A DIGITAL TWIN BUSINESS MODELLING APPROACH

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ABSTRACT

Digital Twins are one of the most trending topics. However, there are still open issues in the development of Digital Twins. One of these impediments is formulating a clear and valid value proposition of a Digital Twin. Therefore, this paper presents a novel business modelling approach for Digital Twins. Based on a literature review and an academic case study, different business modelling approaches and techniques were systematically compared, selected and adjusted in order to develop a new framework suitable for describing the value of Digital Twins. It consists of 10 steps – (1) describe a basic development concept of the DT, (2) identify the customer segments, needs and pain points, (3) derive a value proposition (4) identify revenue streams and values created, (5) identify key activities, (6) resources needed, and (7) necessary partners. (8) Adapt the organization to fit the business model and (9) evaluate the cost structure of the project. In the end, document and communicate the new business model (10). Each step is supported by auxiliary methods, tools and procedures. The approach was applied to a scientific case study. In an initial evaluation the overall applicability and usefulness of the approach were confirmed.

Keywords: Digital Twin, Digital / Digitised engineering value chains, Business models and considerations, Case study

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1 INTRODUCTION

Nowadays, companies of all sizes and from all industries are confronted with a variety of challenges in the development and production of products. The demand for ever shorter innovation times in the face of increasing complexity and a greater number of product variants increases the requirements on the product development process (Ehrlenspiel and Meerkamm, 2017). In addition, there is an increasing demand for more individualized, high-quality products, with lower production costs at the same time (Gundlach and Fay, 2022). Many companies try to address these challenges with the potentials and possibilities digitalization offers. Especially the "fourth industrial revolution" (Industry 4.0) and other data-driven approaches are able to leverage technical product development (Masood and Sonntag, 2020; Trauer et al., 2020b). One of the most trending and promising concepts in industry 4.0 is the digital twin (Eckert et al., 2019).

Since the first mention in the early 2000s, a myriad of different definitions of the term "digital twin" (DT) have been published. None of them is exclusively valid. However, in order to create a common understanding, in this paper the definition of Trauer et al. (2020a) is being used: *"A Digital Twin is a virtual dynamic representation of a physical system, which is connected to it over the entire lifecycle for bidirectional data exchange"*. Depending on the lifecycle phase a DT solution is contributing to the most, the term can be subdivided in "Engineering Twins", "Production Twins", or "Operation Twins" (Trauer et al., 2020a). The DT is said by most to have great potential. Numerous publications promise great benefits of this concept for all phases of the product lifecycle. However, even more than two decades after the first mention of DTs, companies are still struggling in the conception and implementation of DTs (Perno et al., 2022). In a survey, Trauer et al. (2022) analysed the challenges in implementing DTs. Among other things, most of the participants stated that *"identifying a clear and valid value proposition"* is likely or very likely to cause problems in DT projects. Further, one participant specifically suggested to *"...focus on when a DT can add which value"*. Another one suggested to highlight *"advantages of DTs in business use cases"* in future research *"...since - especially in more 'classic' engineering companies - people are quite sceptic against such digitalization and clear arguments and advantages are needed to convince them, that this is the way"* (Trauer et al., 2022). Consequently, there does not seem to be a suitable business modelling approach, practitioners could use to describe and quantify the value of DTs. Therefore, this paper aims at addressing three research goals:

1. Identify elements of existing business modelling approaches suitable for DT solutions.
2. Develop a novel Digital Twin Business Modelling Approach (DTBMA) based on the previous investigation.
3. Initial evaluation of the DTBMA in an academic case study.

2 STATE OF THE ART

2.1 Methodology of the literature review

To structure and guide the systematic literature review, a research strategy was built (cf. Table 1). Some of the terms were truncated to avoid missing important literature due to deviations from the keywords. To identify relevant literature on business modelling, search strings were derived by combining the elements of the columns using the Boolean "OR" operator. The columns were combined by AND operators. The search strings were entered on Scopus (www.scopus.com, updated February 2023).

Table 1. Literature research strategy

	Aspects			
Synonyms	Business Model	Digital Twin	Assessment	Use Case
	Value* (Proposition)	Digital Shadow	Success	Case Study
	Value Creation	Simulation Model	Evaluation	Application
		Digital Model		Scenario
				Industr*

To condense the literature review, the results were systematically limited to the field of engineering, publications containing "Digital Twin" or "Business Model" as a keyword, and finally filtered by their content. The extended keyword search process can be found in Figure 1.

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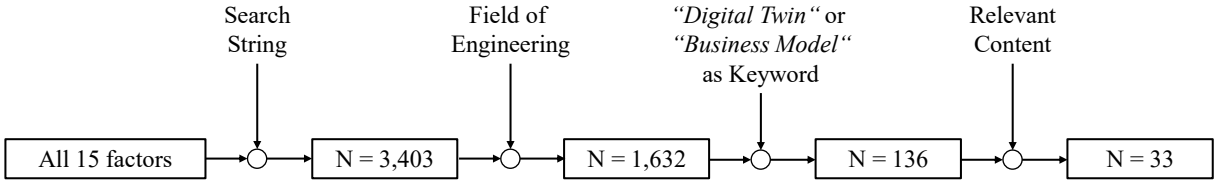

Figure 1. Keyword search process

2.2 Business model

Many definitions on "business models" exist leading to different basic interpretations of the concept (Gassmann et al., 2014). Massa et al. (2017) identified in a literature review three categories of business models - *"(1) business models as attributes of real firms, (2) business models as cognitive/linguistic schemas, and (3) business models as formal conceptual representations of how a business functions"*. Teece (2010) defined a business model as a *"manner by which the enterprise delivers value to customers, entices customers to pay for value, and converts those payments to profit"*. However, DTs per se are often not monetarized, leading to no increased profit. Therefore, in the course of this paper, the definition of Osterwalder and Pigneur (2010) is used, describing business models as *"the rational of how an organization creates, delivers, and captures value"*. To identify the basic elements of existing business modelling approaches, relevant publications were systematically analysed and compared (cf. Table 2).

