementations, emphasizing how these artefacts collectively contribute to advancing both theory and practice in immersive system design for smart farming.

The DSR Knowledge Contribution Matrix classifies contributions along two critical axes. The vertical axis represents the maturity of the solution being applied, ranging from low maturity (novel, experimental, or innovative solutions that have not been widely tested) to high maturity (well-established, validated, and widely accepted solutions). The horizontal axis reflects the maturity of the application domain or problem context, which spans from low maturity (emerging, poorly structured, or underexplored domains) to high maturity (well-known, clearly defined, and extensively studied problem spaces). This two-dimensional classification yields four quadrants: Invention (low solution maturity, low problem maturity), Exaptation (high solution maturity, low problem maturity), Improvement (high solution maturity, high problem maturity), and Routine Design (low solution novelty, high problem maturity).

By situating the artefacts of this study within this framework, it becomes possible to demonstrate how VRDDM and VRDDO occupy positions of high novelty within underexplored domains, while the Proof-of-Concept artefacts reflect the transition towards more mature solutions in evolving problem spaces. This analytical positioning highlights the dynamic interplay between innovation and application in DSR and underscores the unique contributions of this research to advancing immersive system design methodologies.

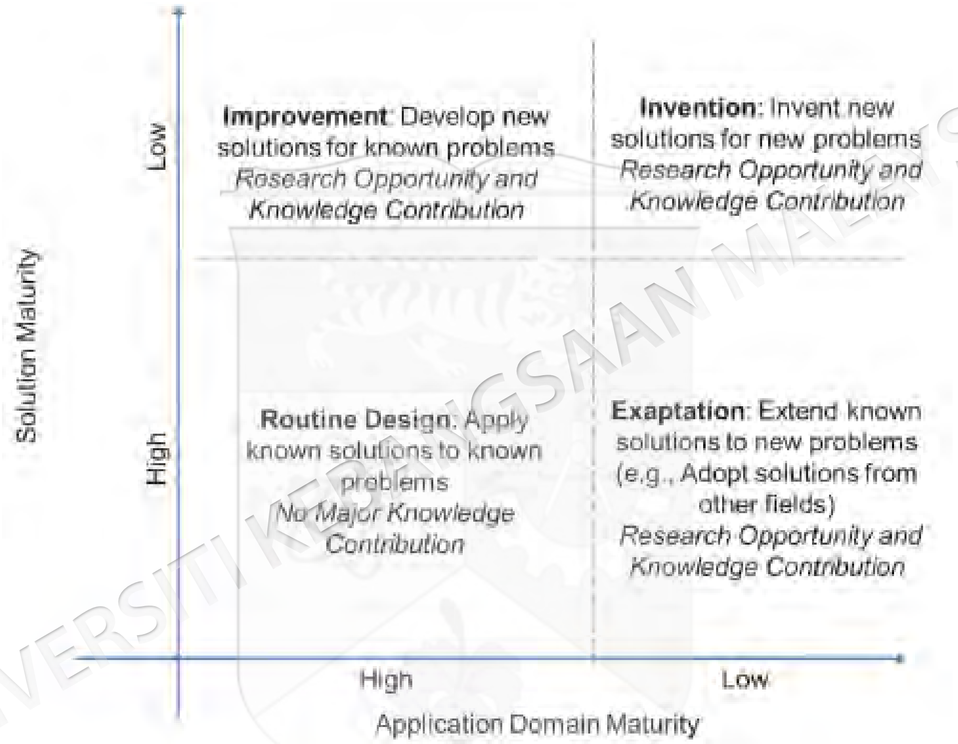


Figure 5.1 DSR contribution types based on solution and domain maturity

Source: Adapted from Gregor & Hevner 2013

To further clarify the characteristics of each contribution type, Table 5.2 summarises the four quadrants and the nature of knowledge produced in each zone.

Table 5.2 Four quadrants and the nature of knowledge produced in each zone

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 5.2 provides a strategic and analytical lens for understanding how various types of research contribute to the body of knowledge in Design Science Research (DSR). It situates contributions within a two-dimensional space, enabling scholars to classify artefacts not only by the novelty of the solutions they propose but also by the novelty and maturity of the contexts in which they are applied. This framework helps to articulate whether a particular study is pushing the boundaries of theoretical innovation, adapting existing knowledge to new domains, improving established systems, or applying known solutions within well-understood environments. Each quadrant in the matrix represents a distinct form of design knowledge contribution, and together they offer a comprehensive taxonomy of how design artefacts advance both academic and practical understanding.

Among these quadrants, Invention (Quadrant 1) is often regarded as the locus of high-impact, groundbreaking research. Contributions positioned here are characterized by the creation of entirely new constructs, models, or artefacts designed to address previously unstructured or poorly understood problems. Such research demands a high degree of creative insight, underpinned by robust theoretical grounding, as it ventures into underexplored or emergent domains. Artefacts within this quadrant are particularly valued in academic discourse because they extend the frontier of knowledge and often set the stage for subsequent studies that further refine or validate their pioneering concepts. Invention-type contributions are critical in domains where existing frameworks and methods are insufficient to meet new challenges such as in the case of this thesis, which explores immersive VR dashboard design for precision agriculture, an area with limited prior methodological standardization.

Improvement (Quadrant 2), by contrast, is situated in domains where both the problem and solution spaces are relatively mature. Contributions in this quadrant focus on enhancing existing processes, systems, or artefacts, often aiming for better usability, efficiency, scalability, or adaptability. While they may not introduce entirely novel concepts, these refinements play a vital role in ensuring the continued relevance and evolution of established design knowledge. Many practical implementations, such as incremental upgrades to user interface frameworks or performance optimization in software systems, fall within this quadrant. Improvement is especially valuable for practitioners seeking operational enhancements in domains with stable requirements and well-understood user needs.

On the other hand, Exaptation (Quadrant 3) represents contributions that adapt or repurpose existing solutions to address problems in novel or less mature domains. This quadrant emphasizes the versatility and transferability of design knowledge, showing how artefacts developed for one context can be successfully applied in another. Such contributions are particularly common in interdisciplinary or emerging fields, where researchers draw on established methodologies or tools from related domains to tackle unfamiliar challenges. In this study, for instance, elements of UX design and ontology-based modelling widely used in software engineering and semantic web applications were adapted for use in immersive VR environments for smart farming. Exaptation contributions demonstrate creative problem-solving by leveraging existing knowledge assets while navigating uncharted application spaces.

Finally, Routine Design (Quadrant 4) encompasses contributions involving the straightforward application of established solutions to well-understood problems. These artefacts are typically operational in nature, offering limited theoretical novelty but potentially high practical value. While important in professional practice and industry contexts, Routine Design is generally not the focus of scholarly DSR, as it lacks the innovation necessary to advance theoretical knowledge. Instead, such contributions often manifest in commercial deployments or operational rollouts where the emphasis is on reliability, efficiency, and consistency rather than on conceptual advancement.

This study produced a series of artefacts spanning from high-level conceptual models, such as the VR Dashboard Design Ontology (VRDDO), to operational systems embodied in the Proof-of-Concept implementations (PoC1 and PoC2). These artefacts vary in their positioning within the DSR Knowledge Contribution Matrix, reflecting the study's layered approach to theory-building and practical validation. To provide a clear and structured understanding of their respective contributions, the next section details the purpose and scope of each artefact before systematically positioning them within the matrix. This analysis underscores how the artefacts collectively advance both theoretical and practical dimensions of immersive system design in smart farming.

5.3.2 Main Artefact – VRDDM

The central contribution of this study is the Virtual Reality Dashboard Design Method (VRDDM), a structured and ontologically grounded methodological framework developed to guide the design and development of functional virtual reality (VR) dashboards. The VRDDM was specifically conceived to address the lack of standardised methods for creating immersive and interactive dashboards within data-intensive domains such as smart farming. This framework responds directly to the fragmented and ad hoc practices observed in current VR dashboard literature, offering a more holistic and repeatable approach to development. The VRDDM is composed of a set of systematic design phases informed by theoretical foundations such as the Unified Ontological Approach (UOA), the Business Model Ontology (BMO), and the Ecological Psychology Perspective (EPP) as well as practical design elements derived from common dashboard building blocks.

At the core of the VRDDM lies its integration with the Virtual Reality Dashboard Design Ontology (VRDDO), which formalises the key components, relationships, and processes involved in dashboard design. The method outlines sequential steps beginning with problem scoping, user needs identification, data and interaction modelling, followed by prototype development, demonstration, and iterative evaluation. Each step is supported by ontological constructs that ensure semantic clarity, structural consistency, and reusability across different contexts. Unlike existing dashboard methods which often lack adaptability to 3D environments, VRDDM incorporates spatial interface design, immersive navigation, and ecological alignment between user perception and data representation. These make the method particularly relevant to domains requiring real-time monitoring, intuitive interaction, and user engagement such as agriculture, environmental management, and education.

In terms of positioning within the Design Science Research Knowledge Contribution Framework (Figure 5.1), the VRDDM resides in Quadrant III – Improvements. This quadrant represents artefacts that offer enhanced solutions to existing problems through improved processes or methods. VRDDM qualifies as an improvement-oriented contribution because it builds upon existing design science research and dashboard literature, but introduces a more coherent, theory-informed, and domain-tailored methodology that improves both the process and outcome of VR dashboard development. The framework not only bridges the gap between conceptual modelling and immersive design but also provides practitioners with a reusable guide adaptable to various applications. As such, VRDDM is a substantive methodological innovation with potential utility beyond the scope of this study's initial application in smart farming.

5.3.3 Sub-Artefact 1 – Literature and Concepts

The first sub-artefact developed in this study was a comprehensive synthesis of existing literature and conceptual foundations relevant to virtual reality dashboard design. This process was carried out through a structured narrative literature review, as detailed in Chapter 2. A total of 13 academic and technical studies were analysed, encompassing diverse VR applications in domains such as health, manufacturing, education, and urban planning. The review focused on identifying methodological patterns, theoretical foundations, design processes, and domain-specific constraints in dashboard development. Particular attention was given to uncovering any existing design methods or formal frameworks. However, the findings revealed that most implementations were ad hoc, lacking standardised procedures or conceptual integration. There was no evidence of ontology-driven methods or frameworks tailored specifically to VR dashboards, especially within agricultural contexts.

Twelve key building blocks were distilled from the literature reviews due to their commonalities. These building blocks emerged from repeated themes and design considerations found across the literature, refined through alignment with ontology engineering principles and user-centred design frameworks. This conceptual groundwork provided the foundational vocabulary and structure for developing the Virtual Reality Dashboard Design Ontology (VRDDO), ensuring the artefact was both theoretically informed and practically applicable. The structured extraction of these components as a sub-artefact played a crucial role in formalising the design knowledge required to develop a reusable and generalisable method for immersive dashboard creation.

