Bringing the Digital Twin to Life

Parametric modeling of infrastructure buildings and their AI-based simulation of passenger flows.

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Summary

The number of passengers in local and long-distance public transport will increase in the next years due to the energy and traffic turnaround. This will put a new focus on the safety of people. How will a station be optimally built and used economically in the future, but at the same time ensure the safety of people?

To answer this question, the project participants of a major project in Munich, the 2nd S-Bahn Main Line, of DB Netz AG have joined forces with accu:rate GmbH, TUM and the specialist planner SSF Ingenieure for the research project BEYOND: In order to support architects, engineers and their clients in decision-making in early phases of planning or redesigning of station buildings, people flow simulations are integrated into parametric BIM models. This combination allows to quickly test and check variants using a machine learning approach. This makes it possible to obtain predictions of expected passenger flows in design variants at the push of a button and to adapt the building design at an early stage with little effort.

1. Introduction

Strengthening the railways is one of the most important projects for the mobility turnaround in Germany. This becomes clear when taking a closer look at the planned investments in the future infrastructure [1].

Especially in large-scale projects, planning errors occur time and again with traditional methods. Such projects are very complex and have to withstand many different requirements. At the same time, this way of working does not allow the many different participants to work on a common model at the same time. Many large-scale projects fail precisely because of this approach: the BER airport blew up the time and budget plan in an unprecedented way [2], the originally planned construction costs for the Elbe Philharmonic Hall were exceeded by more than 10 times [3], and planning errors in the Grenfell Tower in London even led to 71 deaths [4].

Such massive wrong decisions can be prevented or at least reduced with Building Information Modeling (BIM) by creating a common database for a building and a model on which all parties involved collaborate. At the same time, it also allows new digital planning tools to be better integrated into the process, such as engineering methods in fire protection.

2. Engineering methods: status quo

Due to increasing requirements and the growing complexity of structures, engineering methods are being used more and more frequently. Particularly in special construction, requirements often arise that are not considered in the applicable structural, general standards and specifications.

For this reason, engineering methods have become increasingly established in recent years. These methods can be used, for example, to check how a building can be safely evacuated in the event of a fire, based on protection targets.

One of the engineering methods used is people flow analysis, which can be either microscopic or macroscopic. The differences between the types of analysis are discussed in [7].

Important insights can be gained: for example, safe evacuation can be virtually replayed and examined for possible bottlenecks. Evacuation times as well as congestion times can be determined and put into context.
These variables support the fire protection planner in evaluating safety and enable him to compare variants and make decisions about compensatory measures.
Overall, planning becomes more resilient and resilient; in the event of deviations from the building code, safety can be objectively proven. This can be a great advantage especially for approvals in individual cases (ZiE) or for "proofs of equal safety".
Microscopic people flow simulations not only support the creation of evacuation concepts. They can also represent the normal case and provide important insights into the level of service [17] of the station or interchange relationships.

2.1. What is the legal basis for evaluations with simulation?

The advantages of such simulations only take effect if the results of the simulation are close to reality and reliable. They must be valid. For this reason, the creation and execution of simulations must be standardized to ensure that they are testable and can thus be admitted in approval processes.
In recent years, therefore, intensive work has been done on standardization. Within the framework of E DIN 18009-2 [6], engineering procedures in fire protection are defined as a recognized rule of technology for the performance-based verification of personal safety in special structures. This standardization is based on different preliminary work (e.g. [7], [13]). At the international level, ISO-20414:2020 Fire Safety Engineering [8] was published at the end of 2020, which also describes requirements for engineering procedures.
In occupational safety, there has also been progress in the recognition of engineering methods in the application of ASR A2.3 [5]. As part of the update of the guideline, an expert opinion was prepared in which the effects of escape route widths on the evacuation time and the evacuation process were systematically investigated [10]. The investigations are based, among other things, on the use of microscopic simulation programs. In the updated ASR A2.3, which is expected to be published in mid-2021, it should also be possible to use standard-compliant simulations in occupational safety and health to provide evidence.
The current progress in standardization clearly shows the relevance of engineering methods. Simulations for the evacuation of complex underground structures, in particular public transport stations, have already been demanded by the authorities and the fire department.

