Using EPP Theory and BMO-Inspired Approach to Design a Virtual Reality Dashboard Design Ontology

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***Abstract*—This paper introduces the Virtual Reality Dashboard Design Ontology (VRDDO), an ontological framework developed to address the absence of standardized methodologies in designing Virtual Reality (VR) dashboards for complex data visualization, particularly in smart farm monitoring. The VRDDO is built upon the Design Science Research (DSR) approach and anchored in Kernel Theory, specifically the Ecological Psychological Perspective (EPP) theory and Business Model Ontology (BMO). During the design and development phase of DSR, the Unified Ontological Approach (UoA) is applied as the ontology development methodology, to design and construct VRDDO as a design artifact. By offering a structured framework for VR dashboard design, VRDDO aims to enhance data interpretation and decision-making in immersive environments. Additionally, this ontology forms the basis for a Virtual Reality Dashboard Design Method, establishing a systematic and user-centric approach to developing efficient VR dashboards. This research is significant for its potential to improve VR dashboard development across diverse domains, facilitate knowledge sharing, and eliminate fragmented, ad-hoc practices in immersive data visualization.**

Keywords*—Design Science Research (DSR); Ontology Development Methodology (ODM); Ecological Psychological Perspective (EPP); Unified Foundational Ontology (UFO); Virtual Reality Dashboard Design Method (VRDDM)

I. Introduction

Virtual Reality (VR) technology has rapidly evolved in recent years, revolutionizing numerous fields including education, healthcare, entertainment, and business. As VR applications become more sophisticated, the need for effective data visualization and interaction within these immersive environments has grown exponentially. VR dashboards have emerged as a powerful tool to address this need, providing users with intuitive and immersive interfaces to monitor, analyze, and interact with complex data sets. The author in [1] defines a dashboard as "a predominantly visual information display that people use to rapidly monitor current conditions that require a timely response to fulfill a specific role". In the context of VR, these dashboards take on new dimensions, leveraging the unique capabilities of immersive environments to present information in ways previously impossible in traditional 2D interfaces.

The development of VR dashboards involves a complex interplay of various technologies and data sources. These dashboards can integrate data from Internet of Things (IoT) devices, such as sensors and microcontrollers, as well as from open-source databases, big data repositories, and manually gathered information. User input can be collected through various means, including graphical user interfaces (GUIs), VR equipment like head-mounted displays (HMDs) and eye gaze trackers, smartphones, and even physiological sensors like heart rate monitors [2-9]. This diversity of data sources and input methods presents both opportunities and challenges in VR dashboard design and development.

While the widespread adoption of dashboards in various industries has demonstrated its value in improving information comprehension and decision-making, the design of effective VR dashboards remains subject to numerous challenges. Common issues include poor use of virtual space, presentation of insufficient information, and unappealing visual elements that can detract from the user experience. The complexity of mobility data and the unique characteristics of VR environments necessitate a more nuanced approach to dashboard design than traditional 2D interfaces. For complex systems particularly in smart farm monitoring, developers must consider not only the type, volume, and frequency of data updates but also the specific purpose of the dashboard and the needs of its intended users [10, 11]. There is a lack of standardization in designing VR dashboards for smart farming applications. More broadly, the field would benefit from a unified Virtual Reality Dashboard Design Method (VRDDM). Establishing such standards would simplify the design process and reduce complications for developers. The establishment of a Virtual Reality Dashboard Design Ontology (VRDDO) aims to address this need by providing a theoretical framework that can guide developers in creating more effective, user-friendly, and standardized VR dashboard solutions. By establishing common principles and design patterns, VRDDO has the potential to accelerate innovation in this field, improve user experiences, and ultimately enhance the value of VR applications across various domains.

Motivated by the growing demand for immersive data visualization, this study proposes the VRDDO to address the lack of standardized VR dashboard development methods. The VRDDO benefits include enhancing decision-making, improving user engagement, and creating structured design processes adaptable across domains. Our main contributions are the construction of VRDDO based on theories of EPP and BMO and integration with the Unified Ontological Approach (UoA) and Unified Foundational Ontology (UFO).

The remainder of this paper is structured as follows: Section II reviews background and theories. Section III describes the theory used. Section IV proposes the VRDDO framework. Section V concludes the study.

