Exploration of the Digital Twin for Prototyping the Product-Service System Design in a Bus Manufacturing Company

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Abstract. When bus manufacturing companies move forward in their servitization journey for providing service solutions for tourism industry, there is an increasing need to exploit the prototype way to support the realization of design solutions in the early stages of the Product Service System (PSS) design. Digital twin, a new emerging and fast growing technology which connects the physical and virtual world, has attracted much attention worldwide recently. This paper presents a new method for PSS design based on the digital twin approach. The development of product design is briefly introduced first. The framework of digital twin approach is then proposed and analysed. The main work in this research work is how to trade off the 'realism' of the design output of the virtual concept. A case is presented to illustrate the application of the proposed DT approach for product prototyping. Verification activities performed the case in a virtual simulation environment prototype the design concepts in the tourism industry.

Keywords: Digital Twin (DT) · Prototyping · Product Service System (PSS) · Service scenario · Tour bus

1 Introduction

The ongoing digital servitization transformation is pushing manufacturing companies to adopt innovative approaches to manage product development process with customers (Struwe and Slepniov, 2023). Manufacturing companies that were traditionally perceived as product-centered are today increasingly influenced by a service-oriented theory, which claims that manufacturing companies are driven to shift their business focus towards a strategy where customer-perceived value is in the spotlight and where products are bundled with services to offer Product-Service Systems (PSS) (Goedkoop et al., 1999). The industry companies need to move "downstream" knowledge from the entire lifecycle into the early phases of the PSS design process where critical decisions are made (Morelli 2006). At the same time, this raises the awareness of, and requirements for, a new emerging methods that support cross-disciplinary team collaboration in the process of designing and prototyping these PSS solutions. Digital twin (DT) consists of three parts: physical product, virtual product and the linkage between physical and virtual product

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(Glaessgen and Stargel 2012). Building on such a gap, the paper aims to present an DT approach that allows the integration of the PSS design along with the service operational context for prototyping the concepts of the PSS (Furr and Dyer 2014). The intent is to enable the bus manufacturing industries to leverage the use of DT in their early design phase to make decisions on both, PSS design features and service operational strategy, ultimately enabling the prototyping of the potential impact of the transition toward digitalization of tour bus in terms of scenario performance, operational cost, and environmental impact. This paper's research question can be described as: How can product concepts be prototyped using digital twin in the early phase of product service system design?

The paper exemplifies the approach by scenario it in a tourism natural environment describing how the DT have enabled PSS concept design and prototype develop, and how prototype of service solutions is integrated into the digital twin of the operational scenario. The last section summarizes the main content, contribution, limitations, and future perspectives.

2 Research Approach

The research was conducted with guidance from the framework of Design Research Methodology (DRM) proposed by Blessing and Chakrabarti (2009) and is based on a single-Case Study Research (Yin 2014), which has also influenced the research approach in this work. First, the research motivation was clarified by reviewing the literature on PSS design and digital twin (DT), which provided a deeper understanding of the challenges and existing gaps in current research. The research question was defined in collaboration with a bus manufacturing company that designing tour bus for tourism industry applications. The initial dataset was collected through the case company and has been modified and complemented with realistic data and application environment in a nature tourism scenario. The digital twin model and systems simulations have been run using commercially available software. 3D gaming engine/Computer-based simulations. These data were used in the research to create preliminary demonstrators of digital twin, that were discussed with a cross-disciplinary group of experts having knowledge in engineering design, vehicle design, product planning and virtual prototyping). The verification of the impact of the Prescriptive Study results (the digital twin approach) corresponds to the 'Application Evaluation' phase of the DRM.

3 Scientific Background

3.1 Product Service System

A PSS is a marketable set of tangible products and intangible services that together can fulfil a customer's needs (Goedkoop et al., 1999). Product-Service Systems (Mont, 2002) is one of the industrial trends representing the shift in manufacturers' strategic focus from selling a physical product to providing performance and availability, as a way to satisfy more sophisticated needs and expectations (Baines et al. 2007).From the literatures, PSS has been categorized into three needs and expectations (Baines et al. 2007). From the literature, PSS has been categorized into three different groups by product ownership and type of service provided as follows (Tukker and Tischner 2006):

- Product-oriented PSS: Products are sold to the user, but additional services are added, such as maintenance or product-related consultancy.
- Use-oriented PSS: The business model is geared toward selling the product function through leasing or renting, and the product remains under the ownership of the PSS provider.
- Result-oriented PSS: The business model is geared toward selling a result and is closest to offering a pure service where no predetermined product is involved.