Table 2. Overview of basic business model elements

	Osterwalder and Pigneur (2010)	*Gassmann et al. (2014)*	*Jodlbauer (2020)*	*Schneider (2012)*	*Laudon and Traver (2014)*	*Voelpel et al. (2004)*	*Lindgardt et al. (2013)*	*Johnson and Lafley (2010)*	*Bieger and Reinhold (2011)*	*de Kluyver (2012)*	*Chesbrough (2010)*	*Alt and Zimmermann (2001)*	*Hamel (2002)*	*Wirtz (2020)*	**Total**
Customer Segments	x	x	x	x		x	x	x	x	x	x	x	x	x	14
Value Proposition	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14
Channels	x	x	x					x	x	x			x	x	8
Customer Relationship	x	x	x	x									x	x	6
Revenue Streams	x	x	x	x	x		x	x	x		x	x	x	x	12
Key Resources	x	x	x	x		x	x	x	x	x	x	x	x	x	13
Key Activities	x	x	x	x		x	x	x	x	x	x	x	x	x	13
Key Partners	x	x	x	x		x	x	x	x	x	x	x	x	x	13
Cost Structures / Budget	x	x	x				x	x			x			x	7
Market opportunity					x										1
Competitive environment					x									x	2
Market strategy					x										2
Organizational development					x		x			x					3
Competitive advantage					x						x		x		3
Development Concept									x						1
Legal Issues												x			1
Information & Insights (key resources)													x		1
Management team / Leadership & governance					x	x									2
Organization							x								1

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One of the most important elements of business models are the target customers (Osterwalder and Pigneur, 2010; Gassmann et al., 2014). They can be grouped into customer segments, for example, according to demographic, expectation-based, or sales-based criteria (Osterwalder and Pigneur, 2010). To manage the requirements, needs and expectations of the end customers, customer relationships need to be considered. Strategic customer relationships support the acquisition of new customers, the maintenance and management of existing customers resulting in an increase of sales (Osterwalder and Pigneur, 2010). Related to the customer relationship are the channels through which the company interacts with the customer. Channels are used to communicate, deliver, and market the value proposition and play an important role in the customer experience (Jodlbauer, 2020; Osterwalder and Pigneur, 2010). Classic channels include direct (own sales department and internet sales) and indirect (own stores, partner stores, wholesalers) channels (Osterwalder and Pigneur, 2010). However, as DTs are only rarely sold, this plays a minor role for a DTBMA. Internal customers need to be considered, but they will not create any revenue.

Next to the target customers, the value proposition is at the core of most business models. This element represents products and services that the company offers to a specific target customer to solve the customer's problems and fulfil the customer's needs (Jodlbauer, 2020). Every company differentiates themselves from their competitors through their value proposition (de Kluyver, 2012). The value proposition can be developed based on customer requirements, innovations, or the addition of features and attributes to similar existing value propositions (Osterwalder and Pigneur, 2010).

To realize the value proposition key activities, resources, and partners are necessary (Schallmo, 2014; Osterwalder and Pigneur, 2010). The required resources can be human, intellectual, data, information, software, physical, technical, managerial, relational, and financial resources (Hamel, 2002; Johnson and Lafley, 2010). Hereby, it must be determined whether the resources and activities are realized internally or externally. Common partnerships can be related to suppliers, academia, technology, development, design, software, manufacturing, and service providers. Further, revenue streams and cost structures need to be determined (Gassmann et al., 2014). Revenue streams describe the main types of income a company generates (Osterwalder and Pigneur, 2010). Besides the sale of assets, revenue can also be generated by leasing, license fees, user fee for services, and subscription for services (Jodlbauer, 2020). The cost structure includes all costs to execute a business model, namely customer relationship maintenance, channels, key activities, partners, resources, and value creation (Osterwalder and Pigneur, 2010).

2.3 Business modelling for digital twins

Some literature already emphasizes the importance of DTs for the transformation of business models (e.g. Kumar et al., 2022). As other disruptive technologies, DTs require entirely different business models to exploit the benefits (Benta et al., 2017; Li et al., 2020). For example, Li et al. (2020) argue that DTs enable "[…] enterprises to turn products into a dynamic platform, continuously acquire customer needs, take appropriate actions at the right time and in the right scene, provide customers with better products and services, and promote the disruptive upgrading of core processes and customer experience". DTs fundamentally change how products are offered to the customer and by which method the customer pays for the product/service (Aurich et al., 2019). Kampker et al. (2019) for instance showed that DTs allow a payment model based on the availability of a product-service system.