II. Background

A. Design Science Research

Design Science Research (DSR) has emerged as a crucial paradigm in Information Systems (IS) research, complementing the more traditional behavioral science approach. While behavioral science focuses on developing and verifying theories that explain or predict human and organizational behavior, DSR aims to extend the boundaries of human and organizational capabilities through the creation of innovative artifacts. This paradigm is particularly relevant in the context of IS research, which sits at the intersection of people, organizations, and technology. DSR provides a structured approach to understanding, executing, and evaluating research that results in tangible, practical outcomes. In the case of the Virtual Reality Dashboard Design Ontology (VRDDO), DSR offers a methodological framework that guides the design and development of this innovative artifact, ensuring that it is both theoretically grounded and applicable [12, 13, 32].

The Design Science Research Methodology (DSRM) provides a systematic process for conducting DSR, emphasizing the importance of theory-based grounding in the development of design artifacts. This approach is particularly relevant for the VRDDO, which is positioned as a design artifact resulting from the DSR methodology, specifically emerging from the Design & Development stage. The VRDDO aligns with the perspective of DSR practitioners who advocate for kernel theory-based grounding in artifact design and development. By incorporating kernel theories as mandatory components of the DSR methodology, the VRDDO gains a solid theoretical foundation that enhances its validity and applicability. This theoretical grounding not only ensures that the VRDDO is built upon established principles but also facilitates its integration into the broader context of VR dashboard design and development. Through this approach, the VRDDO aims to bridge the gap between theoretical knowledge and practical application, offering a comprehensive framework that can guide researchers and practitioners in creating more effective and standardized VR dashboard solutions.

B. DSR for the Development of VRDD

Building upon the discussion of Design Science Research (DSR) and its methodology (DSRM), it is crucial to explore the various perspectives on the role of kernel theories in the development of design artifacts. Within the DSR field, there are three distinct "schools of thought" regarding the necessity and importance of kernel theories in artifact design and development. Fig. 1 shows the position of each school taught in their beliefs towards whether kernel theories are required for grounding and whether design theories can be accepted as key artifacts [14]. These perspectives offer valuable insights into the theoretical grounding of artifacts like the Virtual Reality Dashboard Design Ontology (VRDDO).

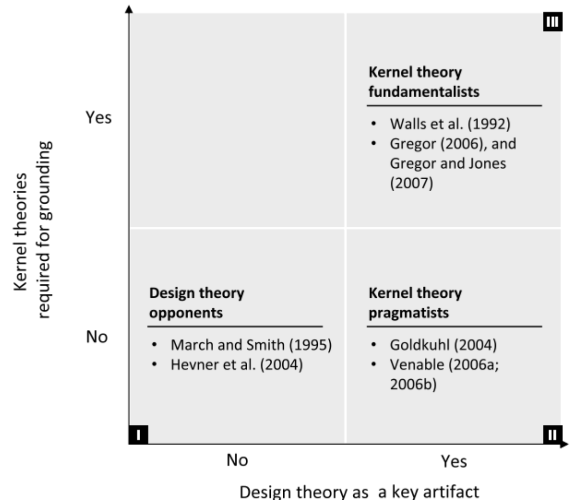

Fig. 1. DSR school of thought [14].

The first school, known as "Design Theory Opponents" (DTO), posits that kernel theories are not mandatory in DSR artifact development. Pioneered by DSR founders in Information Systems (IS) such as [13, 15], this perspective argues that DSR complements Behavioural Science (BS) rather than replicating it. While kernel theories are prevalent in BS research, they are not considered a priority or necessity in DSR. The author in [13] stated that while knowledge from behavioral sciences and design science research may be used in constructing design science artifacts, IS DSR artifacts do not necessarily need to be grounded in kernel theories. This school of thought does not accept theory as an output of DSRM and does not emphasize the need for kernel theories in artifact engineering.

The second perspective, termed "Kernel Theory Pragmatists" (KTP), takes a middle-ground approach. Established by [16-18], this school suggests that while kernel theories are not crucial in the artifact construction process, theory as an output of DSRM is acceptable as an impact and result of the research. This pragmatic stance allows for flexibility in the use of theories within DSR projects.

The third and most stringent perspective is the "Kernel Theory Fundamentalist" (KTF) school, championed by [19-21]. This approach mandates the use of kernel theories in artifact construction and simultaneously accepts theory as an output of DSRM. The author in [19] emphasized that kernel theories from natural or social sciences serve as a foundation for artifact construction. This school of thought insists on rigorous theoretical grounding for all aspects of DSR.

