Using Digital Models to Decarbonize a Production Site: A Case Study of Connecting the Building Model, Production Model and Energy Model

Isabella Deininger[1](✉), Bernd Koch[2], Ralph Bauknecht[3], Mathias Langhans[4], Christoph Falk[5], Andreas Trautmann[6], and Konrad Nübel[1]

[1] Chair of Construction Process Management, Technical University Munich, Arcisstraße 21, 80333 Munich, Germany
isabella.deininger@tum.de
[2] Smart Infrastructure, Siemens AG, Siemenspromenade 2, 91058 Erlangen, Germany
[3] Digital Industry, Siemens Industry Software GmbH, Schwieberdinger Str. 95-97, 70435 Stuttgart, Germany
[4] Digital Industry, Siemens AG, Gleiwitzer Str. 555, 90475 Nuremberg, Germany
[5] Smart Infrastructure, Siemens AG, Otto-Hahn-Ring 6, 81739 Munich, Germany
[6] Smart Infrastructure, Siemens AG, Neuenhofstr. 194, 52078 Aachen, Germany

Abstract. Rapid growth of digital technology has facilitated industry progress, while industrial CO_2 emissions are a major issue to be confronted. Digital Twins can play a major role but so far, they have no common norms, standards, or models yet. On top of this, the majority in literature uses the term Digital Twin, but only a few sources are really describing a Digital Twin, whereby it describes a bidirectional data transfer between the real model and the software model. Until now, Digital Twins focus on a single area of interest and do not consider the broader challenge of CO_2 emissions. This study gives an example how to predict CO_2 emissions for the operation of a production site by merging three Digital Models (Building, Production, and Energy Model). This approach demonstrates how CO_2 emissions can be reduced during operation by selecting an appropriate production scenario and a specific energy source mix in the planning phase. The core task is to enable energy demand reduction by simulating different production scenarios and to identify the best energy source mix with the resulting CO_2 emissions visible. The case study shows that by merging the three Digital Models, it is possible to create an overview of the expected CO_2 emissions which can be used as a basis for further developments for Digital Twins. However, the case study has shown that only manual data exchange between the models was possible. Further developments enabling a common data exchange and the connection of the interdisciplinary digital models through a shared language are urgently needed to speed up developments for Digital Twins and shape an interdisciplinary industry approach.

Keywords: Digital Model · Digital Twin · Building Model · Production Model · Energy Model · BIM · Carbon Dioxide Emissions · Decarbonization

J. Fottner et al. (Eds.): CLEaR 2023, LNCE 390, pp. 69–76, 2024.
https://doi.org/10.1007/978-3-031-44021-2_8

1 Introduction

While the manufacturing sector is a key driver for economic growth, the associated industrial emissions have a significant negative environmental impact [1]. The European Union's CO_2 targets are playing an increasingly important role in developing the European industry [2]. Despite recent developments in highly-efficient technologies, reducing CO_2 emissions is proving hard to achieve. In addition to this challenge, there are still numerous individual IT solutions which leads to data silos that do not represent an ideal standardized system landscape to best tackle the CO_2 emission challenge. Digital Twins have a high potential, but there are no common norms, standards, or models. This is because the availability of data, tools for data collection and modeling tools influence the choice of method [3]. Literature shows how most research focuses on improving modeling techniques rather than on merging different Digital Twins. There is a lack of common space in practice where those modeling techniques can exchange useful information. On top of this, the majority of literature uses the term Digital Twin, but only a few sources are really describing a Digital Twin with a bidirectional data transfer and instead refer to a Digital Model or Digital Shadow [4]. Considering the available digital solutions, this case study combines the three Digital Models (Building, Production, and Energy Model) to show a possible decarbonization strategy in the industrial sector and create a foundation for future Digital Twins.

2 From Digital Models to Digital Twins

Digital Models are used for design purposes, but when it comes to reconfigurable layouts, Digital Twins become more and more necessary [4]. However, there are diverse and conflicting definitions of Digital Twins and ways of classifying them in literature as well as in common usage, which has prevented the establishment of clear standards or frameworks. What a Digital Twin is and how it is represented varies according to the system of the object they are designed for. Kritzinger et al. have investigated the definitions of Digital Twin and define them according to the level of data integration (from the lowest to the highest): digital model, digital shadow, and digital twin. Hence, a digital model involves a non-automated data flow between the physical and the digital twin. A digital shadow involves a one-way automated data flow, while a Digital Twin requires a two-way automated data flow [4].

