BIM-integration of sustainable building certification criteria in the early design stages

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Abstract

Building certification systems, such as the one developed by the German Sustainable Building Council (DGNB), present a common and holistic baseline of sustainability in a building context. They provide designers and engineers with a concrete set of measures that can be implemented to optimize a building and make it more environmentally, socially and economically sustainable. However, sustainability is currently still more of an afterthought in the building industry, due to lack of information in early design stages. Therefore, it is necessary to reconfigure the conventional design process to include sustainability aspects as a design requirement from the very beginning of the planning process. Building Information Modeling (BIM) is well-suited to support such a process.

In this paper, current approaches for integrating DGNB certification criteria into the BIM process are analyzed and relevant criteria for the early design stages, which are able to be depicted within a digital model, are identified. A holistic method is then developed, which can be adapted to all identified criteria, for the optimization of sustainable buildings. This method consists of attribute matrices, which contain detailed model information requirements that can be validated with a model-checking software. Based on the attribute matrices, a sustainability optimization method was developed for the early design stages, utilizing custom model-checking rulesets that enable an iterative optimization process, which can support design decisions through straightforward and instant results.

Two representative example criteria were implemented for model validation. It was discovered that for qualitative criteria the model spaces and spatial relationships are important for determining if the sustainability requirements have been fulfilled. Quantitative criteria, on the other hand, depended more on the specific material and object-based information stored in the model.

Keywords: Sustainable building, early design stages, Building Information Modeling, model-checking, design decision support

1 Introduction

The Architecture, Engineering and Construction (AEC) industry currently produces nearly 40% of global carbon dioxide emissions, consumes about 30% of the world's resources, including 12% of global water use, and produces 40% of global waste [1]. It is therefore undeniable that the conventional building design and construction process must be reconfigured to include sustainability aspects as a design requirement from the very beginning.

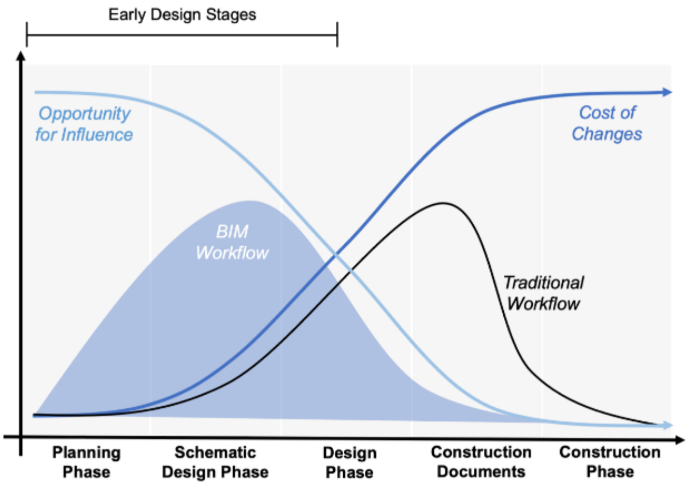

Figure 1: Influence and cost of design changes per planning phase [2]

In the early design stages, the ease with which the design can be influenced is high and the costs and effort associated with making design changes is still low (Fig. 1) [2]. Specifically, the type of construction, the materials selected for the design, as well as energy efficiency measures and building operation concepts can still be influenced the most in these early stages. The criteria catalogs provided by established sustainable building certification systems, such as the DGNB, are fundamental in supporting these early design decisions, as they are set up to help define design objectives by offering concrete recommendations and assessment structures.

By placing emphasis on the early design stages, a disjointed and reactionary design process can be replaced by a more integrated and collaborative approach. This integrated planning process has become a defining feature of sustainable building and Building Information Modeling (BIM) is optimally suited to support such a process [3]. In recent years, BIM has become known as an effective organizational and technological advancements in the building industry. BIM encompasses three main dimensions: a digital representation of a planned or built structure, a process of information exchange, and a system of management and collaboration through which the quality and efficiency of a structure are increased [4]. However, currently a comprehensive link between the BIM methodology and holistic sustainability requirements laid out by building certification criteria is still lacking.