So far, only little research has been conducted in the development of business models for DTs. Prielipp et al. (2021) designed one of the few business modelling approaches that include a conceptual design of marketable smart services based on DTs. However, this work was limited to the textile industry. Schweigert-Recksiek et al. (2020) presented a procedure model for the conception and implementation of DTs. As a first step, use cases have to be derived, assessed, and prioritized (Schweigert-Recksiek et al., 2020). However, assessment and prioritization are done only qualitatively and without a systematic approach. Focusing on digital products in general, researchers and practitioners already adapted to the different and new requirements (Wirtz, 2019). According to Wirtz (2019) there are four basic forces influencing digital business models - (1) convergence and technology, (2) digitalization and innovation dynamic, (3) market complexity, and (4) customer empowerment. Here, especially the second aspect is relevant to the business models of DTs. It leads to changed cost and revenue structures as products become intangible and more emphasis is set on the services (Wirtz, 2019). This also requires novel organization forms including different stakeholders, resources and activities (Wirtz, 2019). To address these changed requirements, Benta et al. (2017) and

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Wilberg (2019) proposed a data-enhanced business modelling canvas which takes data resources and data insights as key elements into account.

3 RESULTS

Based on the findings of the literature review outlined in section 2, a novel business modelling approach for DTs was developed. As described in the previous section, digital products in general and DTs in special require different business modelling approaches, due to their different characteristics. The most important characteristic demanding for new approaches are:

1. Often the customers are only internal, therefore,
2. Often, no additional revenue is directly being created by the DT,
3. The added value of DTs is multifaceted. It is very difficult to identify all indirect effects and their interaction.
4. For the identified added values, it is often complicated to quantify them.

Based on these characteristics, the most common business modelling elements (cf. Table 2) were systematically checked on applicability for DTs. In total, ten aspects were identified and form the Digital Twin Business Modelling Approach (DTBMA). Hence, the DTBMA is not a development of entirely new business modelling methods, but an adoption of existing approaches to fit the needs of DTs. An overview of the DTBMA is shown in Figure 2.

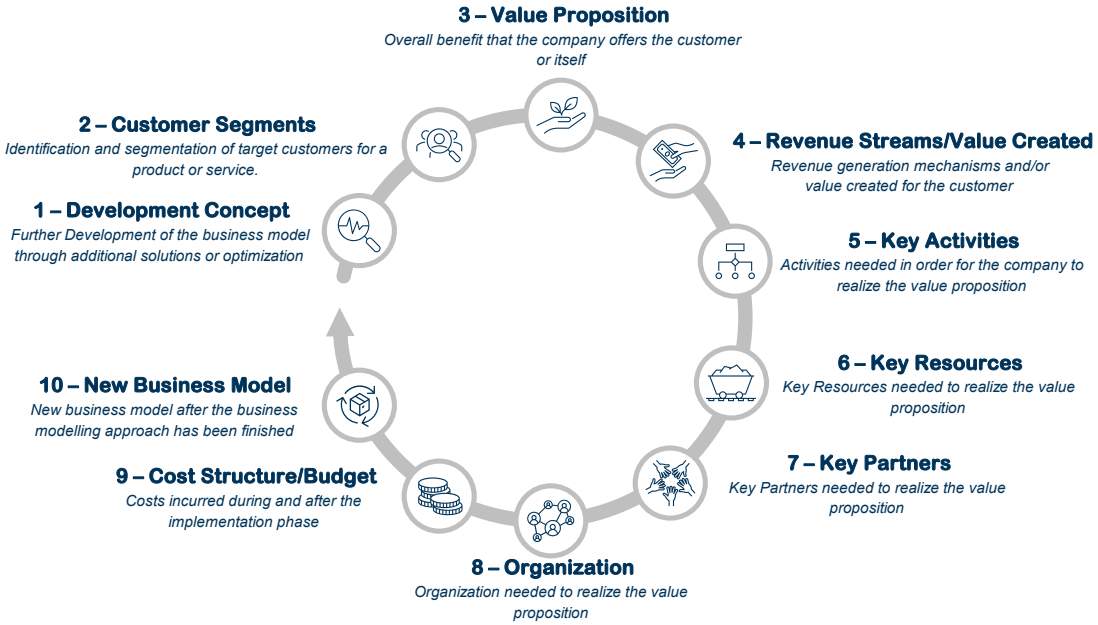

Figure 2. Overview of the digital twin business modelling approach

As described in Schweigert-Recksiek et al. (2020), at the beginning of any DT project an overall vision and strategy should be defined for the DT. Naturally, this is closely related with the business model of the DT. Therefore, the DTBMA starts with a *"Development Concept"* (1). Here, identified DT use cases are evaluated and prioritized depending on the suitability to the respective company. Furthermore, this step also analyses the company's current business model and the overall DT readiness. Various methods and tools like benchmarking or brainstorming are helpful to conduct the mentioned activities. Questions like: "Which use cases are the most attractive for the current business model?", "How ready is the organization for the Digital Twin?", or "How can global trends/innovative technologies be applied to the business model?" must be answered to formulate the hypothesis. As a result of the first step, the company receives an overview of possible use cases, formulates a business model hypothesis, and suggests possible Customer Segments. In addition, the derived use cases are prioritized so that managerial decision-making is facilitated.

