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# Boosting Value Co-creation in the Road Construction Industry through Virtual Prototyping

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**Abstract.** When construction companies move forward in their servitization journey, there is an increasing need to exploit digital tools and models to facilitate the complex and dynamic interactions between entrepreneurs, customers, equipment manufacturers, energy providers and more during the early stages of the construction project design. This paper presents the application Augmented Reality (AR) and Virtual Reality (VR) applications to create distributed ‘experience environments’ for value co-creation in the road construction industry, where to foster participation of all the stakeholders in the needs identification process and the trade-off of the value drivers of the project. After presenting the modelling approach pursued in the work, the lessons learned gathered from preliminary verification activities are presented, pointing to future work in the field.

**Keywords:** Virtual Reality, Augmented Reality, Virtual Prototyping, road construction, Servitization, Product-Service Systems.

## 1 Introduction

Over the last decade, plenty of companies across heterogeneous industrial sectors have started to reconsider how they conduct their business, typically by increasing customer orientation and evolving the way in which the offer of products and services is developed, integrated, and delivered [1]. The construction industry is no exception to this phenomenon. Technological developments and the need to adopt more efficient and sustainable production processes are leading to changes in traditional business models [2].

When construction companies move forward in their servitization journey, they are increasingly relying on developing digitalization capabilities to interact and co-create value with their customers. Yet, despite the common view of the industry is that digital tools can be applied both at the ‘front-end’ and ‘back-end’ of the development process - to boost and improve the extent of servitization and deliver more value to customers – their application in the earliest stages of the process is still limited. Digitalization is seen mostly as an ‘end product’ of the servitization journey – i.e, the creation of digitally-enabled services to enhance productivity and sustainability [3] –

rather than a tool in the hands of the engineer to ‘intentionally design’ value-adding solutions and Product-Service Systems. One major aspect of interest is the use of digital tools and models to facilitate the complex and dynamic interactions between the different actors taking part in the early planning and design stages of construction projects. Entrepreneurs, customers, equipment manufacturers, energy providers and more are required to be active in the discussion and share their knowledge when alternative construction strategies are generated, evaluated and benchmarked, so as to identify the solution concepts that can deliver the highest possible value for all parties. Of particular interest to foster value co-creation during the front-end of a construction project is the use of digital means for the creation of ‘experience environments’ (see: [4]). Augmented Reality (AR) and Virtual Reality (VR) applications are of interest to enhance the participation of stakeholders to support multi-disciplinary needs identification, and to prioritize among heterogeneous value drivers during trade-off studies and concept selection [5].

The main aim of this paper is to present the results from the development of a prototype of such an experience environment in a case study involving a major road construction equipment manufacturer. Its objective is first to present the design of such an environment for value co-creation in relation to the need expressed by the company’s stakeholders. The paper describes the modelling approach pursued in the research work, presenting its application in the selected case study. Finally, this work presents lessons learned from preliminary verification activities with the partner company, pointing to future work for this case study and in the field.

## **2 Theoretical Framework: The Role of AR and VR for Value Co-creation**

Digitalization is acknowledged as a viable path toward addressing increasingly complex and dynamic customer interactions [6]. More in detail, Lenka et al. [7] spotlight how digitalization can leverage the analytic capability of manufacturing firms. This is described as the ability to transform the data available at hand into predictive insights and actionable directives that have operational value for the organization.

The constant inflow of data from intelligent and connected products can be exploited in a customer-centric simulation environment to assess and visualize the value of different design options. These simulated scenarios help in experiencing critical interdependencies before a solution is realised ‘in the field’, hence testing the levers that firms can use to optimize customers’ key performance indicators.

Together with other Industry 4.0 technologies, AR and VR have shown to be effective tools to support value co-creation through inter-firm collaboration, creation of new services, customization of services and products, and long-term relationships with customers [8]. VR and AR applications have been successfully applied, for instance for training and remote maintenance as part of a Product-Service System [9,10].

VR and AR have been extensively used to facilitate cooperation and value co-creation among practitioners, overcoming physical distances and improving creative expression [11]. They can also empower customers in co-creation activities by

providing platforms enriched with participatory elements [12]. Mixed reality technologies (combining AR and VR) are acknowledged to be transformative means to actively engage clients, strategically affecting their brand perception and satisfaction [13]. These opportunities could be exploited in design, purchase, factory planning, and more in general, in any decision-making context, especially in collaborative situations [11,13,14].