2 Background & Related Work

Integrating the sustainability certification process into the BIM methodology can lead to many benefits. Above all, a proper integration with BIM improves the communication and information consistency between all project participants [5]. Specifically in the early design stages, different design variants can easily be compared with respect to environmental, social-cultural, and economic factors [6]. By having one centralized building model as a single source of truth, that is always up to date, the repetition of recollecting data every time the model is updated can be reduced. Sharing the required data, plans and information about the building can also be done more easily and directly using the building information model and does not depend on drawings that are generated by each stakeholder, which can vary greatly in depth and quality. Certain values that are required for the certification can be generated directly within the model and checking of these values can even be automated. Furthermore, simulations can be carried out more easily and it is no longer necessary to create a new simplified model each time the design is changed [7]. By combining the BIM methodology with the conformity-based workflows of the certification systems, more consistent models and results can be generated and the certification processes can become more standardized and efficient.

The approaches listed in Table 1 have been developed in an attempt to optimize building sustainability by integrating the DGNB certification criteria into the BIM methodology. The different approaches were analyzed based on their degree of BIM integration, open BIM approach, applicability to all criteria, integration check and link to documentation.

Table 1: Comparison of DGNB/BIM integration approaches

Approach	**Degree of BIM Integration**	**Open BIM**	**Applicability to all Criteria**	**Integration Check**	**Link to Documentation**
Systemic [8]	Low		X		
BEAM/BPS [9]	Medium				X
IDM/MVD [7]	Medium	X			
Phase [10]	High	X			
Rule Set [11]	High	X	X	X	
Attribute Matrix [5]	High	X	X	X	

Based on the results in Table 1, the first four approaches were disregarded because they did not clearly define how the information that was to be incorporated into the model needed to be prepared and organized, the approaches were not applicable to a wide range of criteria and they did not provide a method for checking whether the integration had been successful. The Rule Set Approach mainly focused on the validation of specific requirements using a model checking software but was missing a standardized information structure with which to organize the required information for a successful implementation. The Attribute Matrix Approach, developed in 2019 at the Leibniz University in Hannover as part of the ONIB research project [5] was ultimately found to be the most coherent and practical for the use case of performing sustainability optimizations and certifications. It was selected as the basis for further research due to its high degree of BIM integration and its emphasis on open BIM workflows. It also presented the greatest detail for adequately documenting and incorporating the sustainability requirements set forth by the DGNB and developed a clear methodology for validating its results using a model checking software.

However, the Attribute Matrix Approach was focused mainly on checking for DGNB compliance, only included criteria that could entirely be depicted within the building information model and provided highly detailed compliance outputs that lacked feedback about the actual design itself. It was therefore decided to take this approach one step further and create an iterative sustainability optimization tool that was applicable to as many DGNB criteria as possible. This new approach could deal with a wide range of different criteria requirements and produced a simplified output to provide overall feedback about the designs sustainability while also providing suggestions for improvement. To ensure that the tool would be applicable to the greatest number and range of criteria it was first necessary to carry out a detailed analysis of the DGNB sustainability criteria.

3 Sustainability Criteria Analysis

To understand the holistic benefits that can be achieved through sustainable design, it is essential to consider not only the environmental aspects but rather use the threefold definition of sustainability that equally values the economic and social aspects as well. On this basis, the certification system selected for concretely defining sustainability requirements in this analysis was the DGNB. It is the first system of the 2nd generation of sustainable building certifications that is based on the idea that a sustainable building should ensure the following:

- Environmental protection, by conserving resources (including materials, energy and water) at all building life cycle stages
- Economic viability, by keeping investment risk as low as possible and saving costs in the long term
- User-focus, by prioritizing health, well-being and user comfort, and creating high-quality, flexible indoor and outdoor spaces that are suitable for long-term use. [12]

To create an early design stage sustainability optimization tool on the basis of the DGNB criteria and BIM, it was necessary to determine which DGNB criteria could be considered applicable in the early design stages and which would benefit from an integration into a digital model-based workflow.

