Digital Twin as enabler of Business Model Innovation for Infrastructure Construction Projects

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Abstract

Emerging technologies and methods are becoming an important element of the construction industry. Digital Twins are used as a base to store data in BIM models and make use out of the data respectively make the data visible. The transparency in all phases of the lifecycle of building and infrastructure assets is crucial in order to get a more efficient lifecycle of planning, construction and maintenance. Whereas other industries increased performance in these phases by making use out of the data, construction industry is stuck in traditional methods and business models. In this paper we propose a concept that focuses on the digital production twin. The comparison of planning data with As-Is production data can empower a data driven continuous improvement process and support the decision-making process of future innovations and suitable business models. This paper outlines the possibility to use the data stored in a digital twin with regards to the evaluation of possible business models.

Keywords –

Digital Twin; Business Model Innovation; Infrastructure; Decision-Making

1 Introduction

Delays and cost overruns are frequent in infrastructure construction projects. Only around 25% of construction projects worldwide have come within the range of 10% of their original deadlines from 2012 to 2014 [1]. Globally, rail construction projects are frequently affected by budget and schedule overruns by an average of 44.7% [2]. Whereas other industries almost doubled their productivity over the past decades, the construction industry remained the same [3]. Research has shown that these 75 % of the projects that overrun schedule and costs end up 14 % above the estimated contract sum [4]. Considering railway construction projects, short durations for maintenance as well as new instalments are crucial to avoid a breakdown of the railway network. Otherwise, time overruns are often fined with high penalties [5].

Traditionally, one of the biggest issues is the usage of static schedules that do not reflect real conditions on-site [6]. As a result, schedules become useless and coordination is based on improvisations. Furthermore, progress tracking is often based on rough estimations and thus schedule deviations are not known in detail. Scheduling is usually done according to the experience of the project or site manager and not based on the monitoring of the construction progress. Thus, it is very difficult to identify bottlenecks, as for example a machine that reduces speed and thus leads to a potential decrease of productivity of the following construction processes.

As a result of the previous mentioned issues, problems are often identified in a late stage making it difficult to implement appropriate improvement and innovation actions in time. Furthermore, infrastructure construction projects are loosely connected and improvements are not systematically stored or transferred to future projects [7]. Early identification of bottlenecks and a dynamic definition of improvement actions, innovation possibilities as well as their impact would decrease variability and thus reduce budget overruns. The infrastructure construction industry is seeking for answers to these problems to avoid time and cost overruns. New business models and innovation possibilities are necessary to empower future ways of creating revenue and decreasing variability on infrastructure construction projects.

Research and development are important areas for a company's future existence. Innovation is not only to be understood as the technical implementation of ideas, but the success of new products and system solutions must also include economic success on the market.

The use of digital twin-based approaches in infrastructure construction projects provides the opportunity to enhance efficiency and decision-making. The current focus lies on technical implementation, but in future a concept for value capturing is also needed in the future. This paper proposes a concept of business model innovation for value capturing in infrastructure construction projects. This paper investigates the possibilities of using data from a digital twin to support the decision making process and business model creation.

2 Literature Review

To determine the current status quo of digital twin-based approaches in the context of business model innovation and value creation for infrastructure construction projects desk and literature research were conducted. A research definition for digital twin in infrastructure construction projects was created and the role of digital twin solutions in Business is described.

2.1 Digital Twin - Definition

In literature the term "digital twin" is subject to different definitions, which makes a uniform description difficult. For instance, Klostermeier [8] generally describes the digital twin as the virtual image of a real existing object. Grieves [9] describes three elements that constitute a digital twin: (a) the physical product, (b) the digital twin, (c) the connecting information in between. In a broader sense, the digital twin can include material objects as well as immaterial objects like products, systems, services and processes. Thus, based on these two authors, the definition of the Digital Twin arises as a virtual image of a physical object, product, system, process, or service, in which the connecting information is intelligently available for a wide variety of applications.

Concerning to the construction industry, there is often discussion about the distinction between BIM - 'Building Information Modelling' and Digital Twin. According to Tang [10] BIM can generally only provide static data. In combination with additional connected information, BIM inputs data to the digital twin. Deng [11] describes 5 levels of BIM evolution to Digital Twins:

- Level 1: BIM (Concept, Design, Construction Scheduling…)
- Level 2: BIM+Simulation (FM Operation, Estimation, Sim-Based Prediction …)
- Level 3: BIM+Sensors (Real-Time Visualization, Real-Time Monitoring)
- Level 4: BIM+AI (Decision Making, Data-based Prediction)
- Level 5: Digital Twin (Control, Feedback, Optimization, Interaction)

In addition to the capabilities supported in Levels 1-4, the digital twin relies on the data connecting the physical object and the digital image and enables an intelligent feedback control system that allows optimised results and control strategies.

