BIM Use-Case: Model-Based Performance Optimization

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Abstract

This contribution demonstrates the application of a building information modeling (BIM) use case including solar thermal collectors, photovoltaics (PV) and passive solar heating. It aims to close the performance gap that results from inconsistencies between the individual planning phases. Furthermore, it is shown how the pairing of the building project with a digital twin allows to set up predictive maintenance services and minimize the downtime of heating systems. Simulation software is used to create coupled models of the building and its facilities. For a case of PV combined with a heat pump and passive solar heating, this paper shows how the digital model is continuously and automatically updated as conditions change. With a focus on the building's energy demand, control parameters are optimized in alignment with the hardware. Thus, the energy demand is kept within the close range of the original estimation throughout the standard planning phases.

Keywords: PV, heat pump, building information modeling (BIM), digital twin, simulation, predictive maintenance, remote fault rectification

1. Introduction

Various standards (Bundesarchitektenkammer, 2013; SIA, 2015, 2014) provide a guideline for the planning, realization, and operation of building projects, categorized into different phases. While the individual tasks and responsibilities are clearly defined for each phase, the current state of the art lacks a way to ensure consistency throughout the entire project.

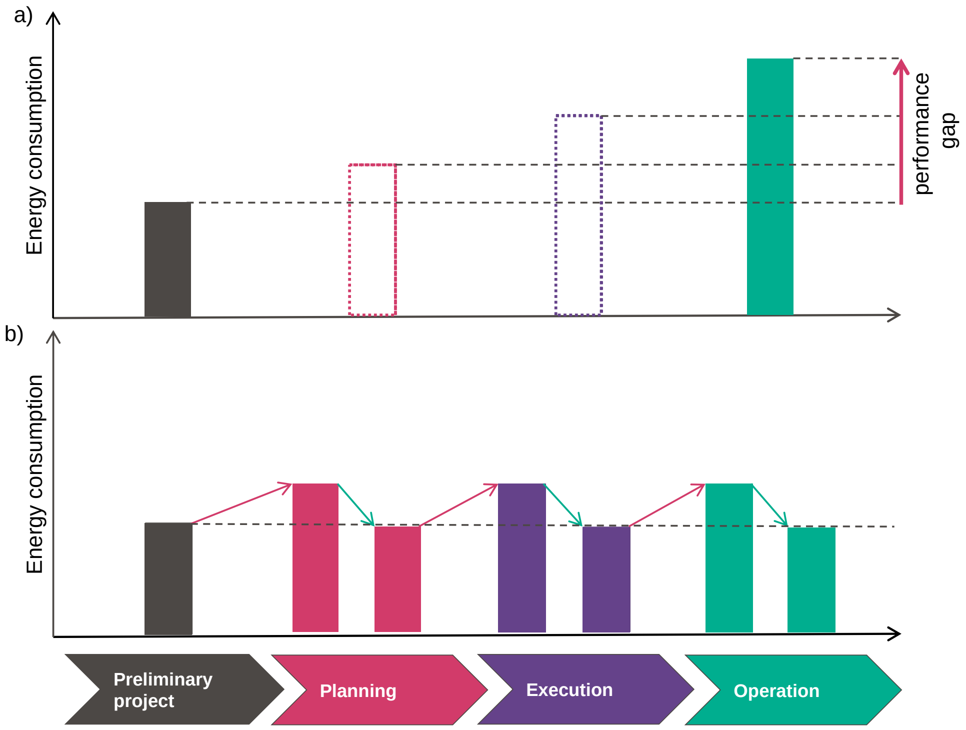

Fig. 1: Qualitative visualization of the performance gap that occurs throughout a project's phases (a) and the closing of the gap by pairing the project with a digital twin (b).

Since responsibilities are passed on to persons of different professions, miscommunication is certain to occur. Adjustments that must be made in later stages are seldom reflected in the earlier phases' documentation. This results in a performance gap (Fig. 1a) and ultimately in unforeseen cost increases for many of the involved parties. In recent years, BIM has been gaining more and more popularity on a global scale thanks to its ability to keep track of changes and adjust models automatically. Its use, however, has mostly been limited to the minimization of material costs (Eastman, 2011), without regarding the energy consumption. This case study augments the use of BIM to include the building's energy facilities and their control parameters, making it possible to continually eliminate performance gaps, as shown in Fig. 1b.