3.1 Early Design Stage Analysis

Integrating sustainability within the early design stages, poses the highest potential for optimization through variant-based design decisions, while also fundamentally incorporating sustainable thinking into the traditional design process. To determine which criteria could be considered relevant in the early design stages, an in-depth analysis of the detailed DGNB criteria descriptions was carried out in Excel. The descriptions were divided into planning, design, construction, and post construction, such as facility management (FM) aspects, with the aspects planning and design encompassing the early design stages. Each criterion was broken down into its individual indicators to determine exactly what parts of the criterion were applicable in which stage of the design and construction process. It was also noted which type of documentation was required for each indicator, as certain indicators only required that a material or element be verified after the building is completed. However, the decisions regarding the material selection or object placement must already be made during the design stage. Once all indicators had been placed in their respective categories, the overall applicability of the criteria was decided based on how many indicators it had in each aspect. The overall applicability was denoted using the symbols '+', 'o' and '-', with '+' indicating that the criteria could be fully considered in the early design stages, 'o' indicating that some indicators fell into the planning and design aspects, however, a substantial number of indicators could not be fulfilled until the construction or post-construction stages and '-' indicating that a criterion could only be considered after building construction had been completed. In creating an overview of the criteria that were relevant in the early design stages, both '+' and 'o' criteria were considered applicable. The 'o' criteria were also included because even if not all indicators were fulfilled in the early design stages, they often included elements that needed to be considered or at least communicated in the early design stages.

Overall, the analysis revealed that 30 of the 37 criteria, which based on the DGNB weighting system accounts for 87.9% of the achievable points, could be considered applicable in the early design stages (see Table 2 for an overview of all applicable criteria). Most criteria that were deemed not applicable in the final analysis fell under the DGNB topic 'Process Quality'. This topic is mainly focused on increasing the construction quality assurance and incorporating facility management aspects, making the criteria more relevant in the construction and building use stages instead of the early design stages.

3.2 Digital Model-based Workflow Analysis

Following the early design stage analysis, all DGNB criteria were analyzed for their ability to be represented and verified using a semantic building information model. The goal of the analysis was to determine whether added value could be achieved through model integration. For this analysis, each criterion was again split into all its respective indicators to get the most accurate results. For each indicator, the type of output (i.e., plan, simulation, photo, etc.), as well as the specific attributes that needed to be included within the output were recorded. Including detailed output information was key in determining if the indicator had the potential of being depicted in a building information model, as the output is ultimately what needs to be created or achieved to attain points for the indicator. The analysis also included a specific section for the added value that could result from digitalization. This was included as a type of feasibility check and preliminary filter. It was included as a chance to critically assess the effects of integrating everything into a digital model in terms of time expenditures and realistic levels of detail that would be necessary. The added value section was also used to help determine the overall ranking of the indicator regarding the digital model-based workflow. Like the early design stage analysis, the symbols '+', 'o' and '-' were used. The '+' denoted indicators that could be fully represented in a building information model and provided a definite added value from being integrated into the digital workflow. The 'o' was used for indicators that could only be partially included in the model but where the added value was still clear. This included indicators that potentially required geographic information systems (GIS) modelling in addition to building modelling, external simulation, storing of measurements, as-built documentation and concepts for later facility management use, scheduling for construction-based indicators, and the use of a digital model for the generation of Excel data. The '-' was used for indicators that could not be incorporated into the digital model-based workflow, such as indicators that required external verification of data sheets, specific values used in calculations, external reports and records, postconstruction measurements and written statements.

The analysis found that 28 criteria, representing 83.3% of the total available DGNB points, would benefit from an integration into a digital workflow (see Table 2 for an overview of all applicable criteria). Of these 28 criteria about 11% required a FM model, and another 11% were based on data that would typically be contained in a GIS model. A further 22% of the applicable criteria would use the model as the basis for a variety of simulations. Based on the analysis, several criteria in the 'Environmental Quality' topic would likely not benefit from an integration into the digital workflow, as they were largely based on external records and written expert evaluations. Furthermore, the 'Process Quality' topic contained numerous criteria that were omitted as they evaluated organizational tasks that are typically carried out before a digital model would be created.