In the context of the VRDDO development, the researcher has adopted a balanced approach, acknowledging the existence and potential contributions of all three schools of thought. While recognizing the arguments against the necessity of kernel theories presented by the DTO and KTP schools, the researcher leans towards the KTF perspective in accepting the involvement of kernel theories in the artifact construction process. However, the researcher does not fully align with the KTF view that theory must be an output of DSRM. This nuanced approach allows for a theoretically grounded development of the VRDDO while maintaining flexibility in the research outcomes.

By considering these diverse perspectives on the role of kernel theories in DSR, the development of the VRDDO can benefit from a rich theoretical foundation while avoiding overly rigid constraints. This balanced approach ensures that the VRDDO is developed with a solid theoretical grounding, enhancing its validity and applicability in the field of VR dashboard design. Furthermore, it demonstrates the complexity and ongoing debates within the DSR community, highlighting the importance of thoughtful consideration of theoretical foundations in the development of innovative artifacts like the VRDDO.

III. Theory Used

In developing the VRDDO, this study adopts the 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) [22, 33]. 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 exist from other business models [22, 23]. 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) [24]. The theory emphasizes direct perception of environmental affordances which features suggestions on 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.

A. *Narrative Literature Review (NLR) for Deriving Key Blocks for Ontology Design*

The proposed VRDDO has to be built with established key blocks depending on its application. The targeted application for the VRDDO is on smart farm monitoring application. Therefore, several key blocks that serve as essential elements for the VRDDO are identified via literature study. The NLR is conducted in a manner that identifies commonalities of each element. In other words, common elements that have been found in other VR dashboard design methods are selected for use as key blocks.

B. *Ontology Design Using a Unified Ontological Approach (UoA)*

The Unified Ontological Approach (UoA) [25, 34] is a framework for ontology development that synthesizes the strengths of various Ontology Development Methods (ODMs) and draws inspiration from successful ontologies like 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.

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.

C. Importance of ODM for Building VRDDO

The Unified Ontological Approach (UoA) is used for building the Virtual Reality Dashboard Design Ontology (VRDDO). As a synthesis of various Ontology Development Methods (ODMs) and inspired by successful ontologies like Business Model Ontology, the UoA offers a robust framework for developing the VRDDO. Its key features - iterative development, consistent notation, flexible formalization, reusability, scenario-driven customization, and comprehensive structural representation - are particularly well-suited for the complex and evolving field of VR dashboard design.

UoA's scenario-driven approach ensures the VRDDO remains relevant across diverse use cases, while its flexible formalization allows adaptation to advancing VR technologies. The focus on reusability enables leveraging existing knowledge from related fields while accommodating VR-specific requirements. Comprehensive structural representation is essential for capturing both structural and dynamic aspects of VR dashboard design, crucial for representing the interactive nature of VR environments. The iterative process allows for continuous refinement, ensuring the VRDDO stays current with VR advancements. By employing the UoA, researchers can create a robust, flexible, and comprehensive ontology that effectively captures VR dashboard design complexities while ensuring adaptability across various domains, ultimately driving progress in VR dashboard design and its applications.

IV. VRDDO

The Virtual Reality Dashboard Design Ontology (VRDDO) shown in Fig. 2 is considered 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 capture 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 VR information dashboards that can effectively tackle monitoring challenges in smart farming and potentially other domains.