5.3.4 Sub-Artefact 2 – VRDDO

The second sub-artefact of this study is the Virtual Reality Dashboard Design Ontology (VRDDO), a formal ontological structure developed to systematise the knowledge required for designing functional virtual reality dashboards. The development of VRDDO directly addresses Research Objective 2, which aimed to propose an ontological framework that organises key knowledge domains essential for immersive dashboard design. The VRDDO serves as the semantic backbone of the main artefact, VRDDM, by offering a structured, reusable, and theory-grounded representation of the elements, relationships, and processes involved in VR dashboard development.

The ontology was developed using the Unified Ontological Approach (UOA) and anchored in the Unified Foundational Ontology (UFO), which provides a high-level philosophical and semantic foundation for modelling complex knowledge structures. Building on the 12 key building blocks derived from the literature review (Sub-Artefact 1), VRDDO translates these design concepts into formal entities and relationships. Each concept such as user, sensor data, visualisation type, spatial layout, interaction modality, and feedback loop was ontologically modelled using OntoUML, allowing for syntactic validation, semantic precision, and visual representation of design knowledge. The result is a coherent structure that encapsulates both technical and experiential aspects of VR dashboard design, enabling consistent interpretation and reuse across projects.

A distinctive feature of VRDDO is the incorporation of the Ecological Psychology Perspective (EPP) as a theoretical lens to guide the modelling of user-environment interactions. Rooted in Gibson’s theory of affordances, the EPP emphasises the direct perception of actionable possibilities in an environment. This theory was operationalised in VRDDO by modelling affordances as relationships between users and dashboard elements, such as data indicators, spatial tools, and interaction triggers. For instance, a 3D temperature gauge affords grasping or zooming, depending on user goals and system feedback. By embedding these perceptual-action cycles within the ontology, VRDDO supports the design of dashboards that are not only functional but also perceptually aligned with users’ real-time decision-making needs in immersive settings.

Moreover, the VRDDO contributes to bridging the gap between abstract design concepts and their real-world implementation in VR platforms. The ontology provides a formalised structure that enhances the clarity, consistency, and adaptability of the VRDDM framework. It enables design teams to reason about design decisions more rigorously, improves communication among stakeholders, and lays the groundwork for tool development, template generation, and system interoperability. Ultimately, the development of VRDDO reinforces the theoretical robustness of the overall design method and stands as a pivotal contribution of this study in advancing the use of ontologies in immersive technology design.

5.3.5 Sub-Artefact 3 – VR Dashboard Prototype

The third sub-artefact produced in this study is the Virtual Reality Dashboard Prototype, which served as a practical demonstration of the VRDDM and VRDDO frameworks in action. Developed using the Unity3D platform, the prototype was designed based on the context of precision agriculture, specifically drawing data scenarios from a real-world smart farming site in Tok Dor, Besut. This prototype translates the ontologically modelled concepts and interaction mechanisms into an interactive 3D environment, thereby serving as a validation tool for the design method proposed in this research.

The prototype consists of an immersive VR environment that enables users to visualise and interact with critical farm data, including soil moisture, temperature, humidity, and crop health indicators. These data points were represented through spatially arranged objects and visual elements, such as interactive 3D gauges, rotating data panels, and colour-coded plots. The interface was designed with affordances in mind drawing from the Ecological Psychology Perspective (EPP) to allow intuitive user actions such as zooming, rotating, or selecting data nodes in a way that mimics real-world perception and behaviour. The environment also integrates feedback loops, where changes in data values trigger visual and auditory cues to simulate real-time decision-making scenarios.

This artefact not only demonstrated the applicability of the VRDDM framework in a real domain but also provided a foundation for collecting evaluation feedback through stakeholder interviews. The prototype allowed stakeholders to assess the usability, interactivity, and value of immersive dashboards in practical farm operations. Moreover, it validated the transferability of the ontological design model into functioning systems. The success of this prototype implementation supports the overall claim of this study that structured, ontology-driven design methods can significantly enhance the development process and user experience in virtual reality environments.

5.3.6 Fourth School of Taught on Theory Used in DSR

This study aligns with the Fourth School of Thought on theory use in Design Science Research (DSR), which emphasises the use of theory to inform the design and development of artefacts. Rather than testing existing theories or generating new ones, this approach focuses on applying established theoretical constructs to guide and strengthen the artefact creation process. In the context of this study, multiple theoretical foundations were strategically integrated into the development of the VRDDM and its supporting artefacts.

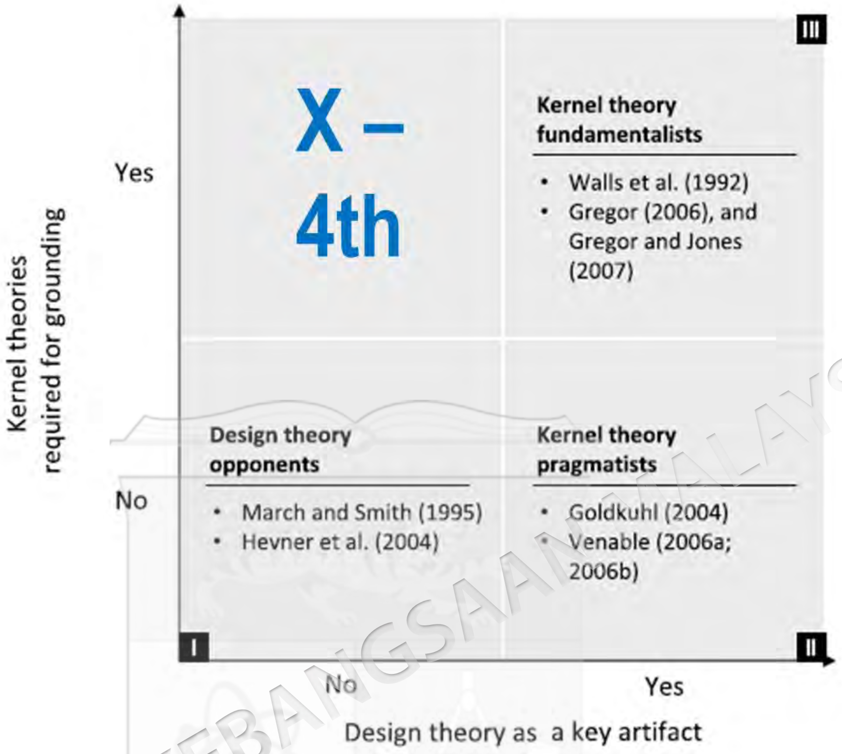


Figure 5.2 Design theory schools

Specifically, the Unified Foundational Ontology (UFO) was employed to guide the formal structuring of domain knowledge in the VRDDO, ensuring semantic consistency and clarity. Simultaneously, the Ecological Psychology Perspective (EPP) was used to shape how user interactions were modelled, particularly in terms of affordances and perception-action relationships within immersive environments. The Business Model Ontology (BMO) further provided a strategic lens to represent operational goals and actor relationships relevant to dashboard use in smart farming. Together, these theories did not serve as hypotheses to be tested, but as design scaffolds that enhanced the coherence, reusability, and relevance of the artefacts. This positioning reflects the core values of the Fourth School, where theory serves as a design enabler within the DSR process.

5.3.7 Positioning of Artefacts within DSR Contribution Models

Having introduced the artefacts developed in this study, this section positions each artefact within two established frameworks for classifying design science research contributions. The first framework is the Quadrant Model of Problem and Solution Maturity proposed by Gregor and Hevner (2013), which provides a structured approach to assessing the nature and maturity of research outputs. This model enables the precise mapping of each artefact along two key dimensions: the maturity of the problem being addressed (ranging from low to high) and the maturity of the solution provided (also ranging from low to high). By leveraging this model, the contributions of the Virtual Reality Dashboard Design Method (VRDDM) and its associated artefacts can be clearly categorized, demonstrating their relevance both to theory and to practice. This classification highlights how the artefacts advance knowledge in the domain while offering practical tools for immersive dashboard development.

a. Positioning in the Quadrant Model (Problem-Solution Maturity)

The Quadrant Model of Problem and Solution Maturity, developed by Gregor and Hevner (2013), provides a robust framework for categorizing design science research (DSR) contributions along two critical dimensions: the maturity of the problem domain and the maturity of the solution applied. This two-dimensional model maps research artefacts into one of four quadrants, Invention, Improvement, Exaptation, and Routine Design, each representing a distinct type of knowledge contribution. By positioning the artefacts of this study within this framework, it is possible to articulate their novelty, relevance, and alignment with the overall goals of design science. Figure 5.2 illustrates this model, with the vertical axis representing solution maturity (low to high) and the horizontal axis reflecting domain maturity (low to high).

In the context of this study, the Virtual Reality Dashboard Design Method (VRDDM) and Virtual Reality Dashboard Design Ontology (VRDDO) are central artefacts that directly address gaps in the existing literature on immersive dashboard development. The domain of virtual reality dashboards for smart farming represents a relatively underexplored area, characterized by fragmented approaches and limited methodological standardization. Although VR technologies have been applied in other domains such as healthcare and urban planning, their use in precision agriculture remains novel, especially for real-time monitoring and decision support. This situates the problem domain at a low to moderate level of maturity, as it involves emerging challenges with few established design practices. On the other hand, the solutions proposed VRDDM and VRDDO demonstrate moderate solution maturity, since they build upon established theoretical foundations (Unified Ontological Approach, Business Model Ontology, and Ecological Psychology) while integrating them into a novel methodological framework tailored for immersive dashboard design.

The VRDDO, serving as a semantic backbone, systematizes key elements such as user interface principles, interaction design processes, and knowledge representation. Its ontological structure allows for flexible yet consistent modelling of complex smart farming data within VR environments. While ontologies themselves are not a novel construct in information systems, their application in this specific domain for immersive dashboard design is pioneering. This positions VRDDO within Quadrant 1 (Invention) of the model, as it represents a ground-up innovation addressing an underexplored problem. It introduces new constructs and relationships that did not previously exist in this context, making a theoretical contribution by extending ontological methods into a novel application area.

The VRDDM, which builds on VRDDO and operationalizes its concepts into a stepwise design method, falls slightly differently within the quadrant framework. As a methodological artefact, it blends existing design science concepts with domain-specific requirements. Its contribution lies in its ability to guide designers and developers through the complexities of VR dashboard creation for smart farming, ensuring usability, semantic consistency, and ecological validity. Given its reliance on foundational theories but applied in a novel context, the VRDDM aligns with Quadrant 3 (Exaptation). Here, the method adapts and extends known solution principles such as iterative design-evaluation cycles and ontology-driven modelling into the emerging domain of precision agriculture. This cross-domain adaptation highlights the flexibility and transferability of design science knowledge, demonstrating how established approaches can be leveraged to tackle new challenges.