3.3 Qualitative vs. Quantitative Criteria

The analyses revealed that overall, 17 criteria, accounting for 44.4% of the total DGNB score, were both applicable in the early design stages and would benefit from an integration into a digital workflow (see Table 2). Of these 17 applicable criteria, about 30% were categorized as qualitative, dependent on subjectively defined parameters, and approx. 70% were quantitative and could be expressed by objective, predefined parameters. This skewing to the quantitative side was to be expected, as quantitative criteria are generally more likely to benefit from an integration into a digital model-based workflow and are therefore more likely to have been considered applicable. In preparation for the integration of these indicators into the digital building model, it is important to distinguish that quantitative indicators can be expressed by predefined parameters, for example a maximum window height in meters or the total number of safety equipment items installed in a building. Qualitative indicators, on other hand, are dependent on subjectively defined parameters. This means that the parameters and the values integrated into the model must first be decided on by the designer or DGNB Auditor and can vary based on the opinions and experiences of the creator of the model.

Table 2: Sustainability criteria analysis overview

Topic	Criteria Short Code	Criteria Name	Applicable?				Qualitative vs. Quantitative
			Early Design Stage	Digital Model-based Workflow	Other Exclusion Condition	YES	
Environmental Quality	ENV1.1	Building Life Cycle Assessment	+	+	Out of scope		Quantitative
	ENV1.2	Local Environmental Impact	o	o		X	Quantitative
	ENV1.3	Sustainable Resource Extraction	-	o			Quantitative
	ENV2.2	Potable Water Demand and Wastewater Volume	+	-			Qualitative
	ENV2.3	Land Use	+	-			Qualitative
	ENV2.4	Biodiversity at the Site	+	-			Quantitative
Economic Quality	ECO1.1	Life Cycle Cost	+	+	Out of scope		Quantitative
	ECO2.1	Flexibility and Adaptability	+	+	Covered by ONIB		Qualitative
	ECO2.2	Commercial Viability	o	+		X	Quantitative
Sociocultural and Function Quality	SOC1.1	Thermal Comfort	+	+		X	Quantitative
	SOC1.2	Indoor Air Quality	+	+		X	Quantitative
	SOC1.3	Acoustic Comfort	+	+		X	Quantitative
	SOC1.4	Visual Comfort	+	+		X	Quantitative
	SOC1.5	User Control	+	-			Quantitative
	SOC1.6	Quality of Indoor and Outdoor Spaces	+	+		X	Qualitative
	SOC1.7	Safety and Security	+	+		X	Qualitative
	SOC2.1	Design for all	+	+	Covered by ONIB		Quantitative
Technical Quality	TEC1.2	Sound Insulation	+	+		X	Quantitative
	TEC1.3	Quality of the Building Envelope	+	+		X	Quantitative
	TEC1.4	Use and Integration of Building Technologies	+	+		X	Qualitative
	TEC1.5	Ease of Cleaning Building Components	+	+		X	Quantitative
	TEC1.6	Ease of Recovery and Recycling	o	+		X	Quantitative
	TEC1.7	Immissions Control	o	o		X	Quantitative
	TEC3.1	Mobility Infrastructure	o	+		X	Quantitative
Process Quality	PRO1.1	Comprehensive Project Brief	+	-			Qualitative
	PRO1.4	Sustainability Aspects in Tender Phase	-	-			Qualitative
	PRO1.5	Documentation of Sustainable Management	-	o			Qualitative
	PRO1.6	Procedure for Urban and Design Planning	+	-			Qualitative
	PRO2.1	Construction Site/Process	-	o			Qualitative
	PRO2.2	Quality Assurance of the Construction	-	o			Quantitative
	PRO2.3	Systematic Commissioning	-	o			Quantitative
	PRO2.4	User Communication	-	-			Qualitative
	PRO2.5	FM-compliant Planning	+	o		X	Qualitative
Site Quality	SITE1.1	Local Environment	+	o	GIS model		Quantitative
	SITE1.2	Influence on the District	+	-			Qualitative
	SITE1.3	Transport Access	+	o	GIS model		Qualitative
	SITE1.4	Access to Amenities	+	+		X	Qualitative

On the basis of the two distinct types of indicators found in the sustainability criteria analysis, two representative example criteria were selected: SOC1.7 Safety and Security to represent qualitative criteria and TEC1.5 Ease of Cleaning Building Components for the quantitative criteria.