PSS are increasingly seen as business strategies created by companies that intend to strengthen their market position and create a competitive advantage through traditional transactional product sales. PSS emerged as a response to make both production and consumption sustainable, for example, by reducing waste by reuse, remanufacturing, and repair, similar to the contemporary recommendation of a circular economy to guide sustainable development. Despite the promises of PSS, manufacturers continue to struggle for optimized financial performance by integrating products and services. The existing research argues that this is largely due to the insufficient theoretical exploration in the manufacturing industry and the lack of a systems approach in PSS design (Rondini et al., 2017).

3.2 Prototyping for Design

The concept of prototyping is to gather information to help in the decision-making process of design creation and inter-disciplinary design, prototypes have a unique capability for enabling sensemaking between stakeholders with differing domain vocabularies by creating a "common language" (Exner 2016). Experiential prototyping techniques endeavor to accomplish three goals towards addressing the problem: understanding existing user experiences and context, exploring and evaluating design ideas, and communicating ideas to an audience (Buchenau et al., 2000). Furr and Dyer assert that rapid prototypes have a fundamental role in hypotheses validation (2014). They also discovered that in some cases it can be beneficial to fake the capability of a product if the experience is your key point of investigation (Furr and Dyer 2014). Prototypes enable sensemaking in design process via the following properties (Exner 2016):

- A prototype visualizes mental ideas
- A prototype supports the comprehension of complexity
- A prototype enables communication, thus removing cultural and linguistic barriers
- A prototype always contains a specific question and is limited due to given constraints
- A prototype tests functionalities and requirements.

3.3 Digital Twin for PSS Design

The concept of digital twin (DT) can date back to Grieves's description about Product Lifecycle Management (PLM) in 2003 (Grieves 2014). Rosen et al. believe that digital twin is the model which can interact between autonomous system behaviours and the environment in the physical world (Rosen et al. 2015). DTs are increasingly developed and used to integrate multidimensional simulation and support decision-making in complex situations (Tao et al., 2019). The applications of DT in the realm

of products (Erkoyuncu et al., 2020), services (Stark et al., 2019), and product-service ecosystems (Tao et al., 2018). While a majority of the applications of DT are in the manufacturing/production-related (Jones et al., 2020). DT also seems to facilitate multi-disciplinary and heterogeneous simulations of complex systems, especially enabled by the building block correspondence of Model-based Systems Engineering (Schluse et al., 2017; Clement et al., 2017). Anchoring the inferences from these studies, one trend was clear that the DT embraced a high-fidelity representation of the physical space. Such an approach may not be suitable for early-stage design decision-making that is typically subjected to many uncertainties. Thus, the empirical study primarily focused on the collection of needs and expectations for the use of DTs in the early stages. More specifically, the focus was to utilize DT to enhance the design space exploration to the PSS level (comprising of the systems, the associated services, and the application environment), and finally to the scenario level (i.e. including the simulation of different operational context) (Bertoni et al., 2022).

Not much attention was paid to make use of digital twin in the first stage of product creation (i.e. the design stage). As pointed out and stated by Dassault, there is huge potential of digital twin in product design (Digital Twins 2015). In addition, if one could establish the product digital twin mode from the design phase, then more related design data, marketing data, user experience data, etc., can be integrated into the product digital mode, and this will result in better serve for the product prototype stage and operation stage (Bertoni and Ruvald 2021).

4 Result: The Proposed Digital Twin Approach for Prototyping

This study's main contribution is to develop the digital twin approach based on the data-driven method and to integrate it into the product development process for prototyping PSS design. To demonstrate the different types of data, application methods and software system collaboration support of digital twin in the product development of PSS design. To demonstrate the different types of data, application methods and software system collaboration support of digital twin in the product development process. Ultimately, both academia and industry can learn how to apply the digital twin approach for prototyping of PSS design. The digital twin approach for prototyping the PSS was developed by the authors in previous research that built on a comprehensive literature review of relevant PSS design methodology and digital twin presented in Sect. 3. The digital approach is structured in a framework based on the product development process to ensure broad adoption in manufacturing companies (see in Fig. 1 below). The development and deployment of the DT in the framework consisted of the combination of different types of modules and virtual simulations at different levels of granularity that provide input and output to each other, respectively. Figure 1 shows the logical structure of the DT comprising of the PSS system and virtual prototype models connected hierarchically (scenario-, product-, feature-prototype). **The DT approach** requires selecting a PSS type for designing (Tukker and Tischner 2006). First, select the PSS category based on the high level of product development from three categories: **Product-oriented, Use-oriented, and Result-oriented.** Then value data needs to be collected for creating digital twin of product, and there are three categories of data should collect. For the collection

of different types of data: scenario data, product data and feature data. The scenario data collect from different stakeholders, the product data from bus manufacturers, and the feature data from the supply chain. These three types of data mentioned above into the digital twin approach through the gaming engine, Unity 3D. The all three types of modules need to be developed as 3D modules and be bounded in virtual environment. Therefore, the data output of DT approach can generate three types of prototypes for decision making of PSS design, the result of prototype ensure data authenticity and usability from prototype simulation to data input during the product development process.