2. State of the Art and Challenges

2.1 Collaboration Guidelines

In the DACH region, there are currently three main standards that provide the state-of-the art guideline for the realization of building projects and the collaboration between involved parties:

- HOAI 2013 in Germany (Bundesarchitektenkammer, 2013)
- SIA 112 in Switzerland (SIA, 2014, p. 112)
- ÖNORM B 1801-1 in Austria (ASI, 2009)

They all provide similar guidelines, with differences regarding the exact division of the development process into various phases. Overall, the potential for performance gaps is the same for all three standards. This section examines SIA 112 more closely and describes some of the problems that may arise during its application. The standard divides a building project into six main phases, whereby each phase is subdivided into multiple smaller processes, resulting in a total of 63 sub-phases. Brief summaries of the six main phases are provided in Tab. 1. In the first phase, the commissioner defines the building's requirements such as the building standard and its use. At the same time, an information manager devises the specifications of the building service installations. Using these specifications, a building designer analyses the marginal conditions and devises a concept in phase 2. It is here that the energy demand is estimated for the first time and in phase 3 that the central components (heat pump, buffer storage tank, etc.) are decided upon. Traditionally, the initial concept is documented on paper, i.e. in a functional specification document (SIA, 2014). Thus, any changes (e.g., in the architecture or use of the building) that occur later are not easily reflected in phase 2 and often ignored by phase 3. This potential for a performance gap takes place two more times during this phase. Once, when the smaller components, such as pumps and valves, are defined – for the same reason as the first performance gap occurrence – and once when the initial control strategy and parameters are developed. A modern planning bureau may engineer the control strategy early on using simulation software. This can provide great benefits for the system's efficiency. However, there is currently no simulation tool for building facilities that enables a standardized definition of the control logic. If the building automation technician is not well-versed in the simulation software, the initial control strategy is likely to change and, in a worst-case scenario, to be revised completely. Even if the automation engineer implements the control logic without any changes, there is further potential for performance gaps when a communication protocol is decided upon and incompatible components are replaced without re-optimizing the control parameters accordingly in phase 5. Finally, unforeseen occupant behavior in phase 6 is a very common issue that can significantly impact the effectiveness of the control strategy (de Wilde, 2014).

Tab. 1: The main building project phases defined by SIA 112.

#	Phase	Description/Goals
1	Strategic planning	Definition of requirements and determination of solution strategies.
2	Preliminary studies	Definition of the building project; feasibility analysis; choice of project and executors that best fit the requirements defined in Phase 1.
3	Project planning	Optimization of concept and profitability; definition and verification of costs and deadlines; approval.
4	Tendering	The closing of purchase and work contracts.
5	Execution	Implementation and commissioning of the project.
6	Facility management	Operation, monitoring, inspection, maintenance.

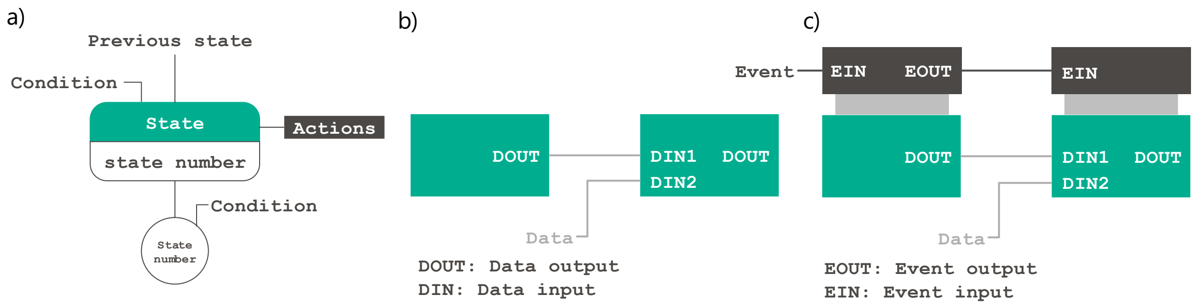

Fig. 2: Qualitative representations of the three standards commonly used in the automation industry: a) State machine (VDI 3812-14); b) FBD (IEC 61131-3); c) FB (IEC 61499).