4 Methodology for Sustainability Criteria Integration in BIM

It was necessary to create a practical integration approach that could deal with both qualitative and quantitative criteria. This required a standardized information structure, that could be used to organize both the qualitative and quantitative information, a building information model into which the relevant information could then be integrated, and finally a verification and optimization software to validate the model integration and provide optimization feedback (see Fig. 2).

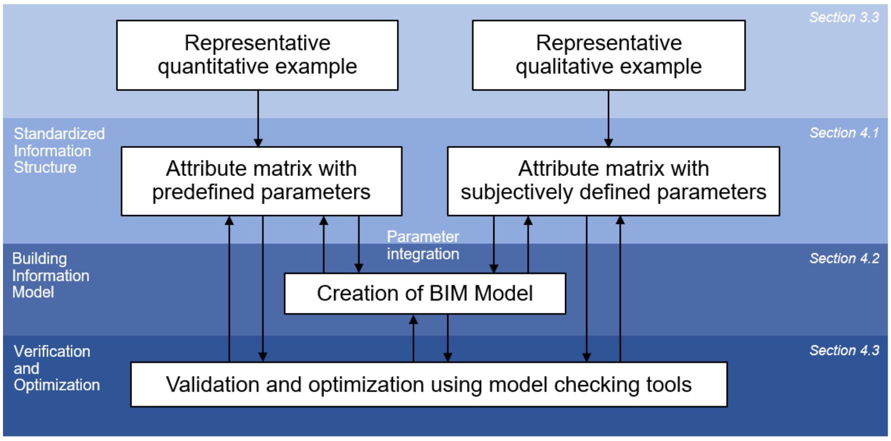

Figure 2: Practical implementation methodology flow chart

4.1 Standardized Information Structure

The first step in developing the standardized information structure was creating detailed process diagrams for the two representative example criteria, SOC1.7 Safety and Security and TEC1.5 Ease of Cleaning Building Components. The process diagram for the criteria TEC 1.5 as well as the sub-process diagram for indicator 2 of criteria TEC1.5 can be seen in Figure 3.

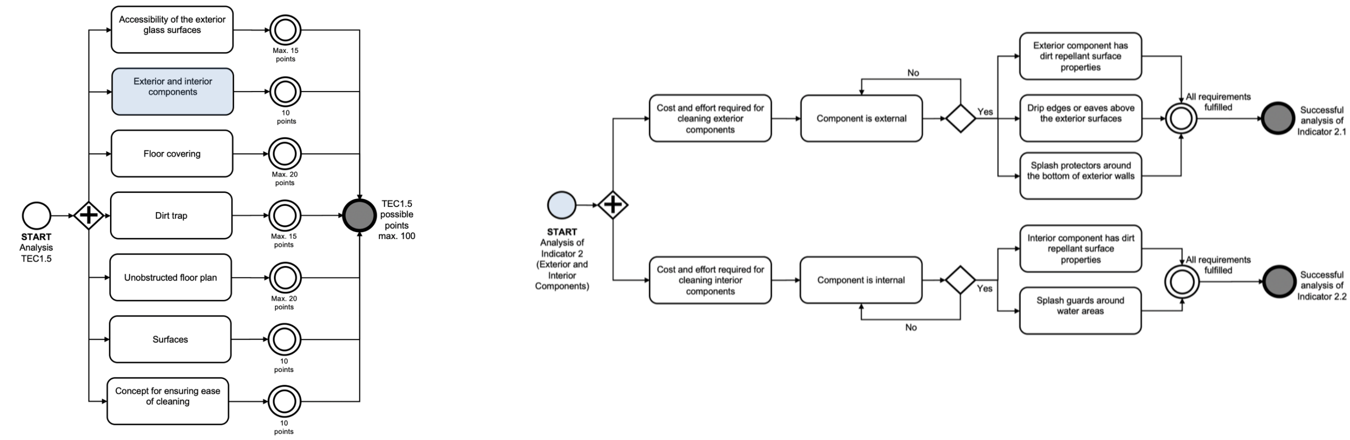

Figure 3: TEC 1.5 process diagram (left) and TEC 1.5 indicator 2 sub-process diagram (right)

These process diagrams were used to fill the first few columns of the attribute matrices with information such as the indicator name and explanation, the type of documentation and check required (such as a model check of distances between components or presence verification of an object type within the model), and the logical checking questions to narrow down the model objects needed for verification (see Figure 4).