2.1 Building Model

Building Information Modeling (BIM) is a process supported by various tools, technologies and contracts involving the generation and management of digital representations of physical and functional characteristics. The fundamental purpose of BIM is to create a model of a real object, while the essential function of a Digital Twin of a building is to emulate the object which it reflects [5]. The presented study deals with the Digital Model of the building after the building modeling stage, so that interactions with other Digital Twins in the operational phase are possible.

2.2 Production Model

A Digital Model of a production site without a connection to the physical object is a Production Model, while a manufacturing Digital Twin with a bidirectional connection offers the possibility to simulate and visualize manufacturing process parameters, workflows, and logistical aspects [4, 6, 7]. A Digital Twin can simulate especially in the operation phase whether the production schedule is viable from an energy demand perspective. The resulting load curves are used as input for the Energy Model to evaluate the necessary energy supply system.

2.3 Energy Model

An Energy Model can simulate future energy processes. With the input of the real energy demand, the main task of the Energy Twin is to optimize the energy supply in terms of decarbonization and the costs over the project lifetime [8]. Energy process simulation software can predict what energy generation technology should be installed to reduce CO_2 emissions [8, 9].

3 Methodology

Despite the enormous benefits of Digital Twins in industry, Kritzinger et al. highlights a lack of case studies that apply the concepts in practice to evaluate the benefits in industry [4]. For this reason, this case study combines the proposed Digital Models of a Greenfield for the future development of Digital Twins to demonstrate a decarbonization strategy, while observing the approach pathway outlined in Fig. 1. Because the status quo of the connection between those simulations do not have a direct interface, the case study created the basis and parameters for further developments in Digital Twins, i.e. for a data store and a shared language [10].

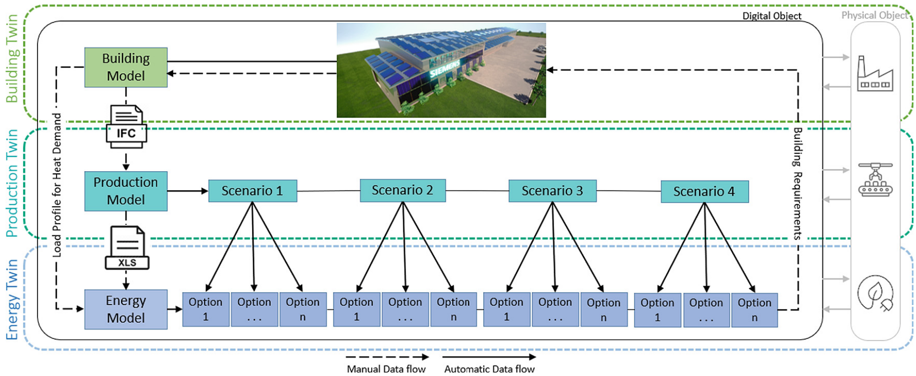

Fig. 1. Digital Model and Digital Twin methodological approach

To find out the requirements of the connections, data was collected from the Digital Models. Based on this data, a simulation of the expected CO_2 emissions was performed.

To achieve the best possible results and to analyze them properly, the case study is motivated by the following question:

How can the combination of the Building Model, Production Model, and Energy Model be used to simulate the energy demand and associated reduction of CO_2 *emissions to run a production site?*

3.1 Case Study

This section presents the main conditions and strategy for the case study project of a ‘Cold Brewed Coffee’ factory (see Fig. 2). By using the three mentioned Digital Models, it is possible to cover a wide range of the planning and operation phase of an industrial building.