The two Proof-of-Concept (PoC) implementations, PoC1 and PoC2, which instantiated the VRDDM in real-world scenarios, occupy yet another position. These artefacts represent instantiations of the method in specific use cases, focusing on practical deployment and validation. PoC1 introduced an initial dashboard prototype, tested in a simulated environment to assess user navigation, data visualization clarity, and interaction responsiveness. PoC2 refined this prototype based on feedback, integrating more sophisticated features such as dynamic thresholds and multi-user support. The iterative enhancement of these prototypes, grounded in VRDDM, demonstrates a clear progression from conceptual design to functional systems. Because these artefacts operationalize the method and demonstrate its utility in a moderately mature domain, they are best positioned in Quadrant 2 (Improvement). They enhance existing VR dashboard practices by introducing refined processes and improved usability within the agricultural context.

The combined positioning of VRDDO, VRDDM, and the PoCs within the Quadrant Model underscores the multi-layered contributions of this study. VRDDO, as a novel ontological framework, pushes the boundaries of existing knowledge and fits within the invention space. VRDDM, while grounded in existing design science and ontological theories, adapts and extends them into a new domain, embodying the principles of exaptation. Finally, PoC1 and PoC2 translate these theoretical constructs into operational artefacts, validating the practical relevance of the proposed frameworks and aligning with the improvement quadrant. This layered contribution structure reinforces the study's alignment with Hevner et al.'s (2004) guidelines for design science research, ensuring that the artefacts developed address both theoretical and practical dimensions.

Furthermore, this positioning demonstrates how the study navigates the tension between novelty and utility, a hallmark of impactful DSR. By introducing VRDDO, the research offers a high-novelty artefact that establishes a new knowledge base for immersive dashboard design. VRDDM leverages and extends this base, ensuring practical relevance and adaptability across domains. The PoCs, in turn, provide empirical validation, ensuring that the theoretical contributions are grounded in real-world use. Together, these artefacts span the full spectrum of the quadrant model, illustrating a comprehensive and balanced research approach that contributes to both academic knowledge and professional practice.

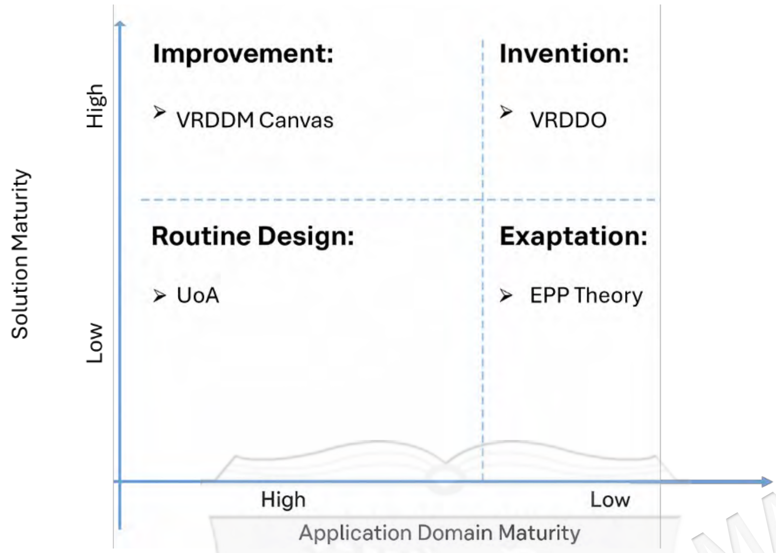


Figure 5.3 VRDDM research positioning

b. Artefact Transitions between Quadrants

The evolution of artefacts in this study from VRDDO to VRDDM and finally to the Proof-of-Concept implementations (PoC1 and PoC2) illustrates a natural progression across the quadrants of Gregor and Hevner's (2013) Problem-Solution Maturity Model. This transition reflects not only the maturation of the artefacts themselves but also the increasing clarity and refinement of the problem domain and its corresponding solutions over time.

At the outset, the development of the Virtual Reality Dashboard Design Ontology (VRDDO) addressed a relatively immature problem space: the lack of a standardized and semantically grounded framework for designing immersive dashboards in smart farming. At this stage, the problem was exploratory, with few established methods or frameworks in literature. The VRDDO, therefore, emerged as a novel construct offering an ontological structure that formalized key concepts, relationships, and design components identified from VRdash01–VRdash12. Positioned in Quadrant 1 (Invention), VRDDO represents a high-novelty, low-solution maturity artefact, laying the theoretical foundation for further advancements.

Building on VRDDO, the Virtual Reality Dashboard Design Method (VRDDM) operationalized the ontology into a systematic process for designing and implementing VR dashboards. While still engaging with an emerging domain, VRDDM demonstrated a higher level of solution maturity by incorporating established design science principles, iterative evaluation, and user-centered methodologies. As such, VRDDM transitions into Quadrant 3 (Exaptation), where known solutions from related domains (e.g., UX design, ontological modelling, and VR development) are adapted to the novel context of immersive dashboards for agriculture. This stage reflects a shift from purely theoretical innovation to practical methodology development, aligning with the DSR principle of bridging theory and practice.

Finally, the Proof-of-Concept prototypes (PoC1 and PoC2) exemplify the application and refinement of VRDDM in real-world scenarios. These artefacts instantiated the method within specific use cases, validating its feasibility and relevance. The iterative enhancements observed from PoC1 to PoC2 demonstrate how user feedback and technical testing contributed to refining interface elements, data visualization strategies, and interaction mechanisms. Positioned within Quadrant 2 (Improvement), these prototypes reflect moderate problem and solution maturity, offering concrete improvements to existing practices and showcasing the practical utility of the research contributions.

This sequential movement across quadrants: Invention → Exaptation → Improvement underscores the dynamic interplay between problem understanding and solution development in DSR. It illustrates how artefacts evolve from high-level conceptual contributions to mature, deployable systems, supporting both theoretical advancement and real-world impact.

5.3.8 Interview Findings - VR Designer vs VR Developer

The evaluation of the VRDDM framework included qualitative feedback from two distinct stakeholder roles involved in immersive dashboard development: the VR Designer and the VR Developer. These roles provided complementary perspectives on the artefact’s usability, practicality, and design guidance.

The VR Designer highlighted the value of the framework in offering structured design phases and visual clarity on user interaction flows. The ontological model was perceived as especially helpful in ensuring alignment between conceptual thinking and interface layout, enabling a more intentional and user-centred design approach. Furthermore, the emphasis on affordance-based interaction derived from the Ecological Psychology Perspective was viewed as highly relevant to immersive environments.

From the VR Developer's perspective, the method’s modularity and ontological definitions assisted in translating conceptual elements into functional VR components. The formalisation of data types, object relationships, and spatial interaction elements streamlined the development process and reduced ambiguity. Both participants agreed that the framework supported better communication between design and development teams, bridging the gap between abstract design intentions and system implementation. Overall, the interviews affirmed the practical relevance of VRDDM in real-world development contexts.

5.4 CONCLUSION AND FUTURE WORK

This study set out to address the absence of a structured and ontologically grounded method for designing virtual reality dashboards, particularly in the context of precision agriculture. As immersive analytics and spatial computing technologies continue to gain traction across domains, the lack of methodological guidance presents a serious limitation for practitioners aiming to harness the full potential of virtual reality (VR) in decision-making environments. Through the adoption of the Design Science Research Methodology (DSRM), this research followed a rigorous, iterative process of problem identification, artefact design, demonstration, and evaluation. The result is a coherent suite of contributions including a main artefact: the Virtual Reality Dashboard Design Method (VRDDM) and three supporting sub-artefacts: the conceptual framework derived from literature, the Virtual Reality Dashboard Design Ontology (VRDDO), and a working VR dashboard prototype.

The VRDDM framework introduced in this study provides a structured, step-by-step guide to conceptualising and developing functional VR dashboards. The method integrates foundational concepts from ontology engineering, immersive user interface design, and domain-specific knowledge. In contrast to existing dashboard development practices which often rely on fragmented techniques and are limited to 2D interfaces, VRDDM offers a unified and reusable approach specifically tailored to immersive environments. By incorporating the Unified Ontological Approach (UOA) and grounding the ontology in the Unified Foundational Ontology (UFO), the method achieves semantic precision and reusability. Furthermore, the integration of the Ecological Psychology Perspective (EPP) introduces a human-centric design element that aligns user perception with system feedback, enabling more intuitive and actionable user interactions.

The study's implementation of VRDDM in a smart farming scenario provided tangible validation of its practicality and adaptability. The Unity3D-based prototype enabled immersive visualisation of environmental metrics such as temperature, humidity, and soil conditions, effectively demonstrating the capability of the method to address real-world agricultural monitoring needs. The evaluation process, involving both VR designers and developers, yielded positive feedback, especially regarding the clarity provided by the ontology, the affordance-driven interaction design, and the modular structure of the framework. These findings confirm that the method is not only theoretically robust but also suitable for practical adoption.

In addition to addressing the research objectives, this study contributes to the advancement of design science research through its positioning in the fourth school of thought, where theory is used to inform artefact construction rather than to be tested or generated. The theories employed UFO, EPP, and BMO served as scaffolds to shape the artefacts' conceptual structure, thereby enhancing the depth, consistency, and generalisability of the contributions. This approach underscores the value of theory-informed design in producing artefacts that are both academically grounded and practically relevant.

Despite the accomplishments, several limitations present opportunities for future work. First, while the prototype demonstrated the method's viability in a precision agriculture context, its generalisability to other domains remains to be empirically validated. Future studies should apply VRDDM to diverse fields such as manufacturing, public health, or urban management to test its cross-domain applicability. Second, the prototype implementation was designed for single-user interaction. With the increasing importance of collaborative decision-making, future work could explore multi-user scenarios, including support for real-time collaboration, annotation, and shared dashboards in VR environments.

Another important avenue for extension lies in the integration of artificial intelligence (AI) features. This includes predictive analytics, voice-guided insights, and conversational interfaces embedded within the VR environment. By combining AI with immersive dashboards, future iterations of VRDDM could support more proactive and intelligent decision support systems. Additionally, further refinement of the design templates and user interface modules potentially in the form of a design toolkit would increase accessibility for novice developers and promote standardisation across development teams.

From a methodological standpoint, the current study relied on semi-structured interviews for qualitative evaluation. To enhance the rigour of the evaluation phase, future research should incorporate quantitative performance metrics, usability testing, and longitudinal case studies to assess the long-term effectiveness and user satisfaction of VRDDM-based dashboards. Finally, the ontological framework itself could be extended by linking VRDDO with domain-specific ontologies (e.g., Agrovoc for agriculture) or IoT standards to enhance interoperability and semantic reasoning capabilities in data integration.