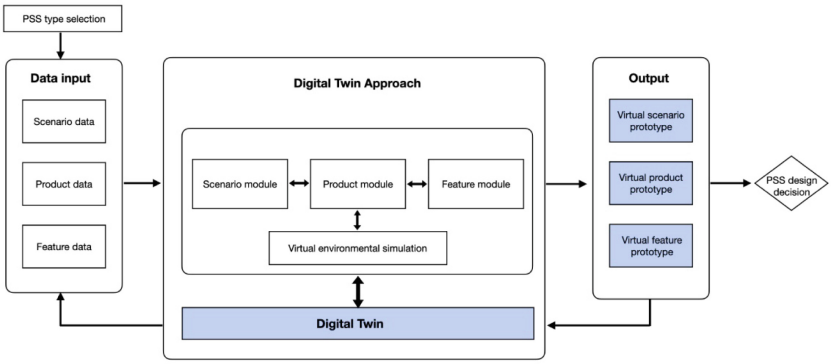

Fig. 1. Framework of digital twin approach for PSS design prototyping.

4.1 Application Case: Prototyping a Tour E-bus Concept for Tourism Industry

Smart E-bus have gradually become the direction of product development and competition in the automotive industry, and new product development methods are transforming towards by applying emerging tools and approaches of digitalization and intelligence. The global bus manufacturing company-King Long Group is also facing the challenge of the bus manufacturing industry needs to adapt to the tourism industry's demand for buses to provide diversified customer-oriented scenarios during nature tourism. It also requires tour buses to provide digital service capabilities for tourists during the journey. It is necessary to develop a virtual prototyping system for user usage scenarios based on King Long's product development platform using emerging technologies such as digital twin, simulation tool and AI, and provide data driven method in the early stage of the development of tour bus. Quantitative data analysis support is provided to ensure the competitiveness of new products and services in tourism service industry as smart products (smart cockpit + digital service), and at the same time applied the method and approach to the design and development of service solution for tourism service.

Creating Digital Twin via Data-Driven 3D Module. In this case, follow the framework of digital twin approach (see in Fig. 2 below). First, the digital twins are developed based on the King Long's tour bus product platform by research team. By using gaming engine, Unity 3D, the design team could develop 3D virtual models of bus products,

including (exterior, interior and cockpit components, interface and passenger character models, etc.). When developing digital twins, it is necessary to comply with from the virtual environment level, such as (operation environment model, transportation systems and natural environment models) to meet the physical and activities requirements of scenario side cockpit components, interface and passenger character models, etc.). When developing digital twins, it is necessary to comply with from the virtual environment level, such as (operation environment model, transportation systems and natural environment models) to meet the physical and activities requirements of scenario simulation. For the product definition, such as develops product key systems of (product appearance, product cockpit, cockpit interior materials, product chassis and battery systems, etc.). For the feature definition, such as (component detail models, functional actions and interactive effects, components) can be grouped or separated for creating independently. The digital twin development is based on combining different types of data into the product 3D models. These data come from three categories: **scenario data, product data and feature data**. In the case, the scenario data is collected and analyzed by researchers through tourism industry data and interviews and collation of product positioning with internal stakeholders of local tourism company in. Product data and feature data comes from product data provided by King Long's R&D department. The three types of data have saved by researchers into Excel format as the input for creating digital twin. This step explores the method of combining the different types of data inputs by digital twins during the product development phase. It also allows product managers and design engineers within bus manufacturing company to see the visualization of the product concept as soon as possible to facilitate collaborative innovation works.