Next the *"Customer Segments"* (2), to which the chosen use cases apply, are identified. Here, it is necessary to differentiate between internal and external customers. While customers outside the company, will lead to a revenue, DTs for internal customers usually do not lead to an increased income. For external customers, a market analysis is conducted to identify the market background and

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determine the market size of the customer. Independently of the type of customer, it is important to collect relevant information about the customer. E.g., what are activities of the target customer, what problems and needs does the customer have to fulfil certain activities. This can be done, for example, through customer interviews, questionnaires, or a Focus Group Discussion (O.Nyumba et al., 2018). At the end of this step the target customer should be defined, and the customer profile understood.
Once the information has been collected the fit between the *"Value Proposition"* (3) and the target customers should be analysed. The value proposition therefore describes the solutions that meet the customer's needs or solve the customer's problems. First, the appropriate solution needs to be described. For the identified product, the values that can be offered to the customers need to be derived. As DT use cases can be very different, this is a difficult task. Literature already provides some overview on the benefits of DTs (e.g. Donoghue et al., 2018; Jones et al., 2020). However, they are usually not described use case specific, which reduces their applicability. Therefore, Christ et al. (2022), developed a DT value framework, clustering benefits in three categories - increasing revenue, saving cost, and improving sustainability. Based on the identified and assessed values, the use case is compared to competitor's products for benchmarking and identifying the own market position. The result of this comparison should reveal the unique selling proposition of the company (Maurya, 2012). Finally, the Value Propositions should be validated by the target customer. For this, Validation Boards can be used. The validation result determines whether a use case is accepted, needs to be reworked, rejected.
Based on the validated value proposition, the *"Revenue Streams/Values Created"* (4) need to be derived. Here, the previously identified benefits need to be assessed and in the best case quantified. Many metrics can be used for the analysis such as the overall equipment effectiveness (OEE) for production use cases (Trauer et al., 2021). For external customers, based on the quantitative analysis, revenue streams can be defined. To do so, questions such as "What pricing is assumed for the products/services?", and "Through which channels is the revenue generated?" must be answered. The revenue can be generated from, e.g., by offering the DT as a service (e.g. Aheleroff et al., 2021), or monetarizing the collected data. To realize the values, *"Key Activities"* (5) are derived. These activities fulfil the goal of delivering value to the customer (implementing the DT, running the DT), creating value, and generating revenue streams. It is also necessary to identify which channels the target customer expects for value delivery and communication and which ones the company wants to serve. The activities require *"Key Resources"* (6). These can be hardware and software resources, like servers, data, sensors, etc. but also human resources such as specialists (e.g., data analysts). Apart from the resources needed for implementation, also the resources required to operate the respective use case must be documented. Mostly, DT projects are collaborative. Therefore, it is important to also consider the *"Key Partners"* (7) of the project at hand. The implementing company may not be able to cover all determined activities and resources from the previous steps by itself. Thus, the company needs to identify partners covering these competencies. The Key Partners needed could be identified by brainstorming in a workshop with subject matter experts. Once the potential partners have been identified they should be analysed and strategically selected. In this context, the technical and business departments should collaborate on the sourcing of the partners to avoid misalignment between the technical expectations and business boundaries.
Next, the *"Organization"* (8) needs to be addressed. As different departments/stakeholders are involved in the implementation and operation of the DT use case it is important to support the coordination and communication between these departments/stakeholders. This is especially important for external partners that work together with internal departments. Clearly distributing the work and responsibilities clarifies the organizational structure and will avoid possible conflicts that could impede the implementation and continuation process of the DT use case.
As a counterpart to the value created the *"Cost Structure"* (9) is calculated. It includes the costs of setting up and maintaining the DT use case, i.e., the customer relationship, channels, activities, resources, and partners. A cost structure includes fixed and variable costs. Respective cost drivers include, for example, order quantity, lot size, and the length of the planning or accounting period (Ehrlenspiel et al., 2020). The ratio between fixed and variable costs is greatly affected by the nature of the DT use case. For example, DT products intended to be sold to external customers might cause a higher share of variable costs. In contrast, internal DT use cases that, focus on the optimization of processes might affect variable costs less. Finally, all acquired information is documented in the last step *"New Business Model"* (10). To visualize the key insights, the business modelling canvases of Osterwalder and Pigneur (2010) and Benta et al. (2017) were combined (cf. Figure 3). By adding "budget" and "value created" as alternatives to "cost structure" and "revenue streams", the canvas was adapted to fit business models for internal

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customers. As data is a core resource and possible source of further benefits, "data resources" and "data insights" were added. Thus, the DTBMA also considers the cyber-physical nature of DTs.

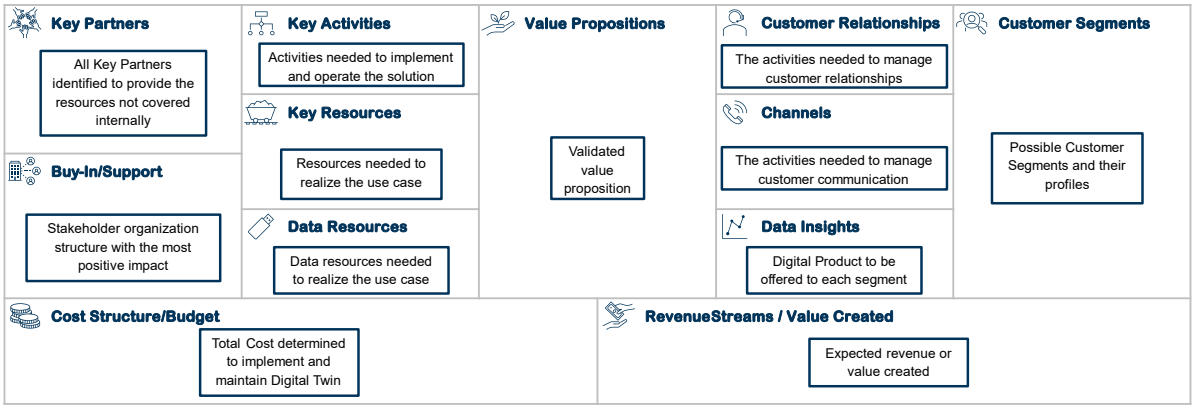

Figure 3. The adapted business modelling canvas (based on Osterwalder and Pigneur, 2010; Benta et al., 2017)

To increase the applicability and usefulness of the developed DTBMA, for each step one-pagers including the goal of the step, involved departments, a short summary, required inputs, activities, and resulting outputs. Key questions are provided, to check whether a step is completed. In addition, further descriptions and templates were created for all associated, activities, methods, and tools are provided.