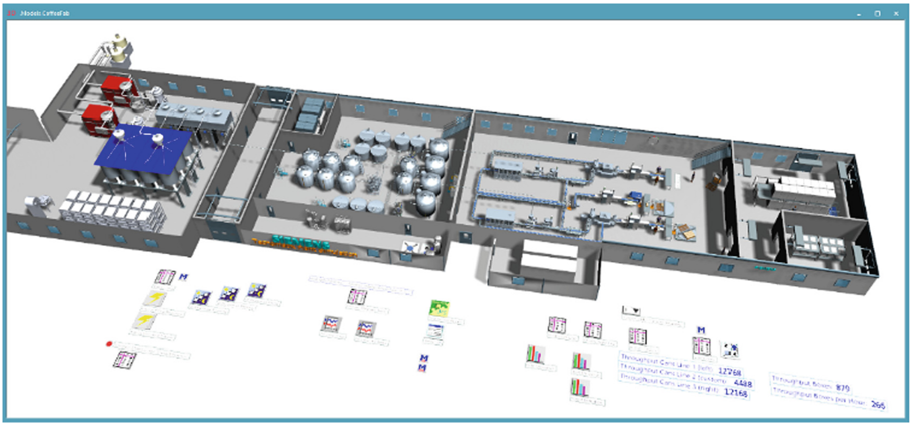

Fig. 2. Digital Model of the production in Tecnomatix Plant Simulation by Siemens

To develop defined input parameters from the Building Model, an architectural model was designed first. After the production building had been modeling in ArchiCAD and the geometries and spatial possibilities of a production were obtained, the IFC Model (Industry Foundation Classes) was transferred to the ‘Siemens Tecnomatix Plant Simulation’ software to obtain the energy demand of the production process. After a first simulation of the production process was performed, the purpose was to find out which adjustments could be made to reduce the energy demand and how to level the load peaks. Therefore, the following optimizations of the production simulation were made based on specific production variations:

To utilize the optimum of the given building geometries, a 3-shift system was operated on all days of the week (Monday to Sunday) in the *first production scenario*. It was assumed that standard conveyors of three parallel filling lines run continuously.

To save energy at the equipment within the production process, the next trial with an automatic stop of the conveyor systems was considered as the se*cond production scenario*. This means that the operation is load-dependent, and the drive units of the conveyors are controllable using sensors for occupancy. This was the first step to reduce energy consumption without negatively affecting the output rate.

In the *third production scenario*, only two work shifts were run during the day, with no shift on Sundays. The aim here was to maintain an almost constant production volume with reduced shift costs and most of the production during the day (energy from photovoltaics (PV)).

Due to the resulting high CO_2 emissions, the additional line was removed in the *fourth production scenario*, while knowing that the throughputs could not be maintained with the same shift schedules.

To cover the load peaks and to obtain information about the required energy sources, the energy demand was put into 'Siemens Power System Simulator for Distributed Energy (PSS®DE)', which is a simulation software that helps to optimize the value of the energy infrastructure investments to maximize the reduction of CO_2 emissions (see Sect. 2.3). While all necessary properties could be transferred from the Building Model to the Production Model through the IFC interface, no building properties could be transferred via IFC to the energy simulation, which is why the heat loads had to be transferred manually from the building as heat load profiles. In addition, further boundary conditions had to be entered manually to obtain an accurate energy simulation. So, the load profiles (kWh) from the process energy of the Production Model could only be imported into the Energy Model via XLS file.

4 Results and Discussions

This section presents the results following the described approach (see Fig. 1) and the central research question. First, the resulting CO_2 emissions of the investigated four production scenarios were compared to carry out further detailed observations on the lowest CO_2 production scenario from the four production scenarios. Therefore, the energy simulation PSS®DE can determine possible energy mix variations based on the input parameters and the required energy demand. PSS®DE categorizes and differentiates various options depending on the different energy sources (see Fig. 4) and generates at least one option with no CO_2 emissions (see Fig. 3). The version with the lowest CO_2 emissions (0,00 to CO_2/year) is the 1st option, whereby the CO_2 emissions increases up to the 10th option. The worst option in this consideration regarding to CO_2 emissions is the status quo, which uses the conventional natural gas boiler for the thermal load and electricity from the public grid. This was based on the emissions of the German electricity mix. At the time of the analysis, these amounted to 201 gCO_2/kWh for natural gas and an average value of 420 gCO_2/kWh for the CO_2-emissions mix factor electricity mix [11, 12].