Verification of Design Concepts from Digital Twin. When evaluating the concept, product managers and design engineers first need to select a specific scenario from the scenario list from the approach (see in Fig. 3 below). Taking the bar scenario as an example in case, the description of the scenario, user needs and user tasks are all derived from market research data, allowing design engineers to have a common understanding and consensus on the scenario. Then the value dimension needs to be assigned a value, which is summarized into two categories: functional value and non-functional value. There are 6 value dimensions in total (Eco-friendly, Flexibility, Comfortability, Digitalized, Profitability and Total cost). Product managers and design engineers can adjust the value weight from 1 to 10 on the simulation interface, and the simulation system will set down the weights for each value dimensions. At the same time, the system uses EVOKE model proposed by Bertoni et al. (2018) to calculating the value evaluation score of the product. For example, the total score for the bar scenario concept = 7.7. The highest overall value score is Profitability = 8.96, followed by Eco-friendly = 8.37 and Flexibility = 8.12. This bar scenario consists of 10 feature items, and the system sorts the features list automatically. Product managers and design engineers can make decisions and analyze design options based on the result of value scores and chart analysis. At the same time, through digital twins, the virtual engine is directly rendering the 3D visualization solutions of the scenario model and product model. The design teams can interact with digital twin design concept from digital interface of the digital approach.

The scenarios and product design concepts completed can be brought into the virtual environment for concept verification through simulation tool. Product managers and

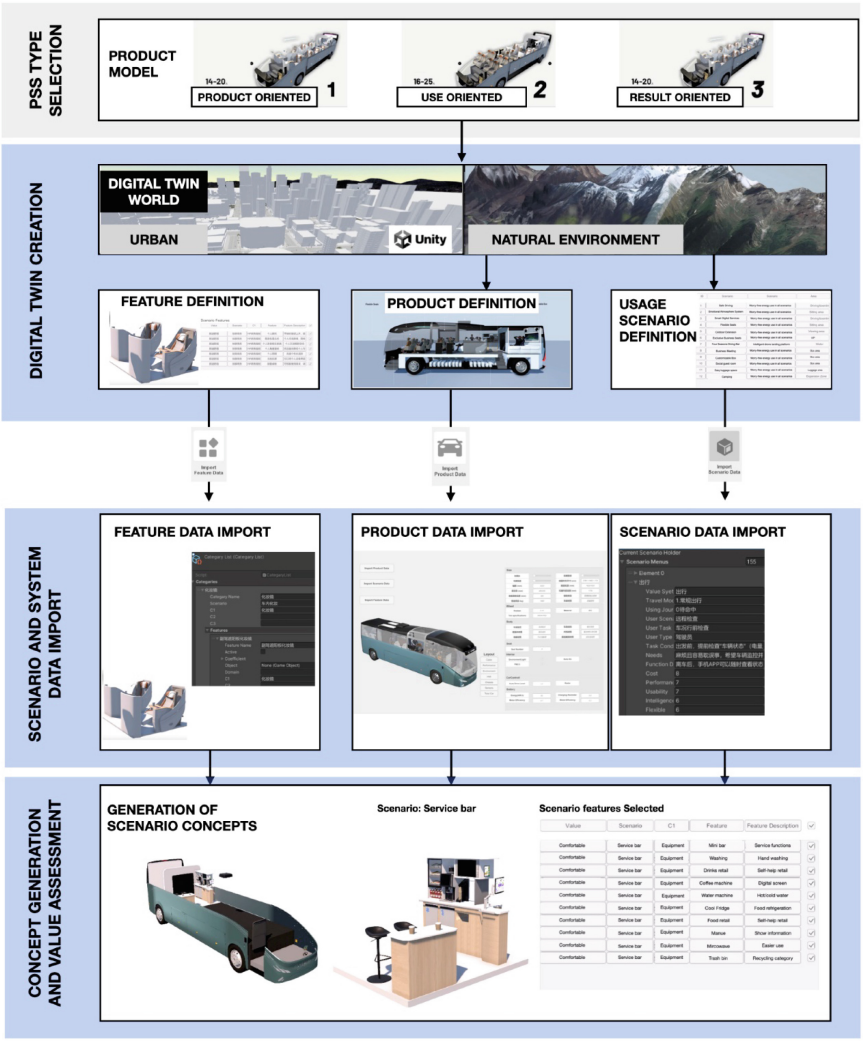

Fig. 2. The framework of the digital twin approach in early phase of tour bus development, King Long case.

design engineers will open the virtual environment in front of the big screen to verify the operational plan in a virtual natural environment in national park. During the simulation, the three visualized prototype modes (**Scenario, Product, Feature,** prototype**) of** the simulation vision can be adjusted to meet different visual needs and graphics performance for large-scale hybrid simulations. In the **Scenario prototype**, you can adjust the impact of factors such as (total service time, total customer number, energy consumption and CO2 saving, etc.). In the **Product prototype**, it shows that the (detailed interior materials of the vehicle cockpit, the passenger behaviours of objects and characters). Hence, the **Feature prototype** shows such as (air conditioning temperature adjustment,