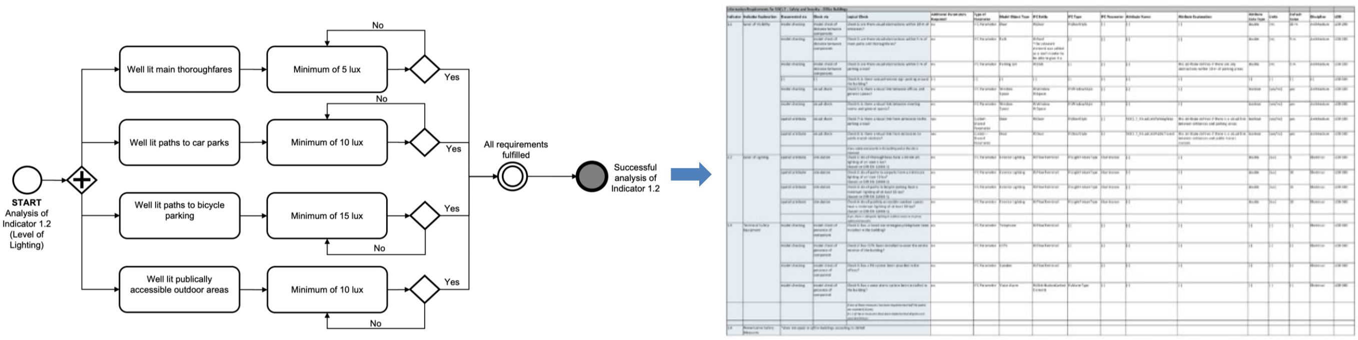

Figure 4: SOC1.7 indicator 1.2 sub-process diagram (left) and SOC 1.7 attribute matrix (right)

To gather the other information required by the attribute matrices it was necessary to use both the Revit model and the model viewing capability of the model checking software Solibri. First the model was exported from Revit as an IFC file, using the IFC2x3 Coordination View, and imported into Solibri. Here the relevant objects could be selected to see what parameters they included. This was used to determine if the required attribute could be depicted as an intrinsic IFC parameter or if a custom parameter needed to be created to translate the attribute into verifiable model content. If the required information could not be found as part of the object information accessed by the model viewer, the object was edited in Revit to include the necessary data as a custom shared parameter. All resulting information about the type of parameter and the default value against which it would be checked were then recorded in the attribute matrix. The completed attribute matrices contained information such as: an indicator explanation, type of documentation, logical checking question, parameter type (IFC or Custom), model object type, attribute name, data type, units, and default value (as predefined by the DGNB or defined subjectively by the designer).

The development of the attribute matrices and the creation of the building information model were heavily interconnected, as an understanding of the model data was essential for properly defining and integrating the parameters within the attribute matrices.

4.2 Building Information Model – Case Study

The building information model case study used for this research was an office building created in Revit. The model covered approximately 872 m² across two stories and was only developed in detail in areas required to fulfill the DGNB criteria described by the attribute matrices (see Figure 5). The building was meant to function only as a basic architectural model, so the structural integrity of the building and fire safety aspects were not considered. As the developed optimization tool was only focused on the early design stages, the Level of Development (LOD) of the model was capped at LOD 300, meaning that certain design details and intricacies were disregarded. Ultimately the BIM model served as a "single source of truth" for storing and accessing all sustainability-relevant information and was developed iteratively through checking the model components against the requirements detailed in the attribute matrices.