Deriving from this, this paper applies the following operational definition:

"*A digital twin for infrastructure construction projects is a virtual image of the physical construction site with a link of the planning data in comparison to the construction site execution data, which is intelligently available for control feedback and further value creation*".

The planning data is a set of the BIM models, the construction progress plans, logistics plans, etc. The process data relates to the data during the construction process and the construction progress data from, for example, IoT sensors or cameras on the construction site.

At present, digital Twin technologies have their main purpose in real-time data capturing and monitoring, decision-making and maintenance [12].

In the future, digital twin approaches must be applied to infrastructure construction projects and will enable new business opportunities in the infrastructure sector.

2.2 Business Model Innovation with Digital Twins

When digital twins are investigated through the lens of innovation, two approaches can be used: innovation as a process and innovation as an outcome [13]. If seen as an innovation process, a digital twin enables value creation via collaboration through the value chain [14]. If the focus is placed on innovation as an outcome, the utilisation of a novel product, service, process or business model forms the hotspot. In literature product innovation, service innovation, process innovation and business model innovation are prevalent [14]. Herewith, innovation always refers to the development of new products/ services/ processes/ business models, the modification of existing products/ services/ processes/ business models, and the change from one product/ service/ process/ business model to another. Holopainen [14] states that the "Digital twins' ability to synchronize the real and digital worlds also enables novel types of business model innovation, changing existing ways of operating".

With these innovations, new types of revenue streams can be explored. However, the current focus of research and implementation is more on the technology rather than the impact on the construction projects business models. According to Spang [15] little has changed in the partnership for infrastructure projects and the bidding and contracting process in recent years. New business models therefore have high potential in this sector and will also have a high impact to the hole industry.

3 Concept / Proposal

In this paper we want to focus on the digital production twin which contains the scheduling data. The basis which is created in the work preparation phase will be the basis for real-time data that is being collected while construction phase. This concept aims to perform a data-driven continuous improvement process captured within a digital twin solution respectively environment. The focus is on construction processes on railway construction projects.

The concept is based on Lean Management, which focuses on the improvement of the processes by defining and evaluating the Value Stream with a focus on Value-Adding activities and the elimination of waste which is defined as ‘any activity that does not add up to the products value’ [16]. The analysis of the whole value chain leads to an efficient end-to-end process. However, the authors will focus on the construction phase since the main business of the Rhomberg Sersa Railgroup is the construction of railway assets.

The evaluation of production tasks is the basis in order to emphasize improvements respectively to support the business with less variability within the construction phase. A structured way to collect As-Is production data is crucial in order to compare it with planning data within a Digital Twin. In general both datasets need to be aligned with their units and metrics to collect valuable insights for further business models and decision making process.

The proposed concept consists of the following elements:

1. Planning

The planning of construction processes is being conducted in a site simulation software in which the BIM model is the basis for the planning. The construction machines are getting imported into the software and the tasks are planned according to the movement and processes of the machines. The speed of construction is defined by the productivity rates and the experience of the foreman. The planning data is the basis for the digital production twin and can be used for the comparison.

2. As-Is production data gathering

While the construction phase, a structured way to collect As-Is production data needs to be set up. The collected data needs to be aligned with the dataset of the planning phase. To run the comparison, an object-based throughput time needs to be captured and documented.

Since the technology of live image recognition has been difficult to implement on construction sites the first step will be the manual gathering of the data on site. E.g. the foremen will need to have a tool on which he can define the process as done at the moment when the object has been built. The timestamp within the tool will then give the needed throughput time that is necessary for the further use.

3. Identification of deviations / waste processes

The comparison of the data needs to be handled in a Business Intelligence tool or in a software that is tailor made for the needs. The data must be compared and if certain threshold values are exceeded, the system highlights the processes that were delayed.

4. Problem categorisation

As previously described once a deviation that has exceeded the threshold value the system highlights the process that was delayed. The problem then needs to be categorised. Therefore an application is being developed in which the classification can be conducted and the data analysed for further improvement and analysis. As a structure to support the root cause analysis and thus the categorisation the 5 Why’s can support in detecting the cause of the delay [17]. The tool is broadly being used as Lean methodology. The aim is to ask five times why to get deeper into the root cause and a more detailed picture of the problem.