In fact, there is a growing interest in using VR in Computer Supported Cooperative Work (CSCW) systems, especially in design processes, due to the possibility to share information and knowledge, make decisions and review results [15]. The use of VR environments for CSCW appears to be more mature for remote and synchronous collaboration. However, different devices and AR/VR technologies have shown potential for different types of collaboration modalities in the CSCW framework.

Digitalization in general – and AR/VR in particular - are of great interest to cope with the complexity of co-creation processes, decreasing the risk of interpretative ambiguity associated with the different stakeholders' knowledge and expectations. AR/VR applications make it possible to visualize phenomena in a way that different perspectives can be easily integrated, mainly thanks to their interactivity, editability, associability and distributed nature [14]. Users can share and actively manipulate virtual models, simulating the outcomes of proposed changes in real-time. Hence, VR and AR tools can enable companies and customers to identify possible problems and solutions together at an early stage, improving efficiency, success rate, and profitability of co-creation activities.

One of the industries for which VR and AR collaborative environments can be beneficial is the construction sector. They can be exploited to deliver new and better services, improving collaboration, projects understanding and performance. Moreover, their use can be strategic also to improve the company's image, boosting its reputation as a smart solutions provider [16]. In particular, one of the major identified trends in this area regards construction project management, while an emerging one concerns construction equipment [17]. The former stresses collaborative aspects, while the latter includes the design, planning, selection and monitoring of equipment (e.g., excavators and trucks). The intention of this work is to integrate common aspects in both topics.

### **3 An Experience Environment Using Visualization and Interactive Scenario-based Analysis for Value Co-creation**

#### **3.1 Case Study**

The case study company is a world-leading total-solution provider of articulated haulers, wheel loaders, excavation equipment, road development machines, and compact construction equipment. The company business is facing rapid transformations, largely driven by several macro trends, including electrification, digitalization, connectivity, artificial intelligence and sustainability.

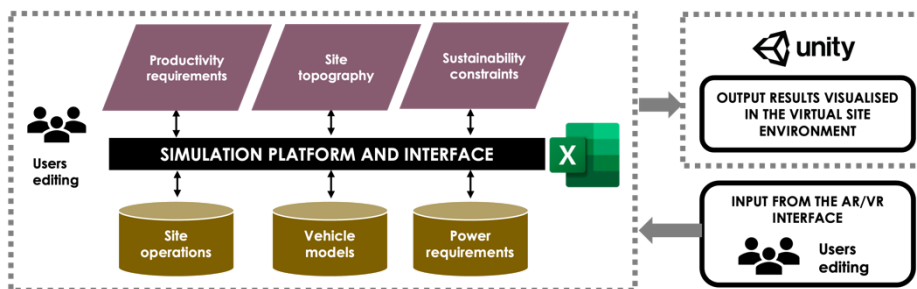
The major need highlighted by the company's stakeholders concerned the potential to present and discuss design choices and their impact on the context of use (i.e., construction sites). This includes, for instance, how a machine or system design choice can affect the possibilities for site optimization. At the same time, desired changes in a site layout and operations could be enabled or hindered by design decisions. Having an overview and understanding of possible advantages and disadvantages in the integration of different product development and site planning strategies requires merging and visualizing multiple stakeholder perspectives.

In particular, the case study has investigated the conditions for carrying out a major emission- and fossil-free infrastructure project in south-western Sweden. The overall goal was to develop a decision support environment that could operate throughout the entire value chain of the project to evaluate alternative construction strategies and boost value co-creation, by fostering the active involvement of customers, contractors and machine/system suppliers in decision making. The proposed VR application is part of such an environment, its main goal being that of supporting the visualization of the results of the underlying scenario modelling work, hence facilitating the interaction between the stakeholders in the project while making decisions.