In conclusion, this study lays the groundwork for a new paradigm in immersive analytics by offering a robust, reusable, and ontologically grounded method for designing VR dashboards. The VRDDM framework and its supporting artefacts represent meaningful contributions to both the academic field of design science research and the practical landscape of virtual reality application development. By bridging the gap between conceptual theory and real-world implementation, this research not only fills a methodological void but also opens new pathways for future exploration in immersive decision-support technologies.

A particularly significant direction for future research involves the incorporation of perdurant concepts into the Virtual Reality Dashboard Design Ontology (VRDDO). Currently, VRDDO primarily models endurant entities, objects that persist over time while maintaining identity, such as sensors, indicators, and user interface components. While this static representation is effective for structural clarity, it lacks the expressiveness required to capture temporal and dynamic phenomena, which are essential in real-world monitoring scenarios. For example, in precision agriculture, data such as soil moisture levels or temperature variations are inherently temporal; they change continuously and must be tracked, interpreted, and acted upon over time. Incorporating perdurant entities such as events, processes, and state transitions would enable the ontology to more accurately represent the evolving nature of the data being visualised.

The integration of perdurant modelling would enhance the capability of VRDDM to support time-based reasoning, real-time anomaly detection, and trend-based interaction patterns within immersive environments. Ontologically, this can be realised by extending the VRDDO with constructs from UFO, which provides a formal structure for modelling events, activities, and situations. By embedding these dynamic constructs into the ontology, future iterations of the VRDDM could allow designers to build dashboards that not only show static values but also communicate changes, rates of change, and contextual histories. This would significantly increase the dashboard's analytical power and usefulness in domains like smart farming, where time-sensitive insights drive operational decisions. Such enhancements will also open the door to more sophisticated AI integrations, such as predictive alerts and automated responses based on temporal patterns within the VR environment.

5.5 SUMMARY

This chapter presented the culmination of the research by outlining the achievements of the three research objectives, highlighting the core and supporting artefacts developed, and discussing their theoretical and practical contributions. The main artefact, VRDDM, was positioned as a methodological innovation supported by an ontologically grounded framework (VRDDO) and validated through a VR prototype. The chapter concludes the study while paving the way for future advancements in immersive analytics and VR design methodologies.

REFERENCES

Abed, H.N., Tang, A.Y.C. & Cob, Z.C. 2014. An ontology-based search engine for postgraduate students information at the ministry of higher education portal of Iraq. *13th International Conference on Intelligent Systems Design and Applications*, pp. 69-73.

Agrawal, R., Wankhede, V.A., Kumar, A. & Luthra, S. 2023. A systematic and network-based analysis of data-driven quality management in supply chains and proposed future research directions. *The TQM Journal* 35 (1): 73-101.

Aida, R. N. F., Ashraf, M. K., Khalid, M. & Zulkafli, N. 2022. 20 May 2022). Majukan tanah terbiar 103,000 hektar. *Sinar Harian*, 20 May: 2 – 3.

Aminu, E.F., Oyefolahan, I.O., Abdullahi, M.B. & 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.

Arjun, S., Murthy, L.R.D. & Biswas, P. 2022. Interactive sensor dashboard for smart manufacturing. *Procedia Computer Science* 200: 49-61.

Awais, M., Wang, X., Hussain, S., Aziz, F. & Mahmood, M. Q. (2025). Advancing Precision agriculture through digital twins and smart farming technologies: a review. *AgriEngineering* 7(5): 137–154.

Bailey, K.D. 1982. *Method of Social Research.* 2nd Edition. New York: Free Press.

Baltabayev, A., Gluschkow, A., Blank, J., Birkhölzer, G., Büsche, J., Kern, M., Klopfer, F., Mayer, L.M., Scheibler, G., Klein, K., Schreiber, F. & Sommer, B. 2018. Virtual reality for sensor data visualization and analysis. *Proc. IS&T Int'l. Symp. on Electronic Imaging: The Engineering Reality of Virtual Reality* 2018: 451-1–451-8.

Bartosh A., & Gu R. 2019. Immersive representation of urban data. *Proc. of the 2019 Symposium on Simulation for Architecture and Urban Design*, pp. 65–58.

Benferdia, Y., Ahmad, M.N., Mustafa, M., Mohamad, U.H., Leong, L.K. 2023. Ontology development methodology for virtual reality-based training (vrt) in ophthalmology domain: phaco cataract surgery case study. In. Zeshan, F. & Adnan, A. (Eds.). *Recent Advancements in Smart Remote Patient Monitoring, Wearable Devices, and Diagnostics Systems*, pp. 68 – 85. Hershey, PA: IGI Global.

Bowman, D.A., Kruijff, E., LaViola, J.J. & Poupyrev, I. 2004. *3D User Interfaces: Theory and Practice.* Boston: Addison-Wesley.

Bravo, M., Reyes, L.F.H & Reyes Ortiz, J.A. 2019. Methodology for ontology design and construction. *Contaduria y Administracion* 64(4): 1–24.

Bright, T.J., Yoko Furuya, E., Kuperman, G.J., Cimino, J.J. & Bakken, S. 2012. Development and evaluation of an ontology for guiding appropriate antibiotic prescribing. *Journal of Biomedical Informatics* 45(1): 120-128.

Brunhart-Lupo, N., Bush, B.W., Gruchalla, K. & Smith, S. 2016 Simulation exploration through immersive parallel planes. *2016 Workshop on Immersive Analytics (IA)*, 19–24.

Burke, M.E. 2007. Making choices: research paradigms and information management. *Library Review* 56(6): 476-484.

Carter, M. & Egliston, B. 2023. What are the risks of virtual reality data? Learning analytics, algorithmic bias and a fantasy of perfect data. *New Media & Society* 25(3): 485-504.

Chatziparaschis, D., Karydis, K. & Mucchiani, C. 2024. Augmented-reality enabled crop monitoring with robot assistance. *International Journal of Robotics in Agriculture* 9(1): 45–62.

Chen, X., Self, J.Z., House, L., & North, C. 2016. Be the data: A new approach for immersive analytics. *2016 Workshop on Immersive Analytics (IA)*, pp. 32-37.

Cheng, C., Kang, L., Cai, S., Li, J. & Sun, R. 2018. Virtual display and interactive experience platform of farming culture based on Unity3D. *IFAC-PapersOnLine* 51(17): 637-642.

Cherry, K. 2023. What are the gestalt principles? https://www.verywellmind.com/gestalt-laws-of-perceptual-organization-2795835 [2 April 2023].

Chimalakonda, S. & Nori, K. 2020. An ontology based modeling framework for design of educational technologies. *Smart Learning Environments* 7: 28.

Chokwitthaya, C., Zhu, Y. & Lu, W. 2023. Ontology for experimentation of human-building interactions using virtual reality. *Advanced Engineering Informatics* 55: 101903.

Chou, C.H., Zahedi, F.M. & Zhao, H. Ontology for developing web sites for natural disaster management: Methodology and implementation. *IEEE Transactions on Systems, Man, and Cybernetics Part A:Systems and Humans* 41(1): 50–62.

Christian Fischer, Robert Winter, Felix Wortmann. (2010). Design Theory. Business & Information Systems Engineering.

Chungyalpa, W., Bedanta, B. & Borah, S. 2016. Business Model Ontology (BMO): an examination, analysis, and evaluation. *Journal of Entrepreneurship & Management* 5(1): 58–67.

Clemente, J., Ramírez, J. & De Antonio, A. 2011. A proposal for student modeling based on ontologies and diagnosis rules. *Expert Syst Appl* 38(7): 8066–8078.

Colomb, R.M. & Ahmad, M.N. 2010. A perdurant ontology for interoperating information systems based on interlocking institutional worlds. *Applied Ontology* 5(1):47-77.

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.

Corcho, O., Fernandez-Lopez, M., Gomez-Perez, A. & Lopez-Cima, A. 2005. Building Legal Ontologies with METHONTOLOGY and WebODE. In Benjamins, R., Casanovas, P., Breuker, J. & Gangemi, A. (ed.). *Law and the Semantic Web: Legal Ontologies, Methodologies, Legal Information Retrieval, and Applications*, pp. 142–157. Berlin: Springer.

Crimaldi, M., Cartenì, F. & Giannino, F. 2021. VISmaF: synthetic tree for immersive virtual visualization in smart farming. Part I: scientific background review and model proposal. *Agronomy* 11(12): 2458.

De Lille, N. & Roelens, B. 2021. A practical application of upon lite for the development of a semi-informal application ontology. *Proceedings of the International Workshop on Value Modelling and Business Ontologies 2835*, pp. 63-70

Dietz, J.L.G. & Mulder, H.B.F. Enterprise ontology a human-centric approach to understanding the essence of organisation.

Dietz, J.L.G., & Mulder, J.B.F. 2024. *Enterprise Ontology: A Human-Centric Approach to Understanding the Essence of Organisation*. 2nd Edition. Cham: Springer Nature.

Doshi, J., Patel, T. & Bharti, S.k. 2019. Smart farming using IoT, a solution for optimally monitoring farming conditions. *Procedia Computer Science* 160: 746-751.

Dubois, A., Teytaud, F. & Verel, S. 2021. Short term soil moisture forecasts for potato crop farming: a machine learning approach. *Computers and Electronics in Agriculture* 180: 105902.

Durai, S.K.S. & Shamili, M.D. 2022. Smart farming using machine learning and deep learning techniques. *Decision Analytics Journal* 3: 100041.

El Chami, D., Daccache, A. & El Moujabber, M. 2020. How can sustainable agriculture increase climate resilience? A systematic review. *Sustainability* 12(8): 3119.

Engelberg, G., Fumagalli, M., Kuboszek, A., Klein, D., Soffer, P. & Guizzardi, G. 2023. Towards an ontology-driven approach for process-aware risk propagation. *SAC '23: Proceedings of the 38th ACM/SIGAPP Symposium on Applied Computing*, hlm.1742–1745.

Escobar, A. 2018. *Designs for the Pluriverse: Radical Interdependence, Autonomy, and the Making of Worlds.* Durham, NC: Duke University Press.

Falcão, R., Matar, R. & Rauch, B. 2023. Using industry 4.0 digital twins in agriculture. https://arxiv.org/abs/2301.09682 [2 April 2023].

Fernandez Lopez, Gomez-Perez, M.A., Sierra, J.P. & Sierra, A.P. 1999. Building a chemical ontology using methontology and the ontology design environment. *IEEE Intelligent Systems and Their Applications* 14(1): 37–46.

Fernandez-Lopez, M., Gomez-Perez, A. & Juristo, N. 1997. Methontology: from ontological art towards ontological engineering. *Proceedings of the Ontological Engineering AAAI-97 Spring Symposium Series*, pp. 33–40.

Fernández-López, 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 (ed.). *Ontology Engineering in a Networked World*, pp. 147–170. Berlin/Heidelberg: Springer.