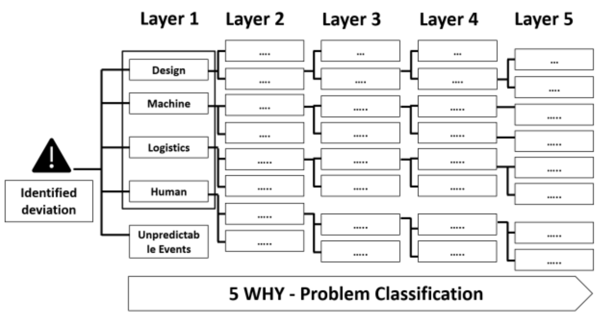

Figure 1. “5-Why” problem classification

A tree diagram (Figure 1) which will be the main structure for the approach will then grow with each problem identified. The different layers of the diagram represent different organisational target groups for decision-making. Whereas the first layer can support the C-Level respectively Top Management in making decisions by highlighting the overall areas in which improvements or innovations should be done, the Layer five can support for example, the machine maintenance department by showing the problems that lead to deviations on a detailed level.

The cross-project view of the diagram will support finding bottlenecks and the identification of innovations that will stabilise and improve processes along the value chain and support units such as maintenance.

5. Improvement and value creation opportunity

evaluation

The insights can then be used as a base for the decision of the innovations that need to be developed within the R&D portfolio. The dataset can be analysed in regards of construction bottlenecks and data-driven improvement actions and business model innovations taken. Different identified problems can be clustered into a improvement actions or initiatives.

6. Impact analysis of value creation and improvement

Once an innovation or improvement solution is developed the success of the decision and development can then be traced by tracking the decrease of the following problems respectively if the reason for deviation occurs again.

3.1 Demonstration Case

In this demonstration case we want to outline a possible case and its outcome regarding the evaluation of future improvements respectively business model creation. The case can be considered as an overall case that focuses on organizational decisions based on collected production data. The digital twin is being used for the data storage and the collected problems are connected to the object in the model.

The management of a company evaluates the digital twin data of the previously described concept for the annual report. The data shows that a major part of the deviations that occurred while construction was caused within the process of gravel tamping. The analysis also outlines that most of these deviations were caused by external subcontractors. The company dosen't have enough machines in order to handle all tamping processes with its own machine assets.

This knowledge gives the opportunity for a valid decision-making process. The company evaluates the opportunities and identifies the following options:

1. Investing in new tamping machines in order handle the processes inhouse.
2. Negotiate Performance-based contracts with the subcontractors.
3. Piloting a Revenue Sharing project on which the risk is shared with all project parties.

After some discussions the decision makers agree on performance-based contracts with their subcontractors that are responsible for the tamping processes. They also define that the year after they want to have a report of the success measure by the responsible manager in order to understand the impact and possible further actions if the decision didn't succeed. By evaluating the upcoming reasons for deviations it can be measured if the decision had the expected outcome respectively if the new business model succeeded.

3.2 Impact on Industry/Projects/Companies

The proposed concept of collecting and analysing data in a digital twin can support in decision making on an organization and project level. For projects a digital production twin can support in short term decision making. That gives the opportunity to collect suggestions for improvements for further projects. Furthermore, that means that a data driven continuous improvement is established and the collected data can support the organization in identifying an overall view about their bottlenecks and thus a data supported basis for decision making of improvements, innovations and new business models. However, the industry needs to handle the needed transparency and align with emerging technologies as well as methodologies.

3.3 **Concept: Business Model Innovation enabled by a Digital Twin**

The described application of a digital twin in infrastructure projects enables business model innovation. To show which business mechanics are enabled, the concept of pattern adaptation according to the St. Galler Business Model Navigator is applied [18]. Gassmann, Frankenberger and Csik have compiled 55 successful business model patterns into a set of sample cards. According to the authors, more than 90% of successful business model innovations can be traced back to the recombination of these 55 basic patterns. In the following, the five most prospectus business mechanics applied to a digital twin have been chosen and will be described in detail.

3.3.1 Digitalization

A Digital Twin includes many aspects of the business model pattern Digitalization.

As the name suggests, the construction work will be made available to customers in digital form as a twin. The construction plans, the sequence planning and the cost planning are built up as digital models, such as BIM4D.

The construction work is digitally recorded utilizing sensors, and the data are processed and displayed. Other aspects are the digital overview of the entire construction site and the possibility of virtual site inspection. This and further possibilities in the sense of digitalization around the construction site can be additional services in the infrastructure industry.

3.3.2 Performance-Based Contracting

In this business model pattern, the price is based on the performance provided by a service or product. Customers do not buy the product directly, but the result of the service, with the product usually remaining in the hands of the customer. The price is then based on the efficiency of the construction work, which is supported by the digital twin service. However, it must be identified which construction activity is significantly improved in its performance by an application of the digital twin. This allows a new structure of pricing in the infrastructure industry.