### 3.2 Integrating VR with Simulation Models

The proposal is to use a virtual experience environment as a platform for output results and visualization, as well as a model interface. Objects and events in the environment are editable in two ways. First, models features' and behaviours, as well as contextual factors (e.g., site, material flows) and requirements (e.g., productivity, sustainability) derive from updatable external data platforms, secondly, they can be further modified by choices made by users interacting with the application interface, displaying the output result in a VR environment

A draft of the VR application was developed together with practitioners from the company. The aim is to support the company practitioners' and customers' decision-making, displaying the value of innovative solutions in the transition towards fossil-free and autonomous systems. In order to achieve such an aim, the VR application works both as an input and output interface between the simulation platform and the users and as a visualization solution for output results in the virtual environment.



**Fig 1** Requirements and simulation/models can be edited by the users through the simulation platform and interface and the VR environment's interface. Output results are displayed in the visualization environment.

The interaction between the VR application and the simulation models is visualized in Fig. 1. Here the users' interaction in the VR application can serve as input for three types of simulation models, namely the vehicle simulation model, the site operation simulation model and the power simulation model.

The vehicle simulation model represents the mechanical feature and behaviour of a single machine and it encompasses various configurations and control strategies via mathematical optimization such as linear, quadratic, stochastic, and/or dynamic programming, and/or heuristics. The site operation simulation models evolve over time via discrete event simulation representing vehicles and material flows in a construction site for a predefined time window using the system configuration and control strategies. The power simulation models assess the needs for power delivery and distribution to the construction site in predefined time windows (e.g. the stress on the electrical network while charging multiple vehicles simultaneously). The simulation platform integrates contextual variables such as site topography, productivity and sustainability constraints, all variables that impact simulation results and that can be negotiated or traded off when planning for alternative construction site design. The VR application is linked to the simulation environment to facilitate such multi-dimensional trade-off decisions by both providing an effective way of communicating results to multiple decision-makers and by enabling scenario-based analysis of the results by allowing an interactive interface for modifying contextual variables and site operations variables.

## **4 Prototype Implementation**

### **4.1 Generation of the 3D Virtual Environment**

The first step in the development of the application was the selection of a real physical environment as a case study. In this case, the case study was based on a road construction site located in south-western Sweden, starting from available video material captured through camera drones. We isolated a stretch of about 16 km and individuated this specific stretch on Google Maps. Data from the map and video were integrated to design the 3D environment using Unity 3D (<https://unity.com/>). The environment was hence developed starting from terrain based on the 2D map (Figure 2) and edited as required by the images captured by the camera drone perspective (Figure 3).

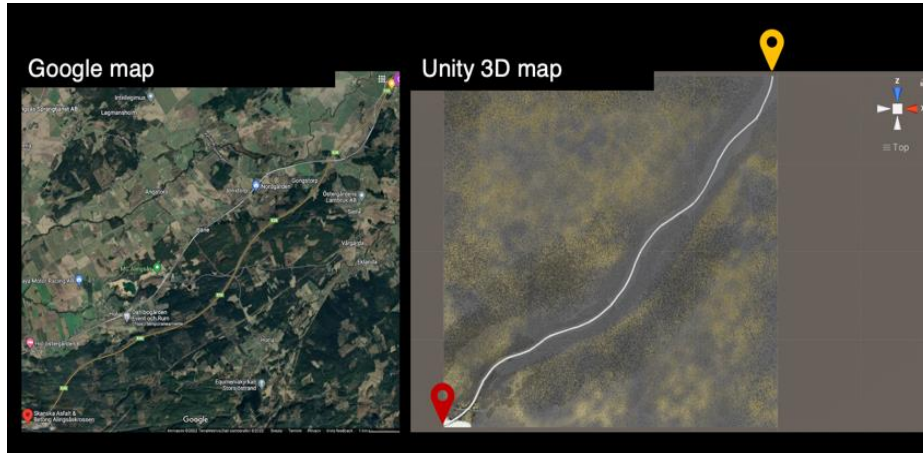


Fig. 2 Start and end points of the stretch of the construction road on Google maps and the corresponding path on the Unity 3D terrain.



Fig. 3 Screenshot from the camera drone video used to generate the virtual scene and the corresponding 3D virtual environment.

#### 4.2 Visualization Hypotheses and Interface Mock-up

The application will allow visualizing possible construction strategies integrating different system configurations merging products and site design. Relevant visualization data in the 3D environment and 2D map can include vehicles models, numbers, and paths, material and energy flows, the position and number of charging points and charging timing. Stakeholders could visualize the current system elements and layout, edit them, and generate a new scenario. A hypothesis of interface and settings was also integrated showing a possible input component can be seen in Figure 4.