2.2. What are the hurdles in the use of such simulations?

However, creating a simulation is often time-consuming and requires deep expertise to set the right parameters and interpret the results correctly.
The method of passenger flow simulations is based on a detailed geometry that reflects current changes and planning statuses. This includes, on the one hand, the correct mapping of the geometry, in particular escape routes and escape route widths. This is where the challenge often lies: simulations are carried out on plan bases that do not contain any semantic information. This information must be added or interpreted manually by the creator.
Normally, the plans are first cleaned up before they can be transmitted to the simulation program. This results in a media break and quickly leads to errors and inconsistencies.
At the same time, important information is often missing due to 2D plans or the plans contain contradictory information, which must then first be clarified with the respective trades.
Also, 2D plans cannot be parameterized: small changes in one place (e.g., the change of the platform width) often lead to manual adjustments in the entire plan and thus make testing of different variants very time-consuming.
On the other hand, the simulation of passenger flows requires exact data on the number of people and occupancy to be considered. This data is often not available and has to be compiled additionally.

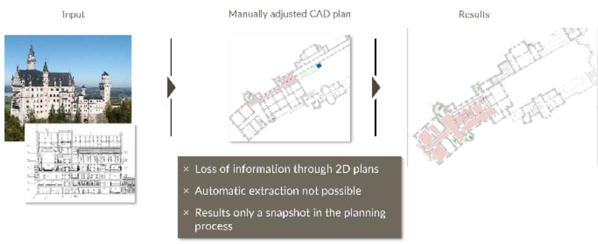

Figure 1 Schematic representation of the process for creating a microscopic simulation.

For these reasons, weeks often pass between the decision to use simulation as a verification method and the results of the simulation. This leads to the fact that the results, when they are available, can already be outdated due to a more current planning status (see also Figure 1).

In the worst case, every change in the plan has to be made manually, which often makes the (repeated) use of such methods unattractive.

To avoid this problem, simulations are usually not created until the approval planning stage. However, it is hardly possible to incorporate changes and findings from the simulation into the planning at that point.

Access to the results is also not integrated: Simulation reports, for example, are submitted with a fire protection concept for approval and are not used further. However, they could also provide great added value during operation and be used as a basis for decisions on subsequent conversion measures. So far, however, they remain only a snapshot of the specific planning status.

In summary, it can be said that, on the one hand, the media disruption generates a not inconsiderable manual effort to create simulations. On the other hand, the findings cannot be used to the extent that would be necessary to guarantee safety and economic efficiency at the same time.

3. Costs and effort: solution BIM?

Simulations can lead to major efficiency gains already in the planning phase, which only become visible during operation. The reason why simulations are not used more often in the design of a building is mainly because costs and benefits are not always in proportion or are only balanced out again later in the entire life cycle of a building.

So what can be done to

a) overcome the media discontinuity and reduce manual efforts,
b) integrate simulations deeply into the planning process and use them in a repeatable way,
c) and thus, guarantee safe, sustainable and economic planning for the entire life cycle?

The answer is to use the BIM working method. This will be explained in more detail in the next sections.

3.1. What is BIM?

BIM stands for Building Information Modeling and is increasingly used in construction planning projects. In the planning of public infrastructure projects, it is already mandatory to plan with the BIM process in the near future [15]. Deviating from the previous planning process, planning is to be carried out here using a 3D (4D/5D/xD) model across different trades on a common digital model. Different views of the model enable the respective trades to incorporate their specific information into the model. In this way, the basis for a so-called digital twin is created even beyond the construction period. This corresponds to a digital copy of the building with all its details. Formerly 2D drawings without semantics thus become virtual objects that can be provided with specific properties and made parameterizable. A wall is then no longer just a line in the plan, but is modeled as a wall object and thus carries properties, such as the material, the fire resistance, the mass, etc. The wall object can also be parameterized.