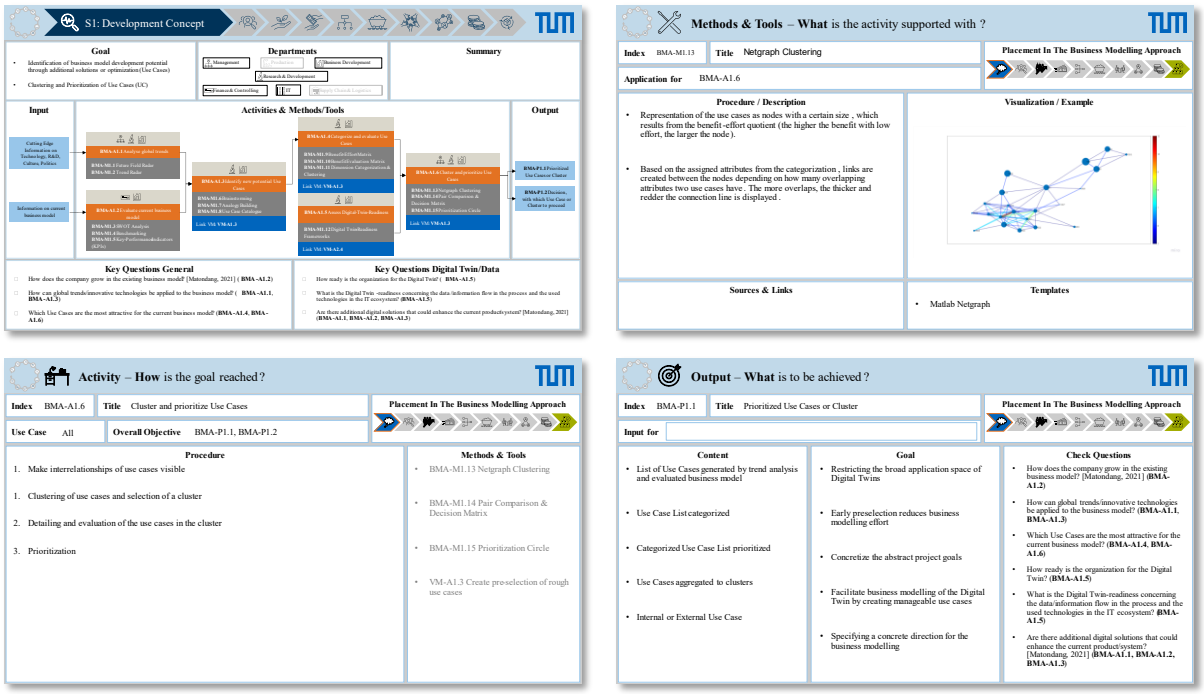

Figure 3. One-pagers to support the digital twin business modelling approach (zoomable)

4 CASE STUDY

The developed DTBMA was applied in an academic case study. This study is based on a demonstrator for IoT in the process industry, resembling a bottle filling station (see ADIRO Automatisierungstechnik GmbH - EduKit PA for Festo Didactic, 2022). The system consists of two tanks that are connected to each other via several pipes and a pump. The pump transports the liquid from the lower tank to the upper tank. along the process line, several sensors are installed, which provide online process parameters. These include pressure, flow rate, pump speed, and liquid level in the upper tank. For this scientific case study, an artificial scenario was designed. A company that operates this plant has had recurring problems with the pipes becoming clogged due to deposits. The pump has to work against the increasing pressure and often gets damaged. In order to avoid this, a DT

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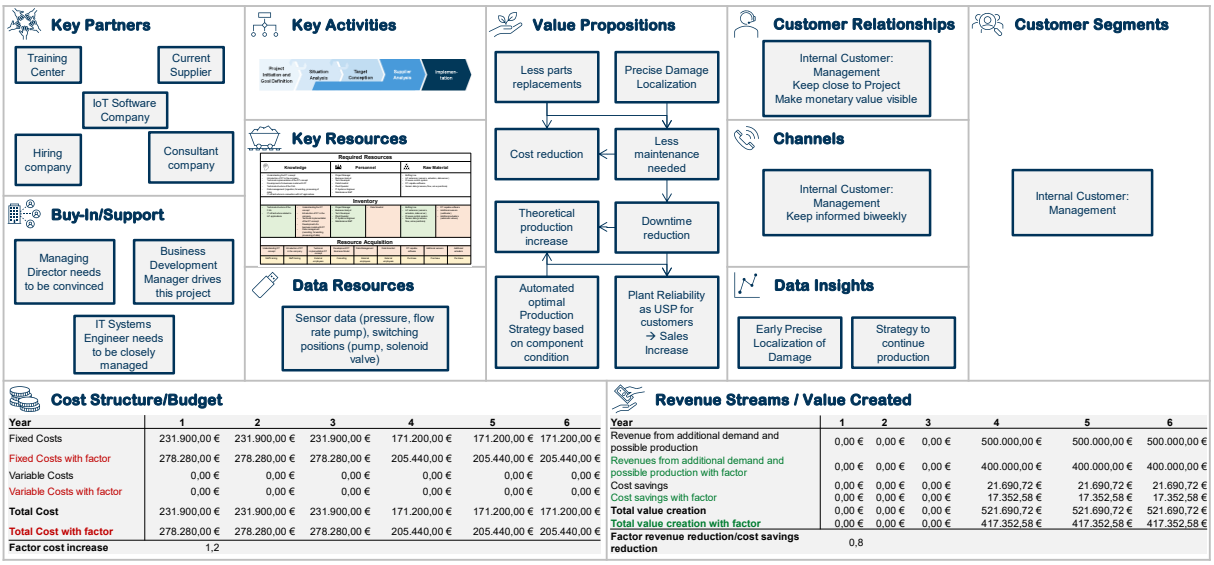
use case for "preventive operations" is to be introduced. Here, the DT should be able to detect clogged pipes in real-time. Instead of shutting down the production entirely, the DT will control the pump and the system in a way, that the pump will not be damaged while stopping production. In addition, the maintenance will be planned and supervised in a cost and time optimal manner by the DT. For this use case, the DTBMA was applied in order to describe the value. All steps were conducted. For this use case only internal customers were considered. Consequently, the DT is not directly creating a revenue stream. However, costs can be significantly reduced and sustainability improved. As it reduces downtimes of the plant, production volume will increase, leading in an increased revenue. Assuming a conservative scenario, the DT will already have amortized 4 years after the start of the project. The resulting business modelling canvas can be found in Figure 5.