**Fig 4** Application interface. On the right, is an example of a 3D view of vehicle paths. On the right, are possible factors to manipulate and simulate in the virtual environment .

This visualization framework is intended to be integrated with simulation models and external data platforms related to the various scenario, displaying system requirements, resources demand, operators needed, consumption data, financial, and overall sustainability impact of different alternatives. Finally, users would be able to set system constraints in terms of resource demand and consumption, individuating the optimal solution matching their overall needs and expectations. Specifically, they would decide the parameters to set as independent variables and see how they affect the whole system.

### 4.3 Industrial Feedback

The approach of integrating the simulation platform and the experience environment has been tested in an industrial pre-study featuring the design of a fully electrical construction site. The tool leverages visualization and interactive scenario-based analysis for collaborative generation, evaluation and comparison of new designs. This includes different aspects of product-service systems designs, construction sites and activities planning, to merge the stakeholders' perspectives.

The current 3D environment was presented to stakeholders from the industrial partner. The environment was explored as an output component through a camera view moving through the site and showing different perspectives. The user could visualize the top view showing possible material flows following machines (Figure 4) as well as close-up views of vehicles and construction areas following an operator through the site (Figure 5).



**Fig 5** The user can explore the site following a virtual operator showing the construction equipment and operations.

The study was developed as a proof-of-concept featuring a realistic setting and showed the potential to quickly forecast, in an early stage of development, the economic and environmental impacts of new machines and systems configurations. This capability is expected to consistently reduce the development time and the time to market for cost-efficient autonomous solutions based on electromobility in the construction equipment, speeding up the shift to a fossil-free industry, while, at the same time, lowering the environmental impact and delivering a safer workspace by moving away workers from the risky environment.

The next steps discussed with the company's stakeholders consist of the implementation of more specific case studies, starting from the identification of constraints and variables in decision-making processes. Some of the possible factors can be observed in the current interface (Figure 4).

## 5 Discussion and Conclusions

In this work, we presented the concept of a virtual experience environment value co-creation in decision making through the simulation, editing and comparison of possible system configurations for the construction industry.

The presented application is based on shared visualization of a simulated real environment, real-time manipulation and updates by integrating products and context requirements. This concept merges the advantages of VR in value co-creation, considering interactivity, editability, interoperability, and associability. The successful implementation of the application will require the integration of simulation models and external data. Interoperability aspects will be boosted by the implementation and integration of digital twins.

Moreover, there will be further investigation of visual information and interaction aspects. This includes experimenting with a variety of visual representations, graphic quality, and simulation realism and details. It can also include multisensory stimuli, different devices, input and feedback technologies, and user configurations. For instance, the design might vary considering in-presence and remote setups, haptic displays, immersive devices as well as AR versions.

Results from this activity will constitute a first proposal and testing platform for the company, as a means to improve communication with stakeholders and find converging objectives, shaping solutions in a collaborative and more efficient way. The current results highlight the potential and expectations for the system's concept for the case study. This positive outcome emerged throughout the collaboration with our industrial partner and from the feedback to the initial prototype. However, the effectiveness of the experience environment for specific decisions compared to traditional supports will be assessed in future works. The next steps will require additional discussion with the company stakeholders, to further develop the prototype according to the decision processes to investigate and compare. Moreover, further studies should consider situational factors like the number of decision-makers involved, their expertise, as well as time constraints and collaboration modalities in the CSCW framework.

Future development will also include more efficient modelling and generation of the 3D environment, directly from data acquired by camera drones, since the current method is not suitable to support large infrastructure models.

An experience environment can work as a 'boundary object' for value drivers trade-off in complex system planning and design, adding to value models [18] visualization and interactivity levels, allowing a more effective representation and understanding of value and activity flow in collaborative contexts.

Importantly, there are several aspects to be considered beyond the technology and design ones. The development and integration of similar tools with the company's business and practices will require further reflection on the new emerging roles and interactions for customers and service providers, to fully enable the potential of mixed reality tools for value co-creation.