Few, S. 2013. *Information Dashboard Design: Displaying Data for At-A-Glance Monitoring.* 2nd Edition. Burlingame, CA: Analytics Press.

Fischer, C., Winter, R. & Wortmann, F. Design Theory. *Bus Inf Syst Eng* 2: 387–390.

Fonou-Dombeu, J.V. & Huisman, M. 2011. Semantic-driven e-Government: application of uschold and king ontology building methodology for semantic ontology models development. International Journal of Web & Semantic Technology 2(4): 111–20.

Gibaud, B., Kassel, G., Dojat, M., Batrancourt, B., Michel, F., Gaignard, A. & Montagnat, J. 2011. NeuroLOG: sharing neuroimaging data using an ontology-based federated approach. *AMIA Annu Symp Proc.*, pp. 472-80.

Gibson, J.J. 1986. *The Ecological Approach to Visual Perception.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Goap, A., Sharma, D., Shukla, A. K. & Rama Krishna, C. 2018. An IoT based smart irrigation management system using machine learning and open source technologies. *Computers and Electronics in Agriculture* 155: 41-49.

Gokhale, P., Deokattey, S. & Bhanumurthy, K. 2011. Ontology development methods. *DESIDOC Journal of Library & Information Technology* 31(2): 77–83.

Gong, L., Söderlund, H., Bogojevic, L., Chen, X., Berce, A., Fast-Berglund, Å. & Johansson, B. 2020. Interaction design for multi-user virtual reality systems: an automotive case study. *Procedia CIRP* 93: 1259-1264.

Gordon, K. 2020. 5 principles of visual design in UX. https://www.nngroup.com/articles/principles-visual-design/ [4 April 2022].

Gregor, S. & Hevner, A.R. 2013. Positioning and presenting design science research for maximum impact. *MIS Q*.37(2): 337–356.

Gregório, J., Reis, L., Peyroteo, M., Maia, M., Mira da Silva, M. & Lapão, L. 2021. The role of design science research methodology in developing pharmacy eHealth services. *Research in Social and Administrative Pharmacy* 17(12): 2089-2096. https://doi.org/https://doi.org/10.1016/j.sapharm.2021.05.016

Gruber, T.R. 1993. A translation approach to portable ontology specifications. *Knowledge Acquisition* 5(2): 199-220.

Guarino, N. & Poli, R. 1995. The role of formal ontology in the information technology. *International Journal of Human-Computer Studies* 43(5-6): 623-965.

Guizzardi G, Botti Benevides A, Fonseca CM, Porello D, Almeida JPA, Prince Sales T. 2021. UFO: Unified Foundational Ontology. *Applied Ontology* 17(1):167-210.

Hales, S.D. & Johnson, T.A. 2003. Endurantism, perdurantism and special relativity. *Philosophical Quarterly* 53 (213):524–539.

Hartnett, J.P. 2021. Ontological design has become influential in design academia – but what is it? Eye on design. https://eyeondesign.aiga.org/ontological-design-is-popular-in-design-academia-but-what-is-it/ [27 July 2022].

Harz, N., Hohenberg, S. & Homburg, C. 2021. Virtual reality in new product development: insights from prelaunch sales forecasting for durables. *Journal of Marketing* 86(3): 157-179.

Hevner, A.R, March, S.T., S., Park, J. & Ram, S. 2004. Design science in information systems research. *MIS Quarterly* 28(1): 75-105.

Hj. Md. Nasir, A., Sulaiman, M.F., Leong, L.K., Salwana, E. & Ahmad, M.N. 2024. An approach for developing an ontology: learned from business model ontology design and development. *International Journal of Advanced Computer Science and Applications (IJACSA)* 15(3): 539-554.

Huang, C.R. 2016. Endurant vs perdurant: ontological motivation for language variations. *Proceedings of the 30th Pacific Asia Conference on Language, Information and Computation,* hlm.15–25.

Interaction Design Foundation. 2020. What is interaction design process? https://www.interaction-design.org/literature/topics/interaction-design-process [23 May 2022].

Isa, B.H.M. 2022. Banyak tanah pertanian disediakan kerajaan negeri terbiar, tidak diusahakan sepenuhnya. *Utusan Malaysia,* 31 March: 1.

Jasanoff, S. 2017. Virtual, visible, and actionable: data assemblages and the sightlines of justice. Big Data & Society 4(2): 1–15.

Johansson, I. 2005. Qualities, quantities, and the endurant-perdurant distinction in top-level ontologies. In Althoff, K.D., Dengel, A., Bergmann, R., Nick, M. & Roth-

Berghofer Th (ed.). *3rd Conference Professional Knowledge Management WM 2005, Springer Verlag*, pp. 543–550.

Kaburuan, E.R., Jayadi, R. & Harisno. 2019. A design of IoT-based monitoring system for intelligence indoor micro-climate horticulture farming in Indonesia. *Procedia Computer Science* 157:459-464.

Kamisan, N. 2020. Smart farming - pantau ladang menggunakan telefon pintar. Seminar Teknologi Fertigasi Siri 2/2020 Organized by Jabatan Pertanian 2020, Dewan Sultan Mizan, Universiti Malaysia Terengganu. 13 - 14 October.

Kassel, G. 2005. Integration of the DOLCE top-level ontology into the OntoSpec methodology. LARIA Research Report: LRR 2005-08. https://arxiv.org/pdf/cs/0510050 [21 January 2022].

Keet, M. 2020. A*n Introduction to Ontology Engineering*. 1.5 Version. Cape Town: University of Cape Town.

Klaas, E. & Roopaei, M. 2021. Immersive analytics application in smart agriculture and animal behavior. *Proceedings of the 2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC)*, pp. 290–296.

Koh, J.B. 2020. Metadata models and methods for smart buildings. Ph.D. Dissertation, University of California San Diego, California.

Kuechler, B. & Vaishnavi, V. 2008. On theory development in design science research: anatomy of a research project. *European Journal of Information Systems* 17(5): 489-504.

Kumar, P. & Ashok, G. 2021. Design and fabrication of smart seed sowing robot. *Materials Today: Proceedings* 39: 354-358.

Kumari, K., Mirzakhani Nafchi, A., Mirzaee, S. & Abdalla, A. 2025. AI-Driven future farming: achieving climate-smart and sustainable agriculture. *AgriEngineering* 7(3): 89.

Kumari, S., Raghuram, P., Venkatesh, V.G. & Shi, Y. 2022. Future perspectives on progressive farming with adoption of virtual reality technology for sustainable quality in agriculture. *The TQM Journal* 34(2): 250-279.

Lamsfus, C.; Martin, D.; Salvador, Z.; Usandizaga, A. & Alzua-Sorzabal, A. 2009. Human-centric ontology-based context modelling in tourism. Proceedings of MCIS 2009, Atenas, Grecia, 25–27 September.

Lasseur, R., Laurenson, S., Ali, M., Loh, I. & Mackay, M. 2023. Designing profitable and climate-smart farms using virtual reality. *PLOS ONE* 18(6): e0286723.

Leong, L.K., Riza, M.A., Nasir, A.M., Mohamad, U.H., Ahmad, M.N. & King, D.W.Y. 2024. Virtual reality dashboard design ontology (VRDDO): a theoretical view. *International Conference on Computer, Control, Informatics and its Applications (IC3INA)*, pp. 36-41.

Li, W., Batty, M. & Goodchild, M.F. 2020. Real-time GIS for smart cities. *International Journal of Geographical Information Science* 34(2): 311-324.

Lioutas, E.D., Charatsari, C., La Rocca, G. & De Rosa, M. 2019. Key questions on the use of big data in farming: an activity-theory approach. *NJAS – Wageningen Journal of Life Sciences* 90-91: 100297.

Liu, J., Zhang, X., Li, Y., Wang, J. & Kim, H.J. 2019. Deep learning-based reasoning with multi-ontology for IoT applications. *EEE Access 7:* 124688-124701.

Lutters, E. & Damgrave, R. 2019. The development of pilot production environments based on digital twins and virtual dashboards. *Procedia CIRP* 84: 94-99.

Ma, Q. & Millet, B. 2021) Design guidelines for immersive dashboards. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 65(1)*, pp. 1524-1528.

March, S. & Smith, G. 1995. Design and natural science research on information technology. *Decision Support Systems* 15(4): 251-266.

Masullo, M., Pascale, A., Toma, R.A., Ruggiero, G. & Maffei, L. 2022. Virtual reality overhead crane simulator. *Procedia Computer Science* 200: 205-215.

McArthur, T. 1992. *The Oxford Companion to the English Language.* New York: Oxford University Press.

MDEC. 2020. Aplikasi teknologi pintar dalam pertanian Seminar Teknologi Fertigasi Siri 2/2020 Organized by Jabatan Pertanian 2020, Dewan Sultan Mizan, Universiti Malaysia Terengganu. 13 - 14 October.

Millais, P., Jones, S.L. & Kelly, R. 2018. Exploring data in virtual reality: comparisons with 2D data visualizations. Extended Abstracts. 2018 CHI Conference on Human Factors in Computing Systems, Montreal QC, Canada. 21–26 April.

Mingers, J. & Willcocks, L. 2004. *Social Theory and Philosophy for Information Systems.* Chichester: John Wiley & Sons Ltd.

Mohamad, U.H., Ahmad, M.N., Benferdia, Y., Shapi'i, A. & Bajuri, M.Y. 2021. An overview of ontologies in virtual reality-based training for healthcare domain. *Frontiers in Medicine* 8: 698855.

Mollel, M., Quiroz L.F., Varley, C., Firestine, A., McLoughlin, M.E., Kafunah, J., Kharkar, S., O'Farrell, J., Ndlovu, N., Johnston, A., McKeown, P.C., Brychkova, G., Murray, U., Leiva, S. & Spillane, C. 2025 Digital technologies to accelerate the impact of climate smart agriculture by next-generation farmers in Africa. *Front. Sustain. Food Syst.* 9:1462328.

mondayblog. 2022. The ultimate dashboard template for business. https://monday.com/blog/project-management/dashboard-template/#:~:text=A%20dashboard%20template%20is%20a,to%20build%20your%20unique%20dashboard [14 June 2023].

Mukhopadhyay, A., Reddy, G.S.R., Saluja, K.S., Ghosh, S., Peña-Rios, A., Gopal, G. & Biswas, P. 2022. Virtual-reality-based digital twin of office spaces with social distance measurement feature. *Virtual Reality, Intelligent Hardware* 4(1): 55-75.

Muñoz, E.G., Fabregat, R., Bacca-Acosta, J., Duque-Méndez, N. & Avila-Garzon, C. 2022. Augmented reality, virtual reality, and game technologies in ophthalmology training. Information 13(5): 222.

Musen, M.A. 1992. Dimensions of knowledge sharing and reuse. *Computers and Biomedical Research* 25(5): 435-467.

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.