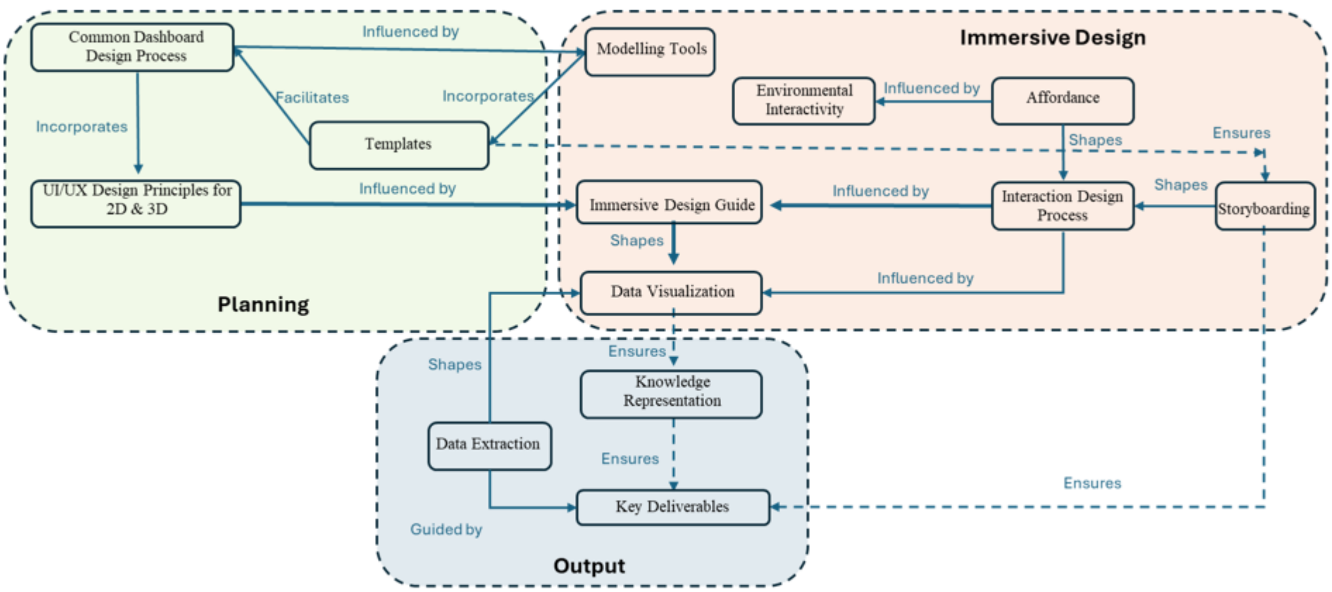

Fig. 2. Proposed VRDDO with concepts derived from key blocks.

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 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 a 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.

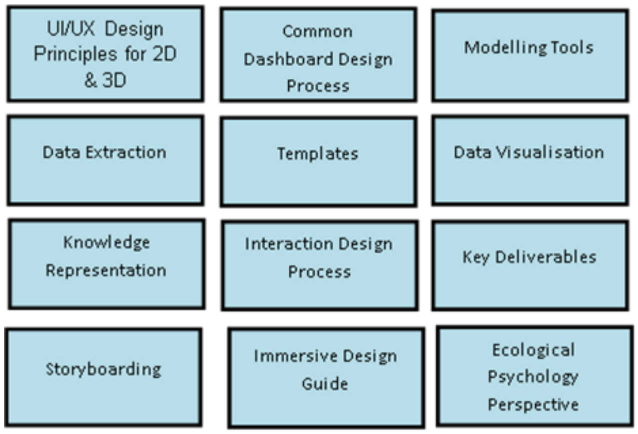

Fig. 3. Related key blocks derived from NLR.

A. *Concepts and Semantics to form VRDDO*

The Virtual Reality Dashboard Design Ontology (VRDDO) is structured around twelve key blocks as shown in Fig. 3, 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 [26]. 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 the 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 facilitate the design process in providing a structured approach to 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 [27].

Data Visualization and Modelling Tools: This block covers the various tools and techniques used for visualizing and modeling 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 [28]. 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.

Ecological Psychology Perspective: Acting as one of the grounding theories for the VRDDO, this block incorporates the EPP theory of affordances into VR dashboard design. It emphasizes the importance of creating intuitive, exploration-friendly virtual environments where users can directly perceive and interact with information. This perspective guides the design of VR dashboards to leverage Natural perceptual systems, enabling users to navigate and comprehend complex data more effectively. This key block provides two concepts in the VRDDO which are affordances and environmental interactivity. Affordances are the possibilities that an environment or object offers to an organism, particularly a human. They are directly perceivable properties that suggest how something can be used or interacted with, such as a handle affording grasping or a flat surface affording sitting. Affordances are relational, depending on both the properties of the object or environment and the capabilities of the organism perceiving them. Therefore, environmental interactivity is the dynamic relationship between an individual and their surroundings, where the environment offers opportunities for action and engagement. It encompasses how people perceive, interpret, and respond to the possibilities for interaction presented by their environment [29]. In the context of VR dashboards, environmental interactivity focuses on designing virtual spaces that intuitively communicate how users can interact with and manipulate data, leveraging natural perceptual cues to enhance user engagement and understanding.