Finally, the problem identification, the requirements definition, and the investigation of the rationale and logic of the presented approach have been performed in collaboration with a single company, thus those can be subjected to the traditional biases of single case analysis. Future case studies on the use of integrated VR environments and simulation models to support value co-creation will be extended to other companies and businesses to gain more insight into the potential of these tools according to various contexts and emerging needs.

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## References

1. Kamp, B., & Parry, G. (2017). Servitization and advanced business services as levers for competitiveness. *Industrial marketing management*, 60.
2. Goulding, J. S., Pour Rahimian, F., Arif, M., & Sharp, M. D. (2015). New offsite production and business models in construction: priorities for the future research agenda. *Architectural engineering and design management*, 11(3), 163-184.
3. Galera-Zarco, C., & Campos, J. A. (2021). Exploring Servitization in Industrial Construction: A Sustainable Approach. *Sustainability*, 13(14), 8002.
4. Bu, L., Chen, C. H., Ng, K. K., Zheng, P., Dong, G., & Liu, H. (2021). A user-centric design approach for smart product-service systems using virtual reality: a case study. *Journal of Cleaner Production*, 280, 124413.
5. Bertoni, M., Bertoni, A., & Isaksson, O. (2018). Evoke: A value-driven concept selection method for early system design. *Journal of Systems Science and Systems Engineering*, 27(1), 46-77.
6. Lerch, C., & Gotsch, M. (2015). Digitalized product-service systems in manufacturing firms: A case study analysis. *Research-technology management*, 58(5), 45-52.
7. Lenka, S.; Parida, V.; Wincent, J. Digitalization capabilities as enablers of value co-creation in servitizing firms. *Psychol. Mark.* 2017, 34, 92–100.
8. Bonamigo, A., & Frech, C. G. (2020). Industry 4.0 in services: challenges and opportunities for value co-creation. *Journal of Services Marketing*.
9. Scurati, G. W., Gattullo, M., Fiorentino, M., Ferrise, F., Bordegoni, M., & Uva, A. E. (2018). Converting maintenance actions into standard symbols for Augmented Reality applications in Industry 4.0. *Computers in Industry*, 98, 68-79.
10. Riboldi, N., Scurati, G. W., Ferrise, F., Bordegoni, M., & Pedrini, S. (2020). Improving Maintenance Services through Virtual Reality. In *Manufacturing in the Era of 4th Industrial Revolution: A World Scientific Reference Volume 3: Augmented, Virtual and Mixed Reality Applications in Advanced Manufacturing* (pp. 49-72).
11. El-Jarn, Hatana, and Glen Southern. "Can co-creation in extended reality technologies facilitate the design process?." *Journal of Work-Applied Management* (2020).
12. Zhang, Tingting, Can Lu, Edwin Torres, and Cihan Cobanoglu. "Value co-creation and technological progression: a critical review." *European Business Review* (2020).
13. Cuomo, M. T., Tortora, D., Festa, G., Ceruti, F., & Metallo, G. (2020). Managing omni-customer brand experience via augmented reality: A qualitative investigation in the Italian fashion retailing system. *Qualitative Market Research: An International Journal*.
14. Kostis, Angelos, and Paavo Ritala. "Digital artifacts in industrial co-creation: how to use VR technology to bridge the provider-customer boundary." *California Management Review* 62, no. 4 (2020): 125-147.
15. Pedersen, G., & Koumaditis, K. (2020, July). Virtual Reality (VR) in the Computer Supported Cooperative Work (CSCW) Domain: A Mapping and a Pre-study on Functionality and Immersion. In *International Conference on Human-Computer Interaction* (pp. 136-153). Springer, Cham.
16. Delgado, J. M. D., Oyedele, L., Beach, T., & Demian, P. (2020). Augmented and virtual reality in construction: drivers and limitations for industry adoption. *Journal of Construction Engineering and Management*, 146(7).
17. Zhang, Y., Liu, H., Kang, S. C., & Al-Hussein, M. (2020). Virtual reality applications for the built environment: Research trends and opportunities. *Automation in Construction*, 118, 103311
18. Panarotto, M., Bertoni, M., & Johansson, C. (2019). Using models as boundary objects in early design negotiations: analysis and implications for decision support systems. *Journal of Design Research*, 17(2-4), 214-237.