2.3 Control Standards

Regarding the design of control logic using simulation tools, a common drawback is the fact that it rarely conforms with industry standards. The widely-used prototyping tool Matlab/Simulink, for example, utilizes a proprietary programming language. -The simulation tool Polysun's programmable controller follow a state logic principle as it is well known from programmable logic controller implementation. Functional calculations and boolean operations are offered similar to spreadsheet applications such as Microsoft Excel. While these languages make control systems more accessible for designers and theoretical researchers, they also result in an additional potential for performance gaps, since the control logic must be ported to standardized languages by building automation technicians. To improve communication between designers and automation engineers, it is necessary to devise a method of linking simulation software with standardized automation logic. Common standards in the automation industry include VDI 3812-14, IEC 61313-3 and IEC 61499. The German VDI 3812-14 provides an easy to read, graphical description of control logic using UML (unified modeling language) state machine (or UML statechart), depicted in Fig. 2a. (VDI, 2018). IEC 61131-3, the most widely-adopted standard in the automation industry (Bolton, 2015), describes six graphical and textual programming languages (IEC, 1993), which are implemented by various integrated development environments (IDEs), such as CoDeSys or MKS Instruments. A relatively new standard, IEC 61499 builds upon IEC 61131-3's graphical "Function Block Diagram" (FBD) language, depicted in Fig. 2b, with the improved "Function Blocks" (FB) language (IEC, 2017), shown in Fig. 2c. Instead of relying on a procedural data transfer, function blocks' internal algorithms are activated by event inputs, and data transfer is triggered by event outputs. Thus, the algorithms and data flows are decoupled from one another. Though it is not as widely adopted as its predecessor, the standard provides an increased flexibility and the ability to develop far more complex control logic (Zoitl, 2014). Furthermore, IEC 61499 applications are mostly XML-based, which allows for cross-compatibility with various runtime environments and IDEs. Exemplary IDEs used for the development of IEC 61499 compliant control applications are 4diac-IDE, FBDK, ISaGRAF, and NxtONE.

2.2 Current Research

Some work linked predictive simulation tools used in the planning phase with the programming of heat pump controllers (Grosskopf, 2017). As an important result, this work lists the mapping between the control parameters used in the simulation and the possible settings in the controller hardware. Furthermore, the identification of heating systems on the basis of log data and subsequent simulation-based optimization has been demonstrated by (Steiger and Shehu, 2018). It is a specific implementation of a digital twin, focusing on the energy facilities. While proposing a software interface to bridge the gap between the planning tool and the hardware and describing the processing of log data in the context of a digital twin, neither of the above-mentioned work reflect the information flow and the operational procedures in the real planning processes.

3. Model-based performance optimization (MPO)

3.1. MPO Use Cases

This case study involves two use cases, both focusing on the continuous use of simulation software to maintain a digital twin of the building project throughout all its stages. Their difference lies within the approach of eliminating the performance gap for the control logic: In the first use case, the simulation software used for designing the control logic and setting its parameters, exports the data to the VDI 3812-14 state machine format, described in section 2.3, to eliminate miscommunication between the designer and the building automation engineer.