Ngo, Q.H., Kechadi, T. & Le-Kha, N.A. 2022. Knowledge representation in digital agriculture: a step towards standardised model. *Computers and Electronics in Agriculture* 199: 107127. (Ong)

Nicola, D. & Missikoff, M. A lightweight methodology for rapid ontology engineering. Commun ACM 59(3): 79–86.

Nie, W., De Vita, K. & Masood, T. An ontology for defining and characterizing demonstration environments. *J Intell Manuf* 35: 3501–3521.

Noy, N.F. & McGuinness, D. L. 2001. Ontology development 101: a guide to creating your first ontology. Stanford Knowledge Systems Laboratory Technical Report KSL-01-05 and Stanford Medical Informatics Technical Report SMI-2001-0880

Osterwalder, A. 2004. The business model ontology: a proposition in a design science research. Ph.D. Dissertation, University of Lausanne, Switzerland.

Park, S. & Lee, G. 2020. Full-immersion virtual reality: adverse effects related to static balance. *Neuroscience Letters* 733: 134974.

Peffers, K., Tuunanen, T., Rothenberger, M. & Chatterjee, S. 2007. A design science research methodology for information systems research. *Journal of Management Information Systems* 24: 45-77.

Perkins, M. 2024. The use of generative AI in qualitative analysis: inductive thematic analysis with ChatGPT. *Journal of Applied Learning, Teaching* 7(1): 390–395.

Phasinam, K., Kassanuk, T. & Shabaz, M. 2022. Applicability of internet of things in smart farming. *Journal of Food Quality* 7692922.

Podder, A.K., Bukhari, A.A., Islam, S., Mia, S., Mohammed, M.A., Kumar, N.M., Cengiz, K. & Abdulkareem, K.H. 2021. IoT based smart agrotech system for verification of Urban farming parameters. *Microprocessors and Microsystems* 82: 104025.

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.

Prescott, M.R., Yeager, S., Ham, L., Rivera Saldana, C.D, Serrano, V, Narez, J., Paltin, D., Delgado, J., Moore, D.J. & Montoya, J. 2024. Comparing the efficacy and efficiency of human and generative AI: qualitative thematic analyses. *JMIR AI* 3:e54482R.

Rakhra, M., Sanober, S., Quadri, N.N., Verma, N., Ray, S. & Asenso, E. 2022. Implementing machine learning for smart farming to forecast farmers' interest in hiring equipment. *Journal of Food Quality* 1: 4721547.

Rauschnabel, P.A., Felix, R., Hinsch, C., Shahab, H. & Alt, F. 2022. What is XR? Towards a framework for augmented and virtual reality. *Computers in Human Behavior* 133: 107289.

Roukh, A., Fote, F.N., Mahmoudi, S.A. & Mahmoudi, S. 2020. Big data processing architecture for smart farming. *Procedia Computer Science* 177: 78-85.

Saddik, A.E., Fatnassi, I. & Ghayoula, C. 2023. Enhancing smart agriculture by implementing digital twins. *Sensors* 23(16): 7128.

Said Mohamed, E., Belal, A.A., Kotb Abd-Elmabod, S., El-Shirbeny, M.A., Gad, A., Zahran, M.B. 2021. Smart farming for improving agricultural management. The Egyptian *Journal of Remote Sensing and Space Science* 24(3) 971-981.

Sarpal, D., Sinha, R., Jha, M.,, Tn, P. (2022). AgriWealth: IoT based farming system. Microprocessors and Microsystems, 89, 104447. https://doi.org/https://doi.org/10.1016/j.micpro.2022.104447

Sattar, A., Ahmad, M.N., Surin, E.S.M & Mahmood, A.K. 2021. An improved methodology for collaborative construction of reusable, localized, and shareable ontology. *IEEE Access* 9: 17463–17484.

Sebei, H., Hadj Taieb, M.A. & Aouicha, M.B. 2020. SNOWL model: social networks unification-based semantic data integration. *Knowl Inf Syst 6*2(11): 4297–4336.

Setti, T. & Csapo, A.B. 2021. A canonical set of operations for editing dashboard layouts in virtual reality. *Frontiers in Computer Science* 3: 659600.

Shamsuzzoha, A., Ferreira, F., Azevedo, A. & Helo, P. 2016. Collaborative smart process monitoring within virtual factory environment: an implementation issue. *International Journal of Computer Integrated Manufacturing* 30(1): 167–181.

Siang, T.Y. 2022. The key elements & principles of visual design. https://www.interaction-design.org/literature/article/the-building-blocks-of-visual-design?srsltid=AfmBOooFe-IgCpMSZ6Qg6ozRe7mYOd39P20NTnwlyl5B8J6uIWpJrdP- [4 April 2022].

Smith, S.P. &Trenholme, D. (2009). Rapid prototyping a virtual fire drill environment using computer game technology. Fire Safety Journal, 44(4), 559-569.

Spoladore, D., Pessot, E. & Trombetta, A. A novel agile ontology engineering methodology for supporting organizations in collaborative ontology development. *Computers in Industry* 151: 103979.

Stănescu, G., & Oprea, S.–V. 2025. Recent trends and insights in semantic web and ontology-driven knowledge representation across disciplines using topic modeling. *Electronics* 14(7): 1313.

Stehle, S. & Kitchin, R. 2020. Real-time and archival data visualisation techniques in city dashboards. *International Journal of Geographical Information Science* 34(2): 344-366.

Studer, R., Benjamins, V.R. & Fensel, D. 1998. Knowledge engineering: principles and methods. *Data & Knowledge Engineering* 25(1-2): 161-197.

Suárez-Figueroa, M.C., Gómez-Pérez, A. & Fernández-López, M. The NeOn methodology framework: a scenario-based methodology for ontology development. *Applied Ontology* 10(2):107-145.

Subotin, S. 2019. Dashboard design - considerations and best practices. https://www.toptal.com/designers/data-visualization/dashboard-design-best-practices [18 April 2022].

Sulaiman, M.F., Ahmad, M.N., Leong, L.K., Mohamad, U.H., Nik Mohd Nizam, N.M.H, Shapii, A. 2023. Ontologies for smart farming. 16th IADIS International Conference on Information Systems (IS ’23), Lisbon, Portugal. 19–22 July.

Symeonaki, E., Maraveas, C. & Arvanitis, K.G. 2024. Recent advances in digital twins for agriculture 5.0: applications and open issues in livestock production systems. *Applied Sciences* 14(2): 686.

Turki, M., Kassel, G., Saad, I. & Gargouri, F. 2016. A core ontology of business processes based on DOLCE. *Journal on Data Semantics* 5(3):165-177.

Uschold, M. & Gruninger, M. 1996. Ontologies: principles, methods and applications. *The Knowledge Engineering Review* 11(2):93-136.

Uschold, M. & King, M. 1995. Towards a methodology for building ontologies. *Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing*, pp. 11-19.

Vankov, D., Schroeter, R. & Twisk, D. 2021. Can't simply roll it out: evaluating a real-world virtual reality intervention to reduce driving under the influence. *PLOS ONE* 16(4): e0250273.

Verdouw, C., Tekinerdogan, B., Beulens, A. & Wolfert, S. 2021. Digital twins in smart farming. *Agricultural Systems* 189: 103046.

Vock, K., Hubenschmid, S., Zagermann, J., Butscher, S. & Reiterer, H. 2021. IDIAR: Augmented reality dashboards to supervise mobile intervention studies *MuC '21: Proceedings of Mensch und Computer 2021*, pp. 248–259.

Wahid, A.S. 2022 Kelantan kenal pasti tanah pertanian terbiar untuk diusahakan. *Sinar Harian*, 21 May.

Walker, R., ap Cenydd, L., Pop, S., Miles, H.C., Hughes, C.J., Teahan, W.J. & Roberts, J.C. 2013. Storyboarding for visual analytics. *Information Visualization* 14(1): 27-50.

Walls, J. G., Widmeyer, G. R. & El Sawy, O. A. 1992. Building an information system design theory for vigilant EIS. *Information Systems Research* 3(1): 36-59.

Wang, C.Y., Chen, Y.J. & Chien, C.F. 2021. Industry 3.5 to empower smart production for poultry farming and an empirical study for broiler live weight prediction. Computers & Industrial Engineering 151: 106931.

Weidner, F. & Broll, W. 2022. Stereoscopic 3D dashboards. *Personal and Ubiquitous Computing* 26(3): 697-719.

Yang, G., Huang, Y. & Zhao, C. 2020. Agri-BIGDATA: a smart pathway for crop nitrogen inputs. *Artificial Intelligence in Agriculture* 4: 150-152.

Yang, P., Sun, J., Yu, H., Bai, G., Ge, Y., Luck, J. & Awada, T. 2023. Transforming agriculture with intelligent data management and insights. *Agricultural Data Science* 5: 201–225.

Ye, Z., JianQin, W. & ZhiHong, L. 2018. An intelligent display platform of traditional farming myth's virtual scene based on Unity3D. *IFAC-PapersOnLine* 51(17): 678-682.

Yoo, S., Gough, P. & Kay, J. 2018. VRFit: an interactive dashboard for visualising of virtual reality exercise and daily step data. *Australasian Computer-Human Interaction Conference*: 229–233.

Youcef, B., Ahmad, M. N. & Mustapha, M. OntoPhaco: an ontology for virtual reality training in ophthalmology domain—a case study of cataract surgery. *IEEE Access* 9: 152347-152378.

APPENDIX A

INTERVIEW QUESTIONS

INTERVIEW QUESTIONS FOR VR DASHBOARD DESIGNER

SECTION A: USABILITY

1. How easy was it to understand and apply the VRDDM Canvas in your dashboard design process?
2. Did the concepts within the VRDDM Canvas feel comprehensive and relevant to your needs?
3. How user-friendly was the overall flow and structure of the methodology?

SECTION B: EFFECTIVENESS

1. To what extent did the VRDDM help you address the specific needs of your intended dashboard users?
2. How did the method guide your choices for data selection and visualization techniques?
3. Did the VRDDM improve the overall quality and purposefulness of your final VR dashboard?

SECTION C: COMPLETENESS

1. Were there any important aspects of dashboard design that the VRDDM did not cover adequately?
2. Did any part of the method feel redundant or unnecessary in your workflow?
3. How well were ecological psychological perspective theory incorporated in the VRDDM?

SECTION D: IMPACT

1. How did using the VRDDM compare to your previous dashboard design approaches?
2. Did it influence your decision-making or workflow in any specific way?
3. Would you consider using the VRDDM methodology again for other projects?

SECTION E: CHALLENGES & LIMITATIONS

1. What were the main challenges or difficulties you encountered while applying the VRDDM?
2. Did any platform-specific or project-related limitations affect your experience?
3. How flexible do you think the VRDDM is when applied to different types of dashboards?