3.2. Which gap does BIM close?

In the semantic data model, arbitrary views can be defined for the different participants in a planning or in the operation of a building. In this way, BIM creates a common information store that is always up-to-date and consistent for all participants. This shared information not only facilitates collaboration during planning, but also maintenance during subsequent operation, since the media break in the handover to operation will no longer exist in the future.

BIM enables the use of versatile analyses, including people flow simulations. Due to the object-based data management and thus existing semantics, engineering methods and other digital tools can be integrated in a continuous way. Thus, they can sustainably support the planning and operation of buildings as an integral part.

The parameterizability of the geometry also enables fast and automated testing of variants.

Standards and limit values can also be stored directly in the system and checked at any time using model checks. In contrast to the previous 2D models, all data required for analyses, e.g., in fire protection, can be stored in the BIM model. The geo-metrics are always up-to-date, even if the status of plans changes. Even in early planning phases, passenger and occupancy figures, initial information for passenger routing, transfer relationships, evacuation concepts and escape routes can be entered and checked.

3.3. How can BIM be integrated into the existing planning process?

The main advantage of the method is to provide consistent and semantic information about a building at any planning stage. For this to be successful in practice, the data model must be standardized.

The IFC (Industry Foundation Classes) data standard [12], which describes the elements and properties of digital building models, serves this purpose. The standard is continuously being developed by buildingSmart International to reflect new data requirements.

For this purpose, so-called MVDs (Model View Definitions) are required, which can be placed over the model like a kind of template to check whether all required relevant data are available in the model. To define this data, IDMs (Information De-livery Manuals) have to be developed. This is done based on typical use cases and the examination of applicable regulations, standards and ordinances.

For this purpose, working groups have been formed both in Germany and worldwide, which will work on the extension of the IFC standard over the next two years. Over the next two years, they will be working on the integration of people flow simulations.

The aim is to enable analyses to be carried out in a repeatable manner with the aid of simulations in all planning phases and to document the results in a comprehensible manner.

Figure 2 shows schematically how fire protection can be integrated into the digital building model based on data.

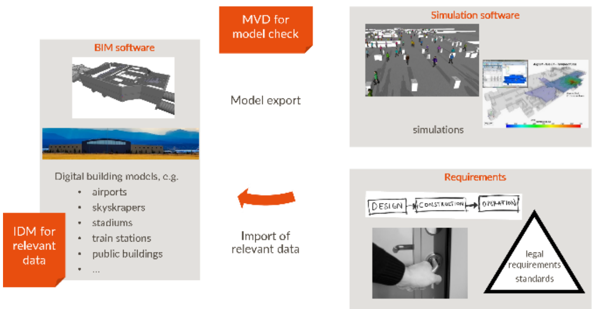

Figure 2 Overview of the future integration of fire protection into the BIM planning process

3.4. First example implementation of the process

Within the scope of two research projects ([11], [12]), the integration of engineering methods has been and is being investigated using the example of people flow simulations. In a first pilot project, it was possible to automatically check the BIM model for missing input data for the simulation using an exemplary MVD (Model View Definition). The planner receives detailed feedback on the missing data and can immediately update the model.

An automated interface can read in the BIM model checked in this way (the microscopic simulation program crowd:it [16] from accu:rate was used in the research project) and a simulation can be created from it with only a few manual steps.

The results were visualized in the form of videos in the existing BIM model. An overview of the process is shown in Figure 3.