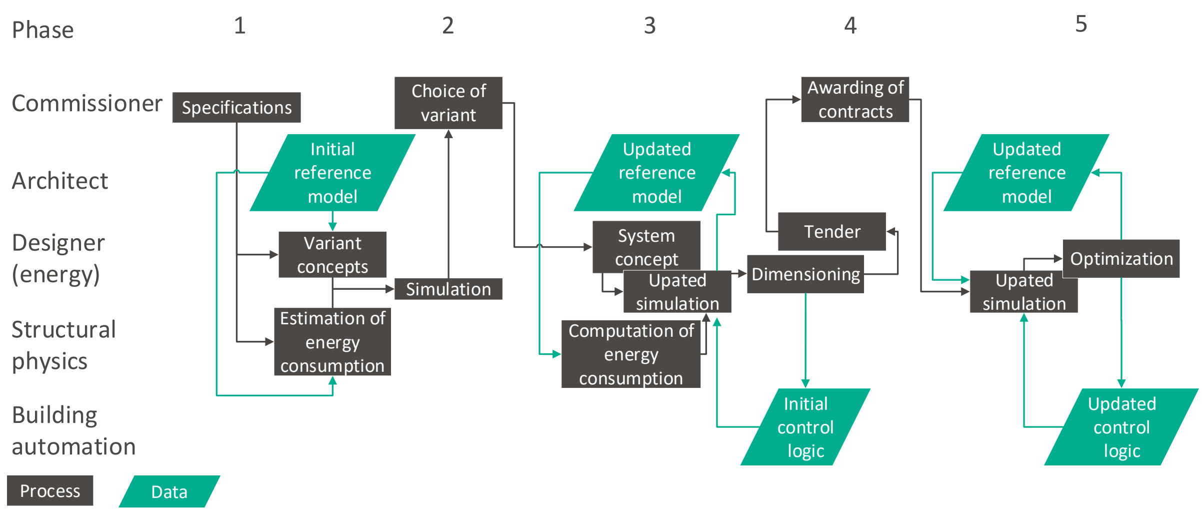

Fig. 3: BIM Use-Case. Simplified schematic representation of Operational Procedure (Meier, 2018).

The second use case is a manual simulation of a scenario in which the control logic is exported by the simulation software into a format that can directly be deployed to the control hardware. To simulate this use case, the control logic is implemented using the IEC 61499 compliant open-source IDE, 4diac and linked with the Simulation tool, Polysun, and MATLAB, via two plugins (Jakobi, 2017) that implement compatible communication protocols. It is envisaged that both use cases be combined to one in the future, with the state machine export of the former being used to aid the integration of the automatically exported IEC 61499 control logic into the system. For brevity, both use cases are described as if they were already combined from henceforth.

3.3. Implementation

During the implementation of the case study, the necessary steps and data flows were documented in a detailed process schematic (Meier, 2018). Fig. 3 provides a simplified representation of the resulting MPO operational procedure. After receiving the specifications from the project commissioner, the architect devises an initial reference model. Based on the reference model, two simulation models are linked via a BIM data platform: A building model (e.g., IDA-ICE or DOE-2) that represents the geometries and climatic parameters and performs simulations to estimate the thermal energy demand, and an energy systems model (e.g., Polysun or MATLAB Simulink with the CARNOT Toolbox) that uses the previously determined thermal demand as a basis for the simulation of the building facilities. The energy systems model combines the thermal technology simulations with electrical components and accounts for the dynamics of energy storage. In a first step, the most important components (PV, inverter, heat pump) are chosen based on weather data and dynamic simulations with a simple control logic applied. With the results, the designer can present the commissioner with multiple variants with a feasibility analysis.

The initial concept is then synchronized with the BIM data platform and a detailed building simulation is performed with the variant chosen by the commissioner. After specifying a detailed facility schematic and 3D model, the provided data are used for more detailed energy system simulations in a coupled setup. In our case study (Fig. 4), it is shown how initial optimizations of the energy consumption are achieved by utilizing Polysun's controller plugin to incorporate a control logic based on (Tjaden et al., 2017). Implemented in 4diac, the control application is handed to an automation engineer in an XML format. The actual control logic can be used as is, without any changes. It is merely necessary to replace the communication interface so far used for co-simulations with one that can connect to the real components. A graphical description of the control system in the UML statechart format provides simplifies this process. Thanks to the ability to integrate the control application directly into the simulation software, refinements made can be integrated into the updated simulation model. This process occurs in a loop until no further optimizations are possible, and is repeated when the smaller components (pumps, valves, etc.) are defined. Furthermore, an update of the reference model triggers an additional repetition of both control optimization loops. After tendering, if the concept is changed due to the awarding of contracts, the simulation models are updated, and the optimization loops are repeated once again with the updated model.