As already mentioned, the fourth production scenario does not achieve the desired production output, which is why the next lowest CO_2 production scenario (3. Production Scenario) is considered in more detail below. The goal of the energy simulation was to use as much renewable energy as possible on-site. Under the main condition that self-produced energy ensures coverage of the energy load, the options from 1 to 6 could be taken into consideration. Due to space constraints in this paper, the following comparative analysis with the most CO_2-neutral option was narrowed down to an ideal option. After

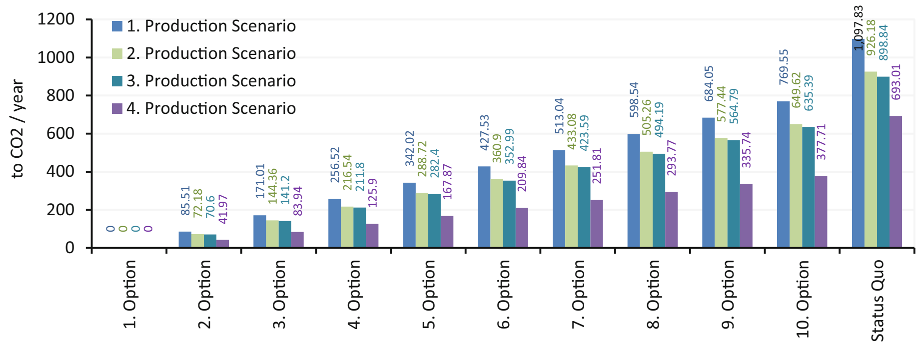

Fig. 3. CO_2 emissions of the considered production scenarios

a plausibility check regarding the operable renewable energies, the energy source mix from option 6 proves to be realistic for the project. Considering the 1st option and at the same time the 6th option for comparison, the following energy source mix is obtained as shown in Fig. 4:

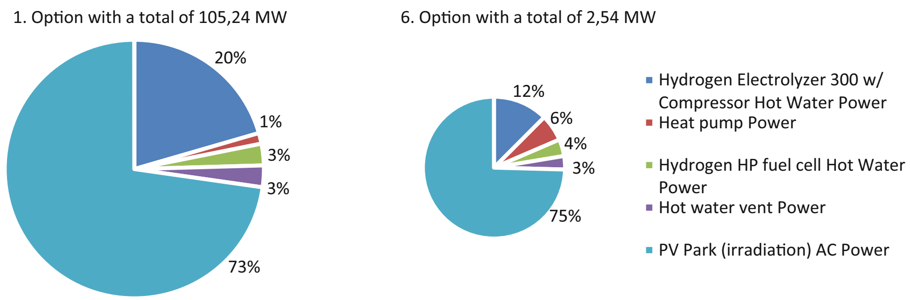

Fig. 4. Energy Source Mix for Option 1 and 6 based on Production Scenario 3

The high amount of the PV power results from the optimizer in PSS®DE. The energy simulation shows that the decarbonization strategy attracts the most renewable energy sources (e.g., from the PV) park). Because only locally generated energy is considered to be CO_2 neutral, it becomes apparent that a very large PV powerplant is needed. If this is not possible on-site and zero CO_2 emissions are intended, a non-local generation should be considered, e. g. with a Power Purchase Agreement (PPA). Regarding to the results of the energy simulation, generation should correlate with the load profile, otherwise higher storage capacities are needed. This means that during the day and during the summer months the demand should be covered by using photovoltaic power generation, while in winter the variants with low CO_2 emissions are bridged with hydrogen as a storage component.

In addition to the energy sources shown in Fig. 4, further energy sources were also taken into account in the energy simulation, but they were not selected as a consequence of the energy simulation. This is since PSS®DE can automatically exclude non-profitable energy sources. Thus, it should be noted that among the renewable energy sources, 0 kW was obtained from wind power. This is explained by the fact that the specific costs for wind power on-site are relatively high compared to PV.

The CO_2 optimizations examined in this article are in favor of increased investments and reduced operational cost. This is aimed to minimize potential changes is energy cost in the future. However, it is essential to weigh the cost of generation on-site (with Capital Expenses CAPEX) against the cost of energy on the market (Operational Expenses OPEX). Consequently, the way of implementing the reduction of CO_2 emissions depends on the decision-maker to what degree someone is willing to invest in the possible sustainable technologies and to the allowed legal boundaries. Therefore, the study evaluated how much of the self-generated renewable energy made economic sense. However, a more detailed consideration of the costs is out our scope since numerous factors would influence the cost calculation.

5 Conclusions

Industrial production makes a significant contribution to CO_2 emissions, and while many individual digital solutions are available, there is a lack of a holistic digitalization for a decarbonization strategy in an industrial environment. Challenges for Digital Twins involve standardization, multidisciplinary collaboration, and a solid basis from Digital Models. This study has shown the current data transfer between three Digital Models for a transparent visualization of a possible decarbonization through the use of future Digital Twins.