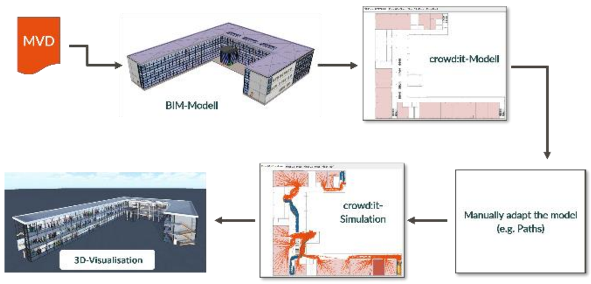

Figure 3 Schematic overview of the automated integration of people flow simulations into the planning process, after completion of the AHEAD project.

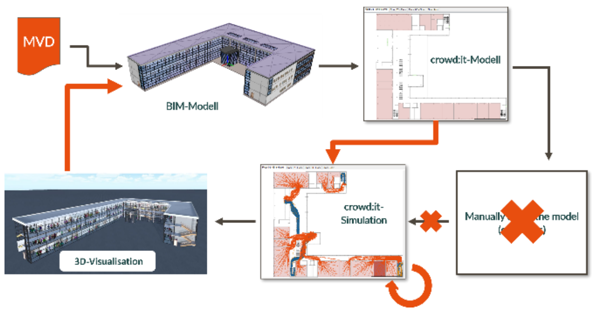

Figure 4 Schematic overview of the automated integration of people flow simulations into the planning process, after completion of the BEYOND project.

In order to automate this process, the data models must be standardized. A working group "Occupant Movement Analysis" at buildingSmart International has just started its work to systematically identify which data are missing in the standard and how they can be supplemented.

This work is financed, among others, by research funds from the successor project BEYOND [12]. The goal in BEYOND is also to persistently feedback the results of the simulations to each planning state and thus have them available at any time (see Figure 4).

A deep integration of people flow simulations into the planning process allows simulations to become repeatable without significant effort. This in combination with parametric modeling paves the way for the use of simulations as data generators for AI.

3.5. Parametric Models as a Basis for AI-based Analysis

As an approach to design exploration during the design phase, parametric designs [18] enable the automatic generation of realistic and rule-compliant designs. The main concept is that the necessary logic for combining the different components is defined using a programming language, such as Python, and adjusted by a set of input parameters. The different combinations and the interaction between these parameters lead to numerous design variants. Examples of existing tools that support parametric modeling are Dynamo [19] and Grasshopper [20], which provide direct integration with Autodesk Revit [21] and Rhino3D [22].