SECTION F: SUGGESTED IMPROVEMENTS

1. What suggestions do you have to improve the VRDDM framework?
2. Are there any additional features, sections, or tools you would like to see included?

SECTION G: OVERALL ASSESSMENT

1. On a scale of 1–10, how would you rate the overall usefulness of the VRDDM in your design process?
2. Would you recommend this method to other dashboard designers? Why or why not?
3. Thank you again for your time and valuable insights.

INTERVIEW QUESTIONS FOR VR DEVELOPER

SECTION A: DASHBOARD RELEVANCE AND UTILITY

1. How well do the VR dashboards reflect the operational and strategic information?
2. Which VR dashboard features do you find most helpful for guidance towards developing a VR dashboard?
3. Are there any areas where some of the concepts fall short in guiding VR dashboard development?

SECTION B: DOMAIN-SPECIFIC METRICS

1. Do the dashboards include key indicators that are commonly used in VR dashboard development?
2. Are there any critical domain-specific metrics that are missing or underrepresented?
3. How reliable or trustworthy do you find the way these metrics are visualised?

SECTION C: INTERPRETABILITY AND CLARITY

1. Is the VR dashboard easy to interpret for developers at different levels or fields?
2. Do you find the guide on layout and visual elements (charts, icons, structure) clear and informative?
3. Would this VR dashboard canvas support rapid understanding or require training for proper interpretation?

SECTION D: ADOPTION AND INTEGRATION

1. How likely is it that this VR dashboard design method could be adopted by any organization?
2. Are they compatible with current workflows, data systems, or performance tracking mechanisms?
3. What factors would support or hinder the integration of these VR dashboards methods into existing development operations?

SECTION E: OVERALL ASSESSMENT

1. How would you rate the VR dashboard design method overall in terms of usefulness and alignment with industry needs?
2. Would you recommend them for wider use across the smart farming sector?
3. What improvements or refinements would you suggest for making them more impactful?

Thank you again for your time and valuable insights.

APPENDIX B

INTERVIEW RESPONSE – VR DESIGNER

July 8, 2025, 10.00 a.m

Liew Kok Leong 10:00 a.m
OK, I hope you're doing well today. First of all, thank you for taking the time to join this interview session. I really appreciate your contribution in designing the VR dashboard mock-up using the VRDDM framework.

VR Designer 10:02 a.m
Thank you. Happy to be here.

Liew Kok Leong 10:04 a.m
Your involvement has been instrumental in testing and shaping how the VRDDM might work in real-world VR dashboard development. Your feedback today will be incredibly valuable in evaluating how practical and effective this method is from a designer's perspective.

For your information, this session is recorded purely for academic analysis purposes. All responses will remain confidential, and your name or organization will not appear in any report or publication.

VR Designer 10:05 a.m
That's fine. Understood.

Liew Kok Leong 10:07 a.m
Great. At any point, if you wish to skip a question, just let me know. Are you ready to begin?

VR Designer 10:08 a.m
Sure, let's go ahead.

Liew Kok Leong 10:10 a.m
Alright. Let's start with your overall experience of using the VRDDM Canvas in your design process. The first question is, how easy was it to understand and apply the VRDDM Canvas?

VR Designer 10:12 a.m
Honestly, I found the VRDDM Canvas quite intuitive. At first glance, the structure might seem a little dense, but it quickly became clear how each section guides you through the design process. It felt logical and flowed nicely. The key blocks acted like reminders of best practices and gave me a systematic way to map out the dashboard design.

Liew Kok Leong 10:15 a.m
Mm hmm.

VR Designer 10:16 a.m
I'd say there was a slight learning curve in connecting the theoretical elements, especially the ontological parts, to practical steps. But once I got past that, it was smooth sailing.

Liew Kok Leong 10:18 a.m
Interesting. Did the concepts within the VRDDM Canvas feel comprehensive and relevant to your needs as a designer?

VR Designer 10:19 a.m
For the most part, yes. The framework covered a wide range of considerations user interaction, data visualization, even storyboarding which really aligned with the challenges we face in VR design. It encouraged me to think more deeply about user actions in immersive environments, which is something I appreciated.

Liew Kok Leong 10:22 a.m
Good. And in your opinion, how user-friendly was the overall flow and structure of the methodology?

VR Designer 10:23 a.m
The flow felt natural starting with understanding the users and their environment, moving into design and development, and then testing. It broke down complex steps into manageable chunks, which reduced overwhelm. It provided a clear roadmap and helped prevent me from skipping critical early stages, like defining user tasks.

Liew Kok Leong 10:27 a.m
Alright. Shall we move to Section B on effectiveness?

VR Designer 10:28 a.m
Yes, go ahead.

Liew Kok Leong 10:30 a.m
To what extent did the VRDDM help you address the specific needs of your intended dashboard users?

VR Designer 10:32 a.m
It helped a lot. The framework's focus on user action possibilities and cognitive load considerations pushed me to prioritize the user experience. It wasn't just about visual appeal anymore; I designed with user goals and context in mind, which made the final dashboard much more usable.

Liew Kok Leong 10:35 a.m
And how did the method guide your choices for data selection and visualization techniques?

VR Designer 10:36 a.m
The method encouraged me to think about the story the data needed to tell. Instead of defaulting to familiar 2D charts, I explored volumetric and interactive 3D visualizations

that fit the VR context better. It was less about “adding cool visuals” and more about enhancing user understanding and action.

Liew Kok Leong 10:40 a.m
Did the VRDDM improve the overall quality and purposefulness of your final VR dashboard?

VR Designer 10:41 a.m
Absolutely. The design felt more cohesive and intentional. The VRDDM acted as a safety net, ensuring I didn’t overlook key design principles or user needs. The final product felt like it had a clear purpose, not just another data visualization.

Liew Kok Leong 10:45 a.m
Alright, now let’s move to Section C, which focuses on the completeness of the VRDDM framework.

VR Designer 10:46 a.m
OK.

Liew Kok Leong 10:47 a.m
Were there any important aspects of dashboard design that you felt the VRDDM did not adequately cover?

VR Designer 10:49 a.m
Hmm, I’d say the framework was fairly comprehensive overall, but there’s room for improvement in a couple of areas. For instance, accessibility wasn’t addressed explicitly. Things like how to design for users with color blindness or motion sickness in VR could make the methodology more inclusive. Also, while the ecological psychology principles are excellent, some practical examples of how to apply them in VR-specific contexts would help designers new to the field.

Liew Kok Leong 10:54 a.m
Mm hmm. I see. Did any part of the method feel redundant or unnecessary in your workflow?

VR Designer 10:55 a.m
Not really redundant, but as an experienced designer, I found the “Templates” block a little less critical for my process. I tend to prefer building from scratch to achieve a more tailored experience. However, for junior designers or for rapid prototyping, I can see its value.

Liew Kok Leong 10:58 a.m
Alright. How well do you think ecological psychological perspective theories were incorporated in the VRDDM?

VR Designer 11:00 a.m
Quite effectively, actually. The method made me pay attention to user perception and affordances in ways I hadn’t consciously done before. For example, it influenced how

I placed interactive elements within the 3D environment to minimize user fatigue and maximize intuitiveness.

Liew Kok Leong 11:03 a.m
Alright, moving on to Section D, which is about impact. Are you ready?

VR Designer 11:04 a.m
Sure.

Liew Kok Leong 11:05 a.m
How did using the VRDDM compare to your previous dashboard design approaches?

VR Designer 11:06 a.m
It felt more structured and deliberate. Previously, I relied a lot on intuition and past experiences, but the VRDDM forced me to step back and analyze the "why" and "who" before diving into "what" and "how." That shift made the design process more focused and user-driven.

Liew Kok Leong 11:10 a.m
Did it influence your decision-making or workflow in any specific way?

VR Designer 11:11 a.m
Yes, definitely. It encouraged me to document my design rationale at each stage, which I hadn't been consistent with before. This not only helped during development but also when explaining decisions to stakeholders.

Liew Kok Leong 11:15 a.m
Would you consider using the VRDDM methodology again for your future projects?

VR Designer 11:16 a.m
Absolutely. Especially for complex projects with multiple stakeholders. It creates a shared language and framework that aligns everyone on goals and processes.

Liew Kok Leong 11:20 a.m
Now let's move to Section E: Challenges and Limitations. What were the main challenges or difficulties you encountered while applying the VRDDM?

VR Designer 11:22 a.m
The main challenge was understanding and translating the ontological concepts into actionable design steps during the early stages. It required some effort to bridge theory with practice. Also, in fast-paced projects, there's always the temptation to skip detailed user analysis, but the VRDDM reminded me of its importance.

Liew Kok Leong 11:27 a.m
Did any platform-specific or project-related limitations affect your experience?

VR Designer 11:29 a.m

Yes. Some interaction ideas suggested by the method couldn't be fully realized due to hardware constraints, like hand tracking limitations. Also, platform-specific UI elements sometimes didn't align with the ideal designs we planned using the canvas.

Liew Kok Leong 11:33 a.m
How flexible do you think the VRDDM is when applied to different types of dashboards?

VR Designer 11:34 a.m
It's very flexible. While designed for immersive VR, the core principles can easily adapt to AR environments or even traditional 3D dashboards. The modular design allows scaling the framework for projects of varying complexity.

Liew Kok Leong 11:38 a.m
Alright. Let's move to Section F on suggested improvements. Do you have any suggestions on what could be improved in the VRDDM framework or canvas?

VR Designer 11:40 a.m
Yes. Adding explicit guidance on accessibility design would be valuable things like designing for VR users with disabilities. Also, perhaps a "Best Practices Repository" within the canvas that includes real-world examples across domains. That would make it more actionable for beginners.

Liew Kok Leong 11:44 a.m
Mm hmm. Are there any additional features, sections, or tools you'd like to see included?

VR Designer 11:45 a.m
An interactive digital version of the canvas would be great, allowing designers to drag-and-drop components and see a live preview of layouts. Integration with popular tools like Unity or Figma could also streamline workflows.

Liew Kok Leong 11:50 a.m
Lastly, Section G: Overall Assessment. On a scale of 1–10, how would you rate the overall usefulness of the VRDDM in your design process?

VR Designer 11:51 a.m
I'd rate it an 8. It's a solid framework that brings structure and theoretical depth. With a few refinements, it could easily reach a 9 or 10.

Liew Kok Leong 11:54 a.m
Would you recommend this method to other dashboard designers? Why or why not?

VR Designer 11:55 a.m
Yes, I would. Especially for teams working on complex, user-centered VR projects. It fosters a thoughtful, disciplined approach. However, I'd suggest some initial onboarding for less experienced designers to help them get the most out of it.

Liew Kok Leong 11:58 a.m

Alright. That's all for today. Thank you so much for your time and thoughtful feedback. It's been very insightful.

VR Designer 11:59 a.m
You're welcome. It was a good discussion.