B. *Restructuring of VRDDO Under UFO*

The development of the VRDDO employed the Unified Ontological Approach (UoA), as proposed by [25], 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 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.

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 [30]. The formalization process included syntactical validation using the OntoUML Plugin in Visual Paradigm, ensuring that the VRDDO framework was free of errors and adhered to formal modeling principles. After the implementation of UFO in the preliminary VRDDO, the relationship between concepts is clarified further. Fig. 4 shows the iterated VRDDO with UFO implementation.

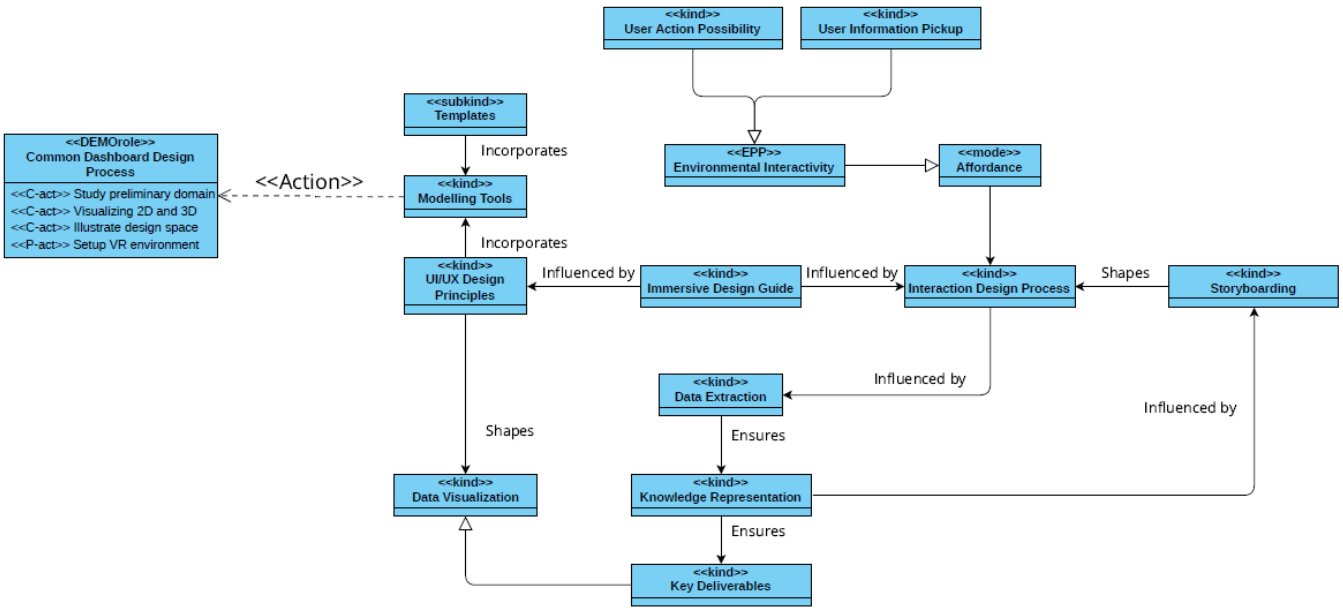

Fig. 4. Proposed VRDDO with concepts derived from key blocks.

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 shape the interaction design process. The 2 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 the object within the 3D VR dashboard. Another concept is known as User information pickup. This concept refers to how the user can know that an object within the VR environment can be interacted with. 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 are both self-explanatory and offer freedom of interaction between users and the VR dashboard. Immersion can achieve greater delivery and clarity for users, especially with a dense amount of information to display within a VR environment.

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 [31]. 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. Table I describes the rationale of each concept in the VRDDO. Compared to existing VR dashboard designs, VRDDO offers a standardized, theory-driven framework with clearer user interaction pathways and enhanced immersive data comprehension. Validation via integration of the Ecological Psychological Perspective (EPP) theory ensures better affordances and environmental interactivity for users.

TABLE I. 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.
Modeling Tools	<<kind>>	Defines the fundamental structures for representing VR dashboard elements, ensuring consistency in visualization and 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.
User action possibility	<<kind>>	Describes how a user can interact with objects (Gestures, other methods of input, etc.).
User information pickup	<<kind>>	Describes how a user can know whether an object is interactable.
Key Deliverables	<<kind>>	Outlines the critical outcomes expected from the VRDDO framework, aligning with both technical and design perspectives.