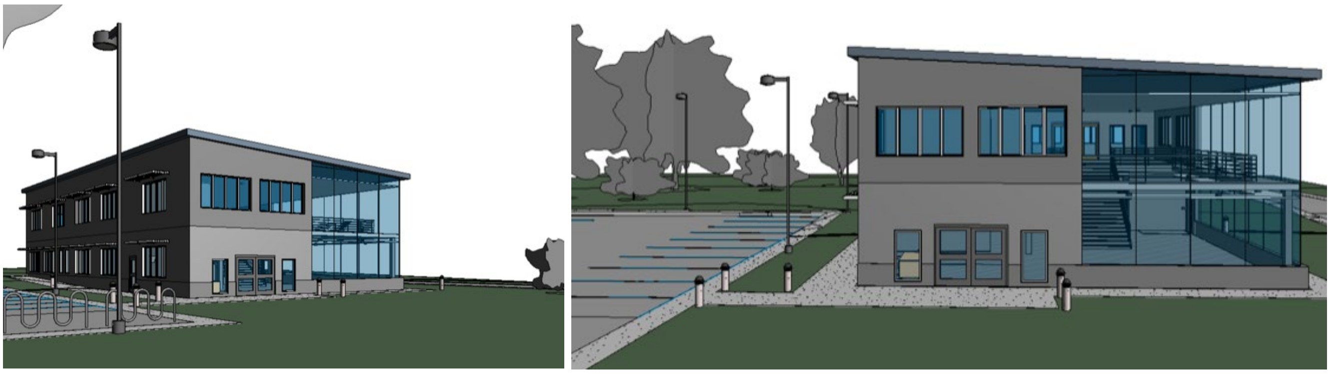

Figure 5: South east (left) and east (right) building elevations of Revit model

4.3 Verification and Optimization

Once the model had been created, the model checking software Solibri was used to validate the attribute integration and provide optimization feedback about where and how a design could be optimized to meet more of the sustainability requirements set forth by the DGNB. To do this, the logical checking questions from the sub-process diagrams and attribute matrices were turned into rules that checked different aspects of the model, such as distances between objects, definitions and names of spaces, material properties and boolean (true/false) parameters. The Solibri Ruleset Manager was used to produce a custom ruleset “DGNB 2018 Ruleset” under which two individual rulesets were created, one for each representative DGNB criterion, TEC1.5 and SOC1.7. Within each criterion ruleset, independent rules were created to check each indicator, with sub-rules created for the indicators that required numerous different parameters as defined in the attribute matrices (Fig. 6). Most of the rules were created using the property rule template and the distance between components template provided by Solibri.