Liew Kok Leong 12:00 p.m
If I have any follow-up questions, I'll reach out again. Thanks once more.

VR Designer 12:01 p.m
Sure, no problem.

APPENDIX C

INTERVIEW RESPONSE – VR DEVELOPER

July 9, 2025, 2:30 p.m

Liew Kok Leong 2:30 p.m
Good afternoon. I hope you're doing well today. Thank you for taking the time to join this interview session. I really appreciate your involvement in testing and providing feedback on the VR dashboards developed using the VRDDM framework.

VR Developer 2:32 p.m
Good afternoon. Thank you, I'm glad to contribute.

Liew Kok Leong 2:34 p.m
Your insights as a developer are very valuable, especially since you were directly involved in building and implementing the dashboards. As mentioned earlier, this session is recorded purely for academic analysis, and your responses will remain confidential.

VR Developer 2:35 p.m
That's fine. Understood.

Liew Kok Leong 2:37 p.m
Perfect. If at any point you want to skip a question or take a break, feel free to let me know. Are you ready to begin?

VR Developer 2:38 p.m
Sure, let's start.

Liew Kok Leong 2:39 p.m
Alright, first, how well do you think the VR dashboards reflect the operational and strategic information?

VR Developer 2:41 p.m
They do quite well overall. The dashboards provide a good balance of high-level strategic overviews and detailed operational data. For example, the environmental monitoring dashboard allows quick scanning of sensor data trends, while also enabling deeper dives into specific data points like humidity or soil nutrient levels. This layered approach is particularly effective in a VR environment where spatial awareness can be leveraged.

Liew Kok Leong 2:45 p.m
Which features of the VR dashboards did you find most helpful as a developer?

VR Developer 2:47 p.m
The dynamic threshold warnings and interactive panels stood out. They provide real-time feedback, making it easier to identify out-of-range values. Also, the modular

design approach guided by the VRDDM helped streamline development because it gave clear expectations for each block's function and interaction flow.

Liew Kok Leong 2:51 p.m
Were there any areas where you felt the concepts fell short in guiding VR dashboard development?

VR Developer 2:52 p.m
Perhaps a bit on performance optimization. The framework does a great job outlining design principles, but in practice, we had to figure out strategies for rendering large datasets efficiently in VR. Including some technical considerations for handling heavy data visualization would strengthen it further.

Liew Kok Leong 2:57 p.m
Moving on, do the dashboards include key indicators that are commonly used in VR dashboard development?

VR Developer 2:59 p.m
Yes, they cover the basics very well sensor data visualization, user interaction metrics, and system health indicators. However, in the context of smart farming, I'd say predictive analytics indicators could be more prominent. That's becoming a key trend in VR applications for agriculture.

Liew Kok Leong 3:02 p.m
Are there any critical domain-specific metrics you think are missing or underrepresented?

VR Developer 3:03 p.m
I'd say temporal trends could use more emphasis. While current data is well-handled, integrating historical patterns for forecasting would elevate the dashboards. Also, more visualization of resource allocation efficiency could be useful for farm managers.

Liew Kok Leong 3:07 p.m
How reliable or trustworthy do you find the way these metrics are visualized?

VR Developer 3:09 p.m
They're quite reliable in terms of clarity and interpretability. The use of immersive 3D charts and spatial layouts reduces cognitive load. But from a technical standpoint, ensuring data refresh rates stay consistent during heavy user interaction is an area we need to monitor closely.

Liew Kok Leong 3:12 p.m
Is the VR dashboard easy to interpret for developers at different levels or fields?

VR Developer 3:14 p.m
Yes, mostly. The canvas provides a structured way for even less experienced developers to understand the system's architecture. But for complete newcomers, there might be a need for a short orientation to VRDDM's terminology and workflow.

Liew Kok Leong 3:17 p.m
Do you find the guide on layout and visual elements clear and informative?

VR Developer 3:19 p.m
Yes. The guidance on visual hierarchy and interaction affordances is excellent. It helped us avoid cluttered interfaces and focus on creating dashboards where information flows naturally.

Liew Kok Leong 3:22 p.m
Would this VR dashboard canvas support rapid understanding, or would it require training for proper interpretation?

VR Developer 3:23 p.m
It supports fairly rapid understanding for experienced developers, but for teams unfamiliar with ontological design concepts, a brief workshop or training session would be beneficial.

Liew Kok Leong 3:26 p.m
How likely is it that this VR dashboard design method could be adopted by organizations?

VR Developer 3:28 p.m
Highly likely, especially in industries like precision agriculture, healthcare, or urban planning where immersive dashboards are gaining traction. Its structured approach fits well with agile development workflows.

Liew Kok Leong 3:30 p.m
Are they compatible with current workflows, data systems, or performance tracking mechanisms?

VR Developer 3:32 p.m
Yes, in most cases. The method integrates well with standard VR development pipelines and can adapt to existing data systems. The modular design blocks make it easier to slot into performance tracking frameworks.

Liew Kok Leong 3:35 p.m
What factors do you think would support or hinder the integration of these VR dashboard methods into development operations?

VR Developer 3:37 p.m
Support factors include clear documentation, modularity, and alignment with existing development tools like Unity or Unreal Engine. Hindrances might be the learning curve for non-ontological thinkers and the resource intensity of high-fidelity VR development.

Liew Kok Leong 3:41 p.m
How would you rate the VR dashboard design method overall in terms of usefulness and alignment with industry needs?

VR Developer 3:43 p.m
I'd rate it an 8. It provides a strong foundation for building immersive dashboards and aligns well with industry needs for user-centric, modular, and scalable design approaches.

Liew Kok Leong 3:46 p.m
Would you recommend this method for wider use across the smart farming sector?

VR Developer 3:47 p.m
Yes, definitely. It's practical, scalable, and supports the type of data visualization needed in smart farming. With minor enhancements, it could become a go-to methodology.

Liew Kok Leong 3:50 p.m
What improvements or refinements would you suggest for making the method more impactful?

VR Developer 3:51 p.m
I'd suggest adding sections on performance optimization in VR environments and embedding best practices for handling large data sets efficiently. Also, integrating some AI-driven predictive modeling guidance could extend its applicability.

Liew Kok Leong 3:54 p.m
Alright, that's the last question. Thank you so much for your time and valuable insights.

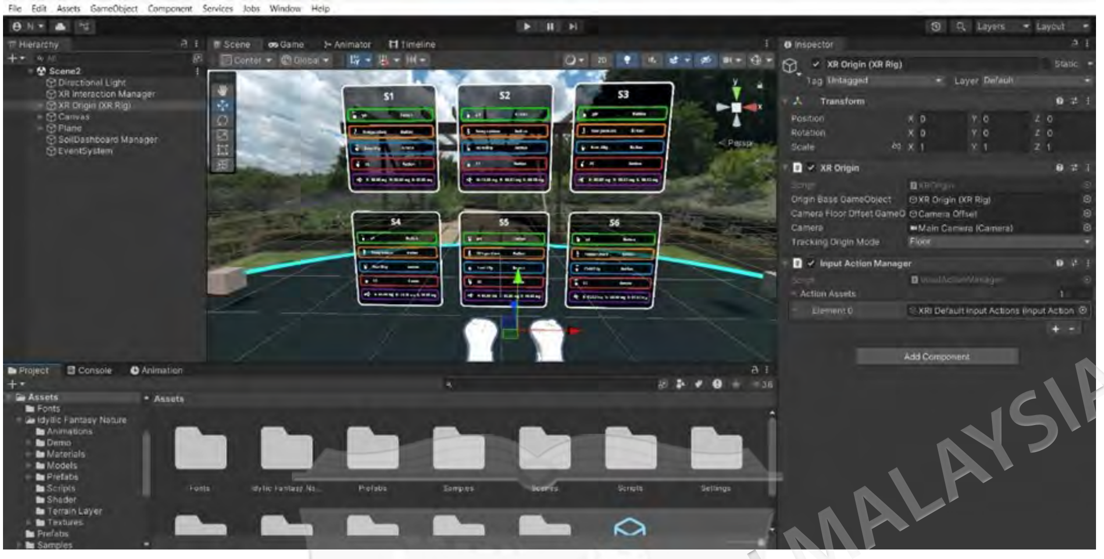
VR Developer 3:55 p.m
You're welcome. It was a productive discussion.

Liew Kok Leong 3:57 p.m
If I have any follow-up questions, I'll reach out again. Thank you once more for your contribution.

VR Developer 3:58 p.m
Sure, no problem. Happy to help.

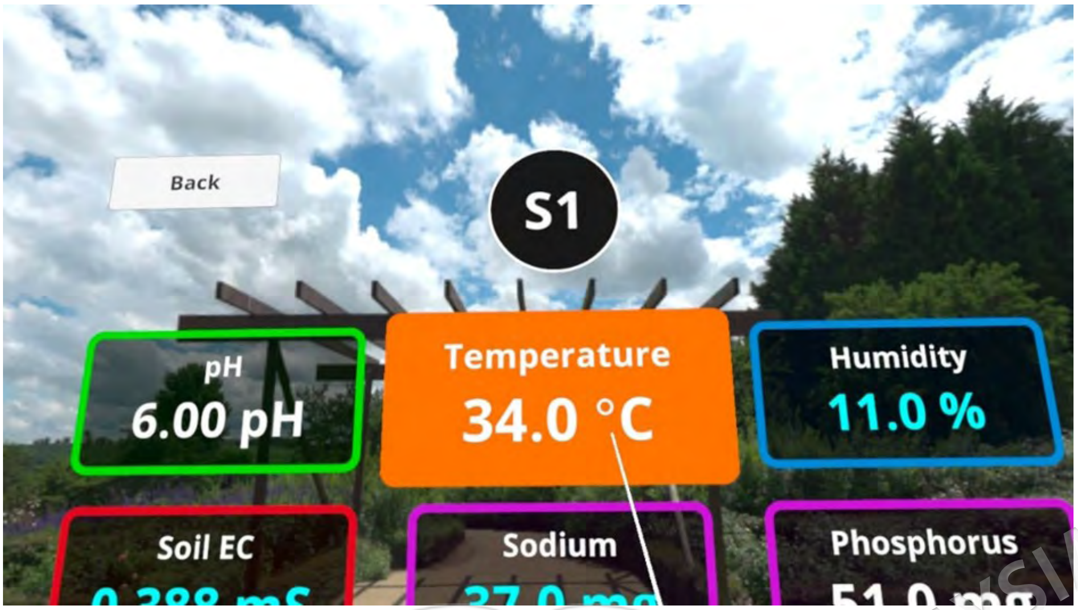
APPENDIX D

VR DASHBOARD POC1 AND POC2



Appendix D.1 VR Dashboard development process in Unity VR

Appendix D.2 POC1 viewing



Appendix D.3 POC2 viewing