Cost Structure/Budget

Year	1	2	3	4	5	6
Fixed Costs	231.900,00 €	231.900,00 €	231.900,00 €	171.200,00 €	171.200,00 €	171.200,00 €
Fixed Costs with factor	278.280,00 €	278.280,00 €	278.280,00 €	205.440,00 €	205.440,00 €	205.440,00 €
Variable Costs	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
Variable Costs with factor	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
Total Cost	231.900,00 €	231.900,00 €	231.900,00 €	171.200,00 €	171.200,00 €	171.200,00 €
Total Cost with factor	278.280,00 €	278.280,00 €	278.280,00 €	205.440,00 €	205.440,00 €	205.440,00 €
Factor cost increase	1,2					

Revenue Streams / Value Created

Year	1	2	3	4	5	6
Revenue from additional demand and possible production	0,00 €	0,00 €	0,00 €	500.000,00 €	500.000,00 €	500.000,00 €
Revenues from additional demand and possible production with factor	0,00 €	0,00 €	0,00 €	400.000,00 €	400.000,00 €	400.000,00 €
Cost savings	0,00 €	0,00 €	0,00 €	21.690,72 €	21.690,72 €	21.690,72 €
Cost savings with factor	0,00 €	0,00 €	0,00 €	17.352,58 €	17.352,58 €	17.352,58 €
Total value creation	0,00 €	0,00 €	0,00 €	521.690,72 €	521.690,72 €	521.690,72 €
Total value creation with factor	0,00 €	0,00 €	0,00 €	417.352,58 €	417.352,58 €	417.352,58 €
Factor revenue reduction/cost savings reduction	0,8					

Figure 4. Business model of the use case "Preventive Operation" (zoomable)

5 CONCLUSION

This paper presents a novel business modelling approach suitable for DTs. The DTBMA was developed based on a systematic literature review and initially evaluated based on an academic case study. Although this approach was successfully applied in the case study, it has some limitations. Biggest drawback is the low level of empirical evaluation. The complete DTBMA was applied only for one use case. Additionally, it was an entirely artificial setting. The methodology was developed to fit all different kinds of DT use cases and applications. Yet, it was not possible to evaluate its suitability. However, special focus was set on designing the approach as generic as possible, whilst not being arbitrary. Lastly, legal aspects were not considered in the DTBMA as legal aspects are very specific for each industry, company, and application. Despite these limitations, two experienced DT experts from a German consulting firm confirmed the general usefulness and applicability of the DTBMA in an initial evaluation interview. The results are depicted in Figure 6.

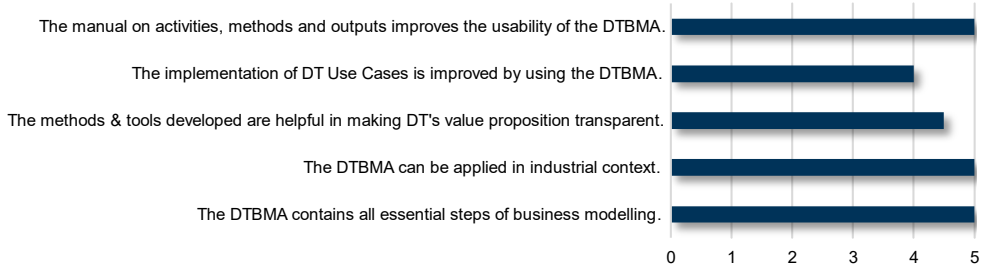


Figure 5. Initial evaluation of the digital twin business modelling approach

In future, the DTBMA needs to be tested in different companies for different use cases. Further, a software should be developed to improve the usefulness of the approach. This software with all methods and tools will be made available. Finally, legal aspects should be included in the DTBMA.

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REFERENCES

"ADIRO Automatisierungstechnik GmbH - EduKit PA for Festo Didactic" (2022), available at: https://www.adiro.com/en/didactic/hardware/edukit-pa.php (accessed 27 February 2023).

Aheleroff, S., Xu, X., Zhong, R.Y. and Lu, Y. (2021), "Digital Twin as a Service (DTaaS) in Industry 4.0: An Architecture Reference Model", *Advanced Engineering Informatics*, Vol. 47, p. 101225. https://doi.org/10.1016/j.aei.2020.101225.