By using the three Digital Models it was possible to cover a wide range of the planning phases of a reference production facility "Cold Brewed Coffee". Four different production scenarios were investigated and compared regarding energy demand, and respective CO_2 emissions based on the energy simulation. As already pointed out in literature and hereby confirmed with the case study, there is a lack of frameworks, and it became apparent that it was a challenge to combine the Digital Models because of their different fields of focus. Thus, this study clearly identified the gaps regarding an automatic transfer of the input parameters to other Digital Models. There must be an interface between the interdisciplinary fields on the part of each level of integration (Digital Model - Digital Shadow - Digital Twin) to transmit and take into account important building parameters (transmission losses, building envelope, thermal insulation, etc.) to other models and to provide a more detailed assessment of energy performance. Because there is a lack of common space in practice where those models can exchange useful information, further work is encouraged to define an interface for the connection of the individual Models in terms of standard information for data exchange and automation to avoid IT island solutions.

Acknowledgments. All authors have read and agreed to the published version of the manuscript and declare no conflict of interest.

The authors wish to express their sincere gratitude and appreciation to Falkenstein Projektmanagement GmbH for the Building Model and due to all members of the project team from Siemens AG for their valuable contribution: Andreas Trautmann, Andy Manley, Bernd Koch, Christian Falkenstein, Christoph Falk, Christoph Neher, Martin Kautz, Mathias Langhans, Nicolas Albornoz, Ralph Bauknecht, Ralph Brecht (in alphabetic order).

References

1. Sabine, C., Ciais, P., Jones, C.: Ask the experts: The IPCC fifth assessment report. Carbon Manag. **5**(1), 17–25 (2014)
2. European Commission: Der europäische Grüne Deal. Mitteilung der Kommision an das Europäische Parlament, den Europäischen Rat, den Rat, den Europäischen Wirtschafts- und Sozialausschuss und den Ausschuss der Regionen. Brussels, 2019/12/11
3. Alavi, H., Vecchia, L.F.D., Forcada, N.: Digital twins' applications for building energy efficiency: a review. Energie **15**, 7002 (2022)
4. Kritzinger, W., Karner, M., Traar, G., Henjes, J., Sihn, W.: Digital twin in manufacturing: a categorical literature review and classification. IFAC-Papers OnLine (2018)
5. Hosamo, H.H., Imran, A., Cardenas-Cartagena, J., Svennevig, P.R., Svidt, K., Nielsen, H.K.: A review of the digital twin technology in the AEC-FM industry. Adv. Civ. Eng., 2185170 (2022). https://doi.org/10.1155/2022/2185170
6. Resman, M., Turk, M., Herakovi, N.: Methodology for planning smart factory. Procedia CIRP **97**, 401–406 (2021)
7. Schuh, G., Kelzenberg, C., Wiese, J., Kessler, N.: Creation of digital production twins for the optimization value creation in single and small batch production. In: 53rd CIRQ Conference on Manufacturing Systems (2020)
8. Yu, W., Patros, P., Young, B., Klinac, E., Walmsley, T.G.: Energy digital twin technology for industrial energy management: classification, challenges and future. Renew. Sustain. Energy Rev. **161**, 112407 (2022)
9. Strielkoswki, W., Rausser, G., Kuzmin, E.: Digital Revolution in the Energy Sector: Effects of Using Digital Twin Technology. In: Kumar, V., Leng, J., Akberdina, V., Kuzmin, E. (eds.) Digital Transformation in Industry – Digital Twins and new business models. Lecture Notes in Information Systems and Organisation, vol. 54, pp. 43–55. Springer, Cham (2022)
10. Erkoyuncu, J.A., del Amoa, I.F., Ariansyaha, D., Bulkaa, D., Vrabic, R., Roy, R.: A design framework for adaptive digital twins. In: CIRP Annals - Manufacturing Technology, vol. 69, pp. 145–148 (2020)
11. Bundesamt für Wirtschaft und Ausfuhrkontrolle: Informationsblatt CO_2-Faktoren. Bundesförderung für Energie- und Ressourceneffizienz in der Wirtschaft – Zuschuss. 1.1. (2021)
12. Umweltbundesamt: Entwicklung der spezifischen Treibhausgas-Emissionen des deutschen Strommix in den Jahren 1990–2021. Climate Change 15/2022 (2022)