3.3.3 Revenue Sharing

In this business model pattern, revenue is shared with the involved stakeholders, such as subcontractors. The value-adding activities performed by the stakeholders are remunerated. This business model pattern promises the most potential for business model innovation out of a digital twin in infrastructure construction projects. With consideration to the added value of risk reduction, cost security and error avoidance as well as the increase in the efficiency of the construction process an increased value scaled to the construction volume and thus a business mechanics with revenue sharing according to turnover is enabled.

3.3.4 Make More of it

This business pattern describes that the available resources and knowledge are not only applied for the own company, but also sold as a service to others. The aim is to multiply the competencies outside the core business. In the thoughts on 'Make More of it', a digital twin enables to sell the results of successful construction projects, such as optimised construction processes or the the know-how of troubleshooting.

3.3.5 Leverage Customer Data

This business model pattern aims to collect customer data and use it profitably. This data can add value internally and/or is resold to external parties. Collecting and analysing data from construction sites can be useful for the current project itself, but also allows to use or sell it to other construction sites or other industries.

To consolidate the points discussed above, Figure 2 illustrates how the elements of a digital twin may influence the factors that typify digital twin innovation (product, service, process or business model) and in turn shows different types of enabled business models. The concept is based on authors' own thinking deducted from the literature described above.

4 Discussion

This study adds to the current understanding of how infrastructure construction projects may use a digital twin to enhance their business model innovation processes and enable their value creation processes.

The proposed concept provides a set of enabled business models for infrastructure construction projects which can evolve from an application of a Digital Twin. This type of business model innovation can have a fundamental impact on the way clients and construction companies work together. In addition, it could lead to an acceleration of infrastructure planning and awarding of contracts, as well as an efficiency increase in the construction phase which results in time and cost savings in the interest of public taxpayers.

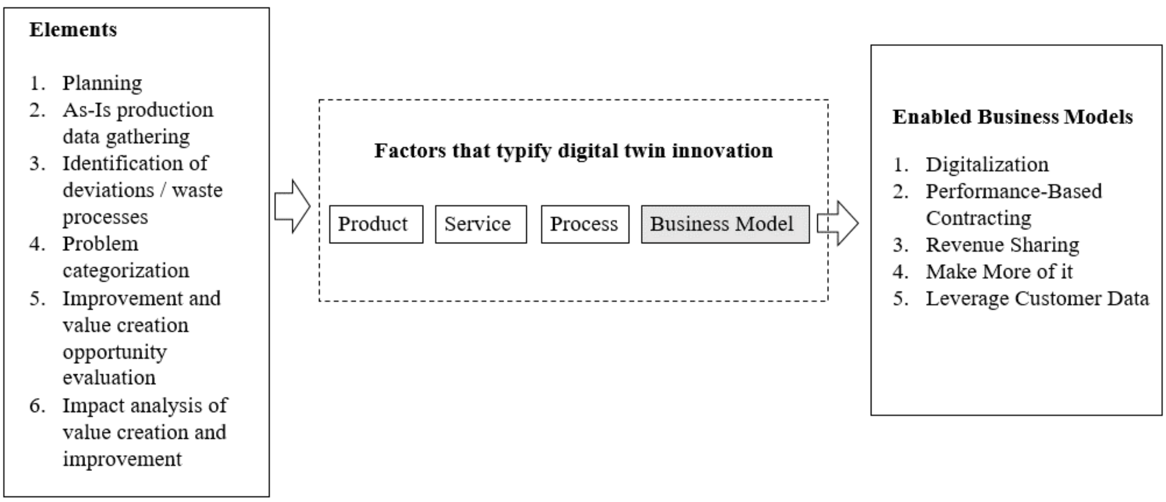

Figure 2. Digital Twin as enabler for Business Model Innovation in the field of infrastructure construction projects

5 Conclusion & Outlook

The use of As-Is data by comparing them with the planned and store them in a structured way in digital twin can support project, companies and the industry to support in their decision-making process regarding innovations and new business models. These decisions can be taken on valid datasets and the success of the decision measured. However, to be able to collect As-Is data and to use it for the proposed concept is a challenge for companies. Even though technology is up to date the use and implementation within the companies are still to overcome because of the lack of change in the last years.

Construction industry is in the middle of a big change and new business models can support in new revenue streams and a methodology that will not just change the future way of working but also the mindset of the whole industry. The concept can also be used for other construction projects respectively industries such as all linear construction projects or building construction. The impact of the improvements is very high on linear construction projects since the level of repetition is high. However the authors will follow up in the further development within railway construction projects.

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