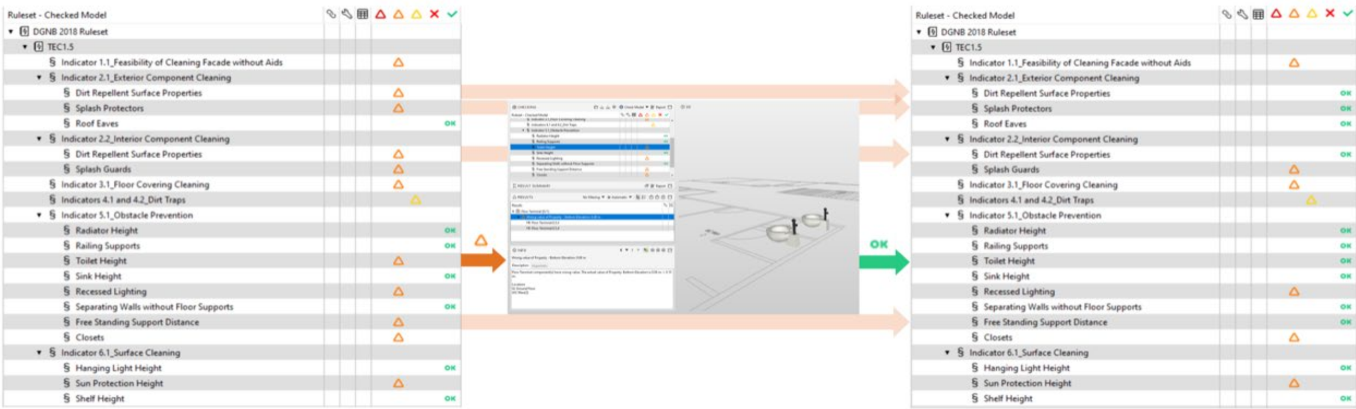

Figure 6: Solibri results before (left) and after (right) optimization

In creating custom rulesets based on these templates, it was discovered that several qualitative indicators could be more reasonably included on the model checking level than within the Revit model itself. For example, visual obstructions in front of doors could be checked automatically using Solibri rather than manually measuring distances within the model and saving these values as a door parameter. The same was true for determining material surface properties. Ultimately, this resulted in many previously defined parameters being removed as it became clear that it made more sense to check certain values automatically with the model checker rather than basing the verification of specific elements on the statements or manual confirmations of the designer. Using Solibri also has the benefit of more easily and comprehensively adding target values and changing these based on the subjectivity of the designer or DGNB auditor. Additionally, acceptable ranges could be defined in the Solibri rules, which allowed for a greater variety of possible values and therefore provided more room for creativity and innovation without needing to update numerous model object parameters in the process.

With the developed optimization tool, it was possible to update the design to meet significantly more of the DGNB requirements, for both quantitative and qualitative criteria within a matter of minutes. A percent improvement of 50% based on indicators of TEC1.5 was achieved in approximately 20 minutes while 3 of the 5 optimization potentials for SOC1.7 could be implemented within 8 minutes. The clearly structured feedback from the optimization tool enabled this fast adaptation of the model and significantly reduced the time normally required to make model changes using a traditional design process. It was found that 84% of quantitative information can generally be included in the building information model through component attributes assigned to model objects as parameters. Over 80% of this information can be checked against pre-defined values in the DGNB or the respective national rules and regulations using a rule-based model-checking software. Qualitative information, of which nearly 95% could be include in the BIM model, can more easily be included in a digital workflow on the model-checking level than as component attributes, as the model checker allows for a greater freedom in defining subjective aspects related to spatial and design layout relationships. It should be noted that it is also not possible to verify the actual quality of a space in Solibri, but rather to check that certain components that have been previously determined to likely enhance the space have been included in the model. In this regard, writing the qualitative rules is far more complex than the quantitative ones, as they require an a priori determination of what elements, spaces and connections will have what subjective effect on the design and ultimately the user. However, as all attribute matrices and rulesets ultimately only need to be created once for each criterion and can then be used on all future projects it is worth defining and documenting a common understanding of qualitative sustainability criteria.

5 Conclusion and Outlook

This research produced a holistic sustainability optimization tool to be used in the early design stages, based on the 2018 version of the DGNB criteria. The analysis of all DGNB criteria found that over 80% of the criteria in the current system are applicable to be considered in the early stages and over 75% of the criteria would benefit of an integration into a digital model-based workflow. This confirms the importance of including sustainability aspects as an integral part of the BIM methodology, especially in the early design stages when it is still easy and inexpensive to make design changes. With the developed tool, sustainability can be implemented in a building context through concrete recommendations that continually adapt to the current version of the design. This allows designers to take full advantage of optimization potentials, and sustainability aspects can be understood and integrated into a design even by individuals with little to no knowledge of sustainable building.

Looking to the future, attribute matrices and rulesets should be developed for all applicable criteria to better understand the full benefit of a holistic sustainability/BIM integration. To allow for the integration of as many criteria as possible in the early design stages, GIS models should also be included in the verification and optimization process. Since the integration of qualitative criteria is subjective, it its essential to work with sustainability and certification experts in defining a sustainability baseline for the qualitative rules to check. Since these rulesets only need to be created once, to then be used on all future projects, it could be considered that the DGNB produce these rulesets along with the criteria catalogs they currently develop. Further research could also investigate if it is possible to include a link between the model checking results and even more detailed improvement suggestions, such as ideas about which materials to substitute, or suggestions for possible changes to the room layout to benefit social interactions and sound insulation. Overall, it is important that the human element of the design and certification process is not forgotten, in terms of both the social side of sustainability but also the innovation potential that designers offer, to adapt to ever changing environmental conditions and social structures.

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