Alt, R. and Zimmermann, H.-D. (2001), "Preface: Introduction to Special Section - Business Models", *Electronic Markets*, Vol. 11 No. 1, pp. 3–9. https://doi.org/10.1080/713765630.

Aurich, J.C., Koch, W., Kölsch, P. and Herder, C.F. (Eds.) (2019), *Entwicklung datenbasierter Produkt-Service Systeme: Ein Ansatz zur Realisierung verfügbarkeitsorientierter Geschäftsmodelle*, Springer Vieweg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-59643-2.

Benta, C., Wilberg, J., Hollauer, C. and Omer, M. (2017), "Process model for data-driven business model generation", in *21st International Conference on Engineering Design*.

Bieger, T. and Reinhold, S. (2011), "Das wertbasierte Geschäftsmodell – Ein aktualisierter Strukturierungsansatz", in Bieger, T., Knyphausen-Aufseß, D. zu and Krys, C. (Eds.), *Innovative Geschäftsmodelle*, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 13–70. https://doi.org/10.1007/978-3-642-18068-2_2.

Chesbrough, H. (2010), "Business Model Innovation: Opportunities and Barriers", *Long Range Planning*, Vol. 43 No. 2-3, pp. 354–363. https://doi.org/10.1016/j.lrp.2009.07.010.

Christ, A., Koch, P., Krastel, M., Schweigert-Recksiek, S. and Trauer, J. (2022), "Ready or not – the Digital Twin is coming! How can companies prepare for it?", *ProductData Journal*, 12/2022, pp. 12–17, available at: https://prostep.epaper-pro.org/pdj2-2022_english/#12 (accessed 27 February 2023).

de Kluyver, C.A. (2012), *Fundamentals of global strategy*, *Open textbook library*, Saylor Academy; Open Textbook Library, Arlington, Virginia, Minneapolis.

Donoghue, I., Hannola, L., Papinniemi, J. and Mikkola, A. (2018), "The Benefits and Impact of Digital Twins in Product Development Phase of PLM", in Chiabert, P., Bouras, A., Noël, F. and Ríos, J. (Eds.), *Product Lifecycle Management to Support Industry 4.0*, *IFIP Advances in Information and Communication Technology*, Vol. 540, Springer International Publishing, Cham, pp. 432–441. https://doi.org/10.1007/978-3-030-01614-2_40.

Eckert, C., Isaksson, O., Hallstedt, S., Malmqvist, J., Öhrwall Rönnbäck, A. and Panarotto, M. (2019), "Industry Trends to 2040", *Proceedings of the Design Society: International Conference on Engineering Design*, Vol. 1 No. 1, pp. 2121–2128. https://doi.org/10.1017/dsi.2019.218.

Ehrlenspiel, K., Kiewert, A., Lindemann, U. and Mörtl, M. (2020), *Kostengünstig Entwickeln und Konstruieren*, Springer Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-62591-0.

Ehrlenspiel, K. and Meerkamm, H. (2017), "Methodik der Integrierten Produkterstellung im Unternehmen", in Ehrlenspiel, K. and Meerkamm, H. (Eds.), *Integrierte Produktentwicklung: Denkabläufe, Methodeneinsatz, Zusammenarbeit*, 6. überarbeitete und erweiterte Auflage, Hanser, München, pp. 197–303. https://doi.org/10.3139/9783446449084.004.

Gassmann, O., Frankenberger, K. and Choudury, M. (2014), *The business model navigator: 55 models that will revolutionise your business*, 1st ed., FT Publishing International.

Gundlach, C.S. and Fay, A. (2022), "Deduction of Digital Twin's applications based on product independent description of use cases", *IFAC-PapersOnLine*, Vol. 55 No. 2, pp. 25–30. https://doi.org/10.1016/j.ifacol.2022.04.164.

Hamel, G. (2002), *Leading the revolution: How to thrive in turbulent times by making innovation a way of life*, Rev. and updated hardcover ed., Harvard Business School Press, [Boston, Mass.].

Jodlbauer, H. (2020), *Geschäftsmodelle erarbeiten*, Springer Fachmedien Wiesbaden, Wiesbaden. https://doi.org/10.1007/978-3-658-30455-3.

Johnson, M.W. and Lafley, A.G. (2010), *Seizing the white space: Business model innovation for growth and renewal*, Harvard Business Press, Boston.

Jones, D., Snider, C., Nassehi, A., Yon, J. and Hicks, B. (2020), "Characterising the Digital Twin: A systematic literature review", *CIRP Journal of Manufacturing Science and Technology*, Vol. 29, pp. 36–52. https://doi.org/10.1016/j.cirpj.2020.02.002.

Kampker, A., Stich, V., Jussen, P., Moser, B. and Kuntz, J. (2019), "Business Models for Industrial Smart Services – The Example of a Digital Twin for a Product-Service-System for Potato Harvesting", *Procedia CIRP*, Vol. 83, pp. 534–540. https://doi.org/10.1016/j.procir.2019.04.114.

https://doi.org/10.1017/pds.2023.13 Published online by Cambridge University Press