C. *VRDDO Iteration*

The iterative refinement of the Virtual Reality Dashboard Design Ontology (VRDDO) aligns with the principles of the Design Science Research (DSR) methodology, which emphasizes a cyclical process of development and evaluation to enhance the robustness and applicability of a design artifact [12]. The transition from the initial VRDDO (Fig. 2) to its refined version incorporating the Upper Foundational Ontology (UFO) (Fig. 4) was driven by successive iterations, ensuring improved conceptual clarity, semantic consistency, and structural coherence. Iterative design is fundamental in ontology engineering, as it allows for the continuous integration of theoretical insights, stakeholder feedback, and empirical validation, thereby fostering ontological rigor and practical relevance. By incorporating UFO, the final VRDDO iteration achieves a higher level of abstraction and interoperability, facilitating a more precise representation of immersive design processes. This iterative approach underscores the necessity of refinement cycles in advancing domain-specific ontologies, ensuring alignment with foundational theories, and enhancing applicability across VR-driven environments.

Compared to existing VR dashboard development approaches [3, 4, 7, 8], which often rely on ad-hoc design practices or lack structured theoretical foundations, the VRDDO offers a standardized, reusable, and theory-driven framework grounded in kernel theories and ontological principles. By leveraging the Unified Ontological Approach (UoA) and integrating the Ecological Psychological Perspective (EPP), the VRDDO ensures that both structural and perceptual aspects of dashboard design are systematically addressed. This approach enhances user immersion, data comprehension, and design scalability, distinguishing VRDDO from conventional methods that typically overlook these multidimensional factors.

D. *The way Forward for the VRDDO*

This study successfully formalized the Virtual Reality Dashboard Design Ontology (VRDDO) based on the Unified Ontological Approach (UoA), EPP theory, and BMO principles. The developed ontology organizes 12 key concepts and demonstrates how affordances and user-centered designs improve information visualization within VR environments. The proposed VRDDO helps to establish and reveal key relationships between concepts that are essential to be considered during the design and development of a VR dashboard. This work is inspired by Osterwalder's work in the creation of the BMC. The BMC is derived from BMO which consists of building blocks. Hence, The VRDDO will be used in our next work to establish a VR dashboard design method (VRDDM). A more detailed discussion on the development of VRDDM will be presented in our future publications.

V. CONCLUSION

The Virtual Reality Dashboard Design Ontology (VRDDO) presents a promising framework for standardizing and enhancing the development of VR dashboards, particularly in the context of smart farm monitoring. By synthesizing various ontology development methods and drawing inspiration from successful models like Business Model Ontology, the VRDDO offers a robust, flexible, and comprehensive approach to VR dashboard design. The incorporation of key theories, such as Gibson's Ecological Psychological Perspective, ensures that the ontology addresses both technical and perceptual aspects of VR interactions. The VRDDO's structured approach, emphasizing iterative development, consistent notation, and scenario-driven customization, provides a solid foundation for creating intuitive and effective VR dashboards. As the backbone of the forthcoming Virtual Reality Dashboard Design Method (VRDDM), the VRDDO has the potential to significantly improve the design and implementation of VR information dashboards across various domains, promoting standardization and knowledge sharing in this rapidly evolving field. While the VRDDO effectively formalizes the key structural elements necessary for VR dashboard design (an endurant perspective), less emphasis was placed on modeling dynamic, time-based interactions (a perdurant perspective). Future research can enhance ontology by incorporating dynamic behavior modeling to address evolving user interactions and real-time data visualization needs in VR environments.

VI. Future Work

Future research will focus on extending the Virtual Reality Dashboard Design Ontology (VRDDO) to incorporate perdurant perspectives, enabling dynamic modeling of time-based user interactions, adaptive interface behaviors, and evolving data visualization within VR environments. By integrating concepts that represent events, processes, and temporal affordances, the ontology can better capture the fluid and interactive nature of immersive VR experiences. Additionally, empirical validation across multiple domains such as healthcare, education, and urban planning will be conducted to evaluate the adaptability and effectiveness of the enhanced VRDDO framework. This progression aims to transform VRDDO into a comprehensive standard for both static and dynamic VR dashboard design across diverse applications.

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