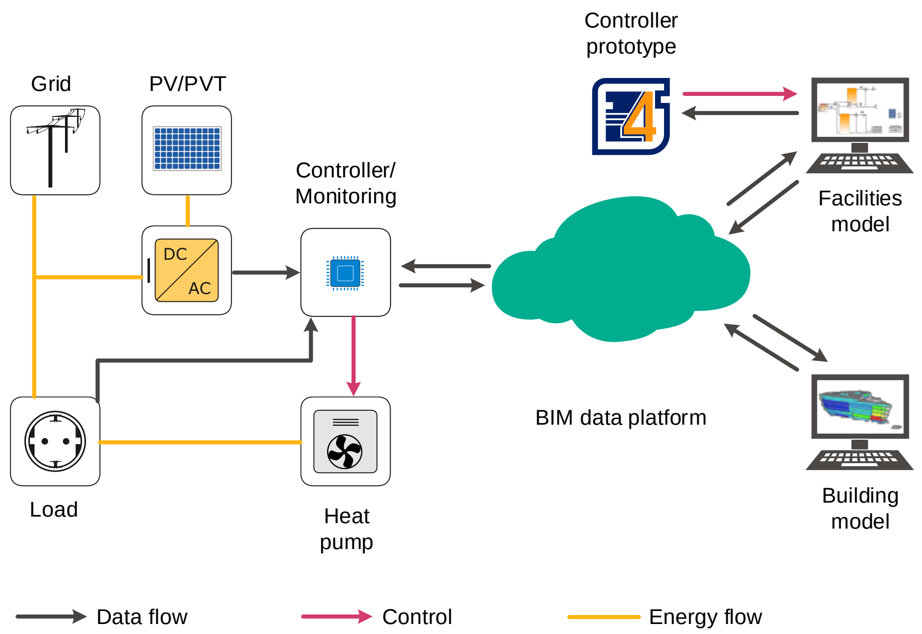

Fig. 4: Visualization of the case study.

Apart from optimizing the heat pump's operation, the IEC 61499 application is designed in such a way that it supports periodical synchronization of control parameters with the BIM data platform, potentially allowing to optimize the control logic remotely without interrupting the running system. Once the controller is applied to the building, the energy production and consumption will be continuously monitored, and the data will be sent to the BIM platform, from where they will be used in the dynamic system simulation for the optimization of control parameters and system components.

3.3. Implementation Levels

The implementation levels of a step-by-step plan for the digital transition based on (Jost et al., 2018) is depicted in Fig. 5. Stage 0 describes the status quo of Switzerland – the currently most common case, in which all involved parties work without simulation models and all data transfer between the parties is analog. In stage 1, the analog data transfer is not eliminated yet, however, individual participants of the project perform their planning based on simulation models. This is the state-of-the-art that is implemented in modern planning bureaus. Our use cases are currently at stage 2. The data is transferred between various digital models using standard protocols. Yet the data transfer does not occur automatically. While this stage requires an increased amount of dedication from all parties, it is an important step on the way to stage 3 (Jost et al., 2018).

In stage 3, all collaboration processes (i.e. data transfer) are fully automated for the digital models. This stage is the first milestone for the MPO process. Finally, stage 4 describes the link between physical systems and their digital twins. While it has not been reached, our use cases are designed with this stage in mind.