Kumar, V., Leng, J., Akberdina, V. and Kuzmin, E. (2022), *Digital Transformation in Industry*, Vol. 54, Springer International Publishing, Cham. https://doi.org/10.1007/978-3-030-94617-3.
Laudon, K.C. and Traver, C.G. (2014), *E-commerce: Business, technology, society*, Tenth edition, Pearson, Upper Saddle River, New Jersey.
Li, X., Cao, J., Liu, Z. and Luo, X. (2020), "Sustainable Business Model Based on Digital Twin Platform Network: The Inspiration from Haier's Case Study in China", *Sustainability*, Vol. 12 No. 3, p. 936. https://doi.org/10.3390/su12030936.
Lindgardt, Z., Reeves, M., Stalk, J. and Deimler, M. (2013), "Business Model Innovation: When the Game Gets Tough, Change the Game", in Deimler, M., Lesser, R., Rhodes, D. and Sinha, J. (Eds.), *Own the future: 50 ways to win from the Boston Consulting Group*, pp. 291–298. https://doi.org/10.1002/9781119204084.ch40.
Masood, T. and Sonntag, P. (2020), "Industry 4.0: Adoption challenges and benefits for SMEs", *Computers in Industry*, Vol. 121, p. 103261. https://doi.org/10.1016/j.compind.2020.103261.
Massa, L., Tucci, C.L. and Afuah, A. (2017), "A Critical Assessment of Business Model Research", No. 11(1), pp. 73–104. https://doi.org/10.5465/annals.2014.0072.
Maurya, A. (2012), *Running lean: Iterate from plan A to a plan that works, The lean series*, 2nd ed., O'Reilly, Sebastopol, CA.
O.Nyumba, T., Wilson, K., Derrick, C.J. and Mukherjee, N. (2018), "The use of focus group discussion methodology: Insights from two decades of application in conservation", *Methods in Ecology and Evolution*, Vol. 9 No. 1, pp. 20–32. https://doi.org/10.1111/2041-210X.12860.
Osterwalder, A. and Pigneur, Y. (2010), *Business model generation: A handbook for visionaries, game changers, and challengers*, Wiley & Sons, New York.
Perno, M., Hvam, L. and Haug, A. (2022), "Implementation of digital twins in the process industry: A systematic literature review of enablers and barriers", *Computers in Industry*, Vol. 134, p. 103558. https://doi.org/10.1016/j.compind.2021.103558.
Prielipp, R., Bojko, M., Göhlert, N. and Pelliccia, L. (2021), "Business models based on digital twins and digital shadows in the textile industry", *wt Werkstattstechnik online*, Vol. 111 No. 07-08, pp. 531–535. https://doi.org/10.37544/1436-4980-2021-07-08-63.
Schallmo, D.R. (2014), *Kompendium Geschäftsmodell-Innovation*, Springer Fachmedien Wiesbaden, Wiesbaden. https://doi.org/10.1007/978-3-658-04459-6.
Schneider, A. (2012), *Geschäftsmodellwandel durch disruptive Innovationen: Fallstudie zum Elektrofahrzeug in Automobilindustrie und Energiewirtschaft, Driesen Wirtschaftswissenschaften*, Driesen, Taunusstein.
Schweigert-Recksiek, S., Trauer, J., Engel, C., Spreitzer, K. and Zimmermann, M. (2020), "Conception Of A Digital Twin In Mechanical Engineering – A Case Study In Technical Product Development", *Proceedings of the Design Society: DESIGN Conference*, Vol. 1, pp. 383–392. https://doi.org/10.1017/dsd.2020.23.
Teece, D.J. (2010), "Business Models, Business Strategy and Innovation", *Long Range Planning*, Vol. 43 No. 2-3, pp. 172–194. https://doi.org/10.1016/j.lrp.2009.07.003.
Trauer, J., Mutschler, M., Mörtl, M. and Zimmermann, M. (2022), "Challenges in Implementing Digital Twins – a Survey", in American Society of Mechanical Engineers Digital Collection. https://doi.org/10.1115/DETC2022-88786.
Trauer, J., Pfingstl, S., Finsterer, M. and Zimmermann, M. (2021), "Improving Production Efficiency with a Digital Twin Based on Anomaly Detection", *Sustainability*, Vol. 13 No. 18, p. 10155. https://doi.org/10.3390/su131810155.
Trauer, J., Schweigert-Recksiek, S., Engel, C., Spreitzer, K. and Zimmermann, M. (2020a), "What Is A Digital Twin? – Definitions And Insights From An Industrial Case Study In Technical Product Development", *Proceedings of the Design Society: DESIGN Conference*, Vol. 1, pp. 757–766. https://doi.org/10.1017/dsd.2020.15.
Trauer, J., Schweigert-Recksiek, S., Onuma Okamoto, L., Spreitzer, K., Mörtl, M. and Zimmermann, M. (2020b), "Data-Driven Engineering – Definitions and Insights from an Industrial Case Study for a New Approach in Technical Product Development", in *Balancing Innovation and operation, 12th - 14th August* 2020, The Design Society. https://doi.org/10.35199/NORDDESIGN2020.46.
Voelpel, S.C., Leibold, M. and Tekie, E.B. (2004), "The wheel of business model reinvention: how to reshape your business model to leapfrog competitors", *Journal of Change Management*, Vol. 4 No. 3, pp. 259–276. https://doi.org/10.1080/1469701042000212669.
Wilberg, J. (2019), "From data to value: facilitating strategy development for connected products", Doctoral Thesis, Laboratory of Product Development and Lightweight Design, Technical University of Munich, Munich, 2019.
Wirtz, B.W. (2019), *Digital Business Models*, Springer International Publishing, Cham. https://doi.org/10.1007/978-3-030-13005-3.
Wirtz, B.W. (2020), Business Model Management: Design - Process - Instruments, Springer Texts in Business and Economics, 2nd ed., Springer Cham. https://doi.org/10.1007/978-3-030-48017-2.

https://doi.org/10.1017/pds.2023.13 Published online by Cambridge University Press