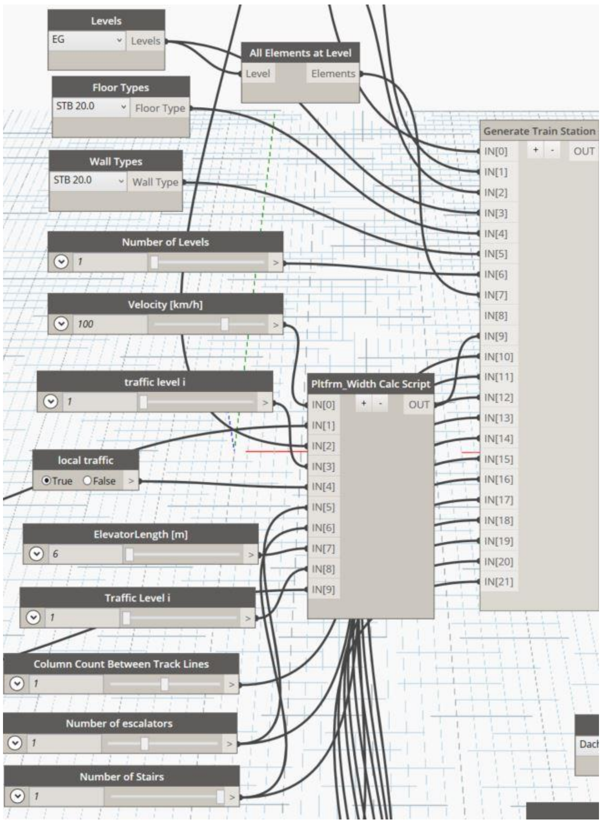

Figure 5 Example parameterization in Dynamo

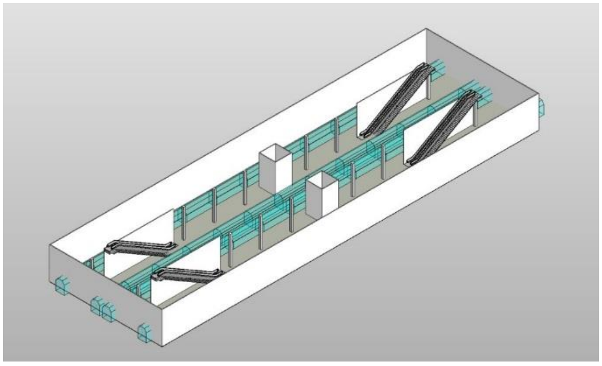

Figure 6 Parameterizable model

Figure 5 and Figure 6 show an example of a parametric dynamo model that takes multiple inputs to automatically generate valid design variants of a station. The various parameters are combined and passed to a logical description implemented in Python to automatically generate a station design.

Recently, artificial intelligence (AI), especially deep learning (DL) models, have shown great progress in various tasks, such as image segmentation and generation [23]. Accordingly, such models have great potential to achieve breakthrough performance in predicting performance and analysis results in real time. However, such DL models require an enormous amount of data to understand the relationship between the building information (neural network input) and the simulation results (neural network output). Such an amount of data is currently not available and requires a lot of manual preparation to be ready for use. Here, parametric models can provide a solution to overcome this limitation. Parametric models can encode various rules, including building codes and company-specific regulations. In addition, parametric models can enrich the building models with "simulation-specific" information, which can facilitate the achievement of a fully interconnected and smooth workflow for generating a sufficiently large dataset of building models and their corresponding simulation results.

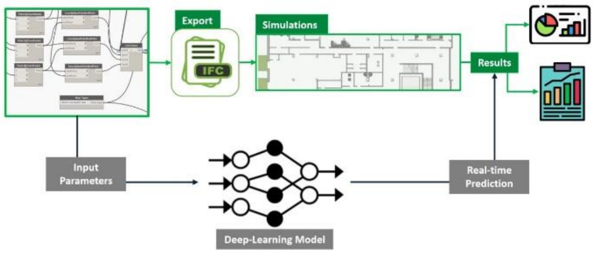

Figure 7 Overview of the integration of the AI process for variant generation.

Figure 7 illustrates the proposed concept for the generation of the data set by the parametric model. First, several different parameter variations are performed, with each design variation exported to IFC. Then, all IFC files are automatically simulated, generating several types of results, such as evacuation times and densities. Subsequently, this data is used to train a DL (Deep Learning) model, using the parameters of the parametric model as input and the simulation results as output. Once the DL model is sufficiently trained, it can be used to provide real-time recommendations during the design process. Such seamless integration of passenger simulation with BIM authoring tools helps in making informed design decisions to achieve higher performing designs.

4. Outlook

The approaches presented here open unprecedented opportunities in the design phase and operation of infrastructural buildings.

Based on the BIM method, deep-learning models can be trained with the help of parameterizable models and people flow simulations in such a way that a large number of design variants can be examined and evaluated at the push of a button.

In this way, the optimal and approvable designs can be identified very early in the planning phase.

This simplifies the planners' work immensely and planning errors can be reduced to a minimum.

BIM in the entire planning process offers many opportunities for the future. Not only can complex buildings be planned and built efficiently and with fewer errors, but the planning is also documented transparently and comprehensibly.

BIM unfolds its added value over the entire life cycle of a building: The planning process is only a small part of this.

If it is possible to transfer the data model to later operation and to keep it consistently up to date, this leads to considerable cost reductions and higher safety of infrastructural buildings.

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