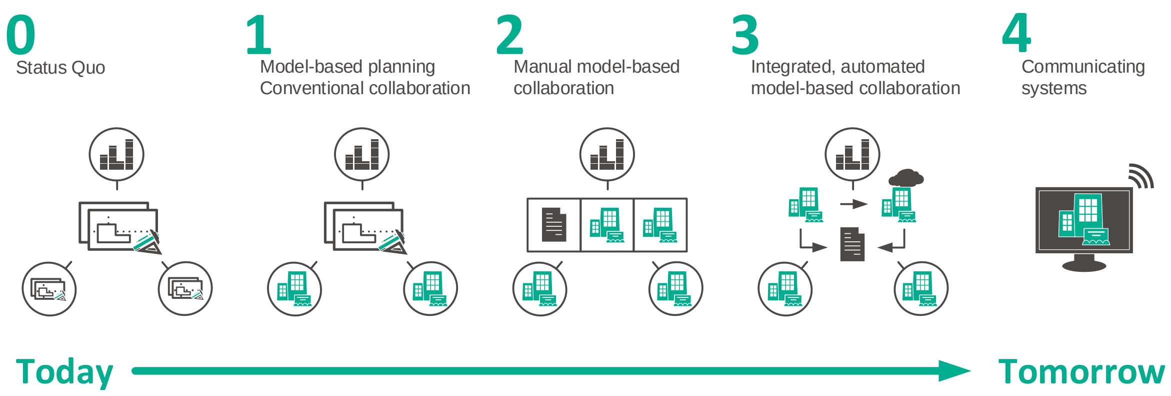

Fig. 5: Step-by-step-plan for the digital transition (Jost et al., 2018).

3.3. Lessons Learned

From previous scientific work, from experience in software engineering and from the support hotline of a commercial planning tool, some lessons learned can be summarized in order to support a successful implementation of supporting tools aiming to facilitate model-based performance optimization.

Create an awareness of the project risks

It is a challenge to motivate project owners to change from the traditional project management to a BIM process. In particular, the costs of the potential energy savings are often not the driver for MPO or for including energy simulation into the BIM process. However, recognizing the project risks as a potential cost hazard is often the basis for a decision to implement a digital twin and systematically avoid the performance gap by use of MPO. Legislation nowadays enforces good energy performance of buildings in the application phase. In a few years, periodical inspections will be required, revealing any performance gaps. High refurbishment costs may occur late in the project or even after closing the project as a consequence of a guarantee claim.

Ensure consistency of data while avoiding the sharing of proprietary or protected data

Many of the powerful players in the building industry try to push their own software solution to become a host for the project-wide BIM data platform. While one single master database in which all information regarding the building process is stored would be a good technical solution. However, nobody volunteers to give relevant proprietary data out of his hand and some information is by law prevented from being shared. In consequence, the BIM industry has to face the fact that in the future numerous databases exist in parallel, potentially with overlapping contents. Continuous consistency checks are a viable remedy for this situation. Software solutions have to support version information and a "consistency flag" indicating that data has been checked and fulfills the consistency criteria. Small pieces of software running in the background and comparing change logs and parameter entries in the various databases have to validate the data and potentially give the alert to the responsible people that conflicts have to be resolved. In the current state-of-the-art, manual interaction cannot be avoided in this process.

Communication interfaces: Variety of hardware solutions & slow convergence of standards

Regarding the elimination of the performance gap by exporting control logic and parameters to a human-readable format to prevent miscommunication in our first use case, it has been found that this alone does not suffice. When the building automation technician decides on a communication protocol, it is likely to turn out that one or more of the previously selected devices must be replaced, due to incompatibility. In this case, the performance gap cannot be fully eliminated if the control application is not integrated directly into the simulation model, as in our second use case. To prevent this miscommunication in the first place, the designer requires early information about the devices' compatibilities with communication protocols. This could be achieved by integrating a list of supported protocols in each device's catalog entry. The simulation tool could then issue a warning to the user if devices with incompatible protocols are placed in the same system. Furthermore, it could use the common compatibilities of the devices to provide the automation engineer with suggestions on which protocols to implement. Combined with the second use case, such a mechanism could even have the long-term potential to eliminate the manual addition of a communication interface to the exported IEC 61499 XML control logic.

4. Validation

In the following section, the usefulness of MPO is assessed based on the experience with the above-mentioned use cases to date. Fig. 6 illustrates the evolution of the cost and energy consumption throughout the step-by-step digital transition plan (cf. section 3.3). It is self-evident that the use of simulation software alone significantly reduces costs as well as energy consumption. These reductions can be attributed to the following benefits, among others:

- The ability to compare various components and project variations in a short amount of time.
- Support in decision-making (i.e. by suggesting contemporary components based on the set energy consumption goals).
- The capability to perform complex tasks with little expertise required.