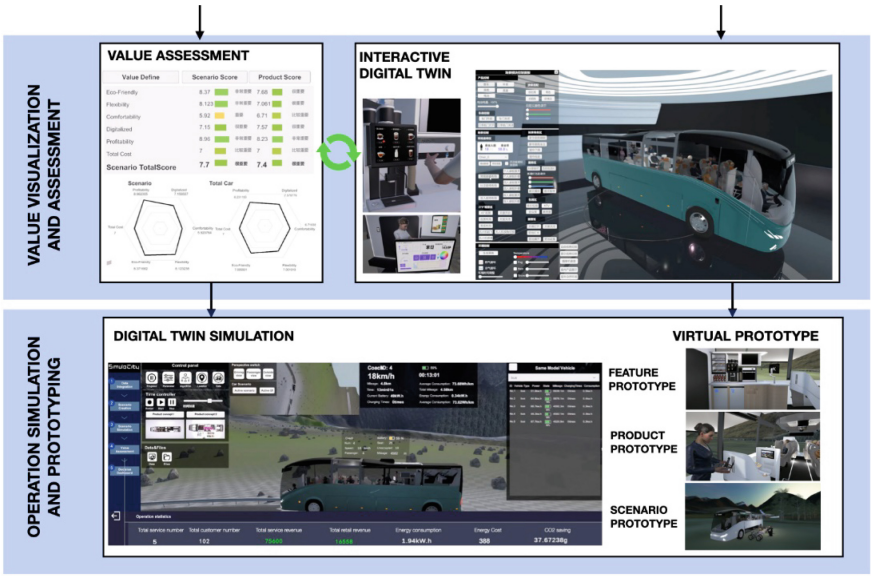

Fig. 3. The framework of the digital twin approach in in early phase of tour bus development for PSS simulation and prototyping, King Long case.

volume, screen con as (air conditioning temperature adjustment, volume, screen content and character movements, etc.). The virtual prototype makes product managers and design engineers interact with scenario performance, service process and customer usage effects in the customized tourism scenarios through digital twin of 3D prototyping. The virtual prototype makes product managers and design engineers interact with scenario performance, service process and customer usage effects in the customized tourism scenarios through digital twin of 3D prototype.

5 Discussion

The current recent research, and scientific literature have repetitively highlighted the potential of digital twin, data-driven decisions for providing a new way of approaching product development in the manufacturing industry. Nevertheless, when designing the product and service in the early design phase of PSS, there are many decisions are still made based on industry experience, intuition, and forward-thinking of engineers, managers, and decision-makers. The digital twin approach presented in this paper is a step toward a more extensive i, there are many decisions are still made based on industry experience, intuition, and forward-thinking of engineers, managers, and decision-makers. The digital twin approach presented in this paper is a step toward a more extensive integration of prototype into the early conceptual design of PSS. At same time, the value visualization of prototype can reduce the uncertainty concept selection in product development process. This paper demonstrates and discusses how the digital twin approach can participate in the early design and decision-making process of tour bus through a case of

a global car company. For the bus industry to use digital twin technology in the design process, and this will help bus company's participators can easier understand and use this approach to design solutions for tourism industry. At the same time, it is necessary to use 3D visualized prototyping to show the service performance and operation results of the design concept in the virtual environment for decision-making. Allow tourism industrial stakeholders and decision-makers to improve the accuracy and objectivity of decision-making through value visualization during the subjective decision-making process.

As the verification for the digital twin approach for prototyping, the researcher conducted a user-focused evaluation by conducting a usage evaluation form for this approach in the case company, and statistically analyzing the results of the scoring form to conduct an evaluation. The evaluation results are evaluated through qualitative user feedback and suggestions on improving the approach. As a result, the design team in bus company also see that the digital twin approach is recognized as a convincing visual prototyping approach. The digital twin as the new way of prototyping the PSS design has only been promoted in the industry recently, and there is a lack of successful cases that have come about through effective approach and tools to prove the product development process changes brought by the digital twin. There is still room for improvement in the way of the digital twin prototyping the PSS concept.

6 Conclusion

This paper addresses the introduction of a digital twin approach for prototyping the PSS design in manufacturing industry. The paper introduces digital twin approach as the prototype tool to promote the product development process in a bus manufacturing company. A digital twin approach that supports prototyping in PSS design is proposed and developed. The approach has been described through the case of the development of tour bus in the early design phase for King Long to address digitalization and servitization transformation challenges. This paper has introduced and vitrificated the result of digital twin approach apply with the case company in the tourism scenario of a national park. Future research will try to apply the digital twin approach to prototype the concept for more service industries, which have relatively higher design requirements for completeness of service solutions, customer scenario, and total value creation for service companies.

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