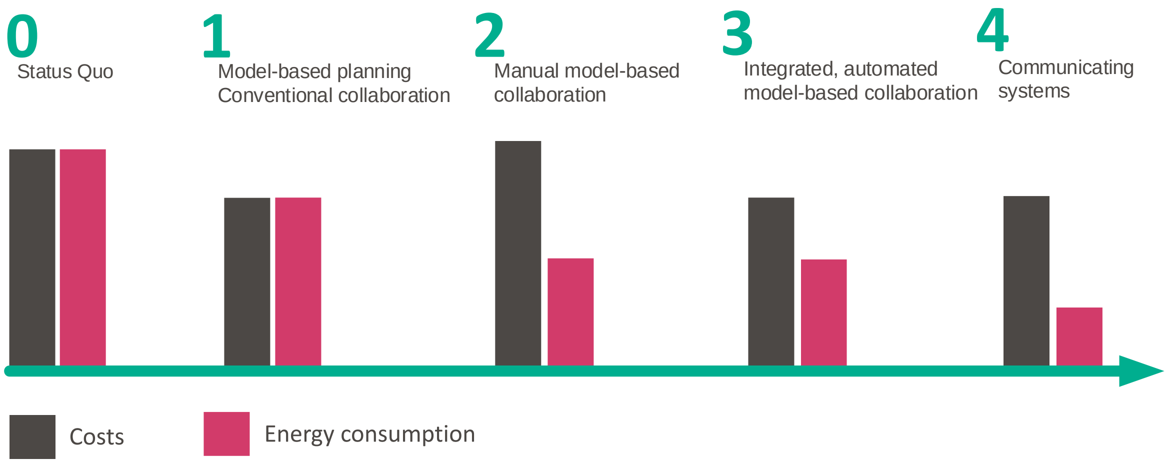

Fig. 6: Qualitative representation of the cost development and the reduction in energy consumption throughout the digital transition stages (Stages 0 – 2: Validated; stages 3 – 4: Projected).

The earlier in the pre-design stage model-based planning occurs, the higher the benefits. For example, (Raji et al., 2017) quantified that the general building design alone "can influence the energy use up to 32 %". With model-based collaboration, the energy consumption is reduced even further, since decision-making support is extended to all planning phases, and therefore helps to eliminate performance gaps. The manual process, however, currently results in a significant surcharge in costs, for the following reasons:

- A high technical expertise is required for the manual model-based collaboration.
- Participants must have proficiency not only in their own line of work but also in the fields they are collaborating with.
- A large amount of time must be invested to ensure a consistent workflow, and to ensure that the same energy consumption levels are achieved as would be expected from an integrated, automated model-based collaboration.

While significant reduction can be reached, another major drawback is the fact that the performance gap cannot be eliminated completely with today's state-of-the art technologies. There is still a long road ahead with the potential for many obstacles.

5. Outlook

All in all, the increased costs of the manual MPO process prevent it from being offered on the market today. If the contracting authority does not demand energy efficiency, there is no motivation for the designer. Another challenge is the need to redesign contracts so that they facilitate the early involvement of parties who would otherwise only contribute to the project after tendering. Nevertheless, the already validated cost reductions due to the use of model-based planning tools in stage 2 can safely be projected to the integrated, automated model-based collaboration stage. An elimination of the manual processes and their drawbacks will at the very least bring the costs back down to the same level as they were in stage 2.

Considering that the energy consumption achieved in stage 3 is unlikely to increase compared to its predecessor, an overall benefit can be anticipated. It is envisaged that the communication between running control applications and the digital models, and their continuous optimization (stage 4), will result in further performance gap reductions, and in due time, a complete elimination thereof. Though it is difficult to perform a detailed cost analysis to date, a significant change in costs compared to the previous stage is unlikely.

To conclude, the achievable welfare of the MPO process provides a high motivation to take the initial cost increase of the current, manual model-based collaboration stage into account.

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