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How to Assess Sustainable Planning Processes of Buildings? A Maturity Assessment Model Approach for Designers

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Abstract: Over the past decades, it has become apparent that increasing demands in the construction industry have repeatedly led to project delays and increased project costs in practice. These demands have increased as a result of international and national action plans that have been developed to achieve the climate target paths and, therefore, the necessary reduction of CO_2 emissions in the construction industry. We address this problem by developing a sustainable construction maturity model (SCOMM) to answer the following research question: "What is a holistic quality assurance tool for the early design phase of buildings to monitor (sustainable) planning practices in order to achieve better certification results?". The model includes a self-assessment procedure for the building design process, based on Software Process Improvement and Capability dEtermination (SPiCE) and the German Sustainable Building Council (DGNB) building certification system. The results show that systemic interactions between sustainability criteria can be identified in the early design phase, allowing the quality of planning practices to be evaluated and early project management to be implemented to achieve the best certification results. Our findings will enable clients and users of the construction industry to better manage the complexity of the sustainable design process and avoid undesirable developments in building projects.

Keywords: maturity assessment; maturity model; building certification; design process; sustainable construction management

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1. Introduction

Due to increasing climate change, both clients and users of the construction industry have recognized the growing importance of sustainable construction [1]. This form of construction demands the consideration of the three dimensions of sustainability (environmental, economic, and social) throughout the life cycle stages of a building. Since the last decade of the 20th century, the use of assessment frameworks to evaluate sustainability in buildings has been firmly established [2–4], resulting in the development of more than 600 available assessment methods [5]. Actors in the construction industry apply these methods to address a spectrum of sustainability-related topics, which vary widely from a single subject, such as energy efficiency, to a broad range of subjects belonging to any of the three dimensions of sustainability.

At the building level, so-called building certification systems have become entrenched. Building certification is basically carried out to improve the building–user–environment system, requiring various sustainability aspects to be considered. The Green Building Council (GBC) focused on aspects of environmental sustainability to support principles of strong sustainability, while contemporary certification systems direct the focus toward the weak sustainability concept, which comprehensively describes the sustainability of buildings. A thorough discussion of both sustainability concepts can be found in [6].

Building certification systems are becoming steadily more holistic. System developers strive to cover the entire life cycle, taking the next necessary steps to considering sustainability aspects in the early building design phase. Integrating additional sustainability aspects in this early phase, however, raises significant difficulties due to the increasing number of factors and their systemic interdependencies, all of which must be considered [7,8]. While some researchers have developed ways to apply systemic approaches in the early design phase, few of these approaches have been applied successfully in practice [8–10]. Another challenge is the fact that assuring quality with the maturity assessment method is not considered as the state of the art. Some initial development concepts for the practical application of such holistic systems have been applied in previous research projects [11–13].

The concept of maturity assessment originated in quality management (QM). Shewhart presented the first drafts of this concept in the 1930s, although these share few similarities with today's maturity models (MMs) [14]. More than 40 years would elapse before Crosby would introduce the related concept of maturity levels, which build on each other and represent a simple but effective analysis and measurement tool. He proposed using a 'maturity grid' for quality management processes, a tool that allows the user to categorize the best practices into five maturity levels and six measurement categories [15]. At the same time, Nolan published an article on the maturity of data processing, defining six growth stages that would need to be achieved before maturity could be reached [16].

The maturity assessment method serves as a valuable tool for evaluating business processes and specific aspects of organizations. As such, it clears a path that leads to an increasingly organized and systematic way of doing business. Maturity assessment tools can be used to measure the current maturity of a particular aspect of an organization in a meaningful way, making it possible for stakeholders to clearly identify strengths and areas for improvement. This, in turn, enables them to prioritize what needs to be done to achieve higher levels of maturity or higher levels of capability. The assessment can be carried out on different levels; the assessment on capability levels differs from one on maturity levels [17]. Specifically, the former considers individual processes, while the latter evaluates process areas (sum of processes). Regardless of the assessment level chosen, all previously defined and specified goals must be met to reach a level of capability or maturity. Processes can also be excluded from this evaluation if they are unnecessary to meet the overall goals [18].

The maturity assessment method has still only infrequently been applied in the construction industry to create a QM [13]. When organizations choose to conduct a maturity assessment, they evaluate the quality of their processes, try to standardize them, and, in the best case, optimize them [19–22]. Where process quality has a significant influence on product quality, an examination of the process maturity level can be beneficial. More mature processes can be used to achieve the desired results and present lower risks more reliably [15]. These processes can also be attractive, because the time, budget, and quality they require can be more easily predicted. Less mature processes are often ad hoc, are not well-planned, and often do not provide the expected results or need to be revised to meet the requirements.

Applying maturity assessment methods in the construction industry helps to optimize planning and construction processes, as the maturity level of the processes carried out strongly influences the quality of the buildings. However, most actors are hesitant to apply the maturity assessment method to evaluate the quality of the building planning processes, as they would need to enter completely new territory. To enter this brave, new world, however, maturity assessments must be introduced and carried out in daily practice. Such assessments can range from distributing simple self-assessment questionnaires to applying full-fledged assessment methods, as recommended in the ISO 15504 series [23–32].

Maturity assessment models still have an application focus of software engineering, covering such topics as data quality, software maintenance, and testing. However, other topics are becoming steadily more important, including information technology alignment, the use of enterprise resource systems, technology and knowledge management or collaboration processes [33]. Regarding MMs, the two most frequently used models are the Capability Maturity Model Integration (CMMI) and the Software Process Improvement and Capability dEtermination (SPiCE).

Further MMs have been developed for the construction industry based on existing MMs for the software industry, mostly Capability Maturity Models (CMM) or CMMI. These MMs mainly refer to project management, as well as individual sub-disciplines of project management, such as risk management and knowledge management. So far, MM have mainly been applied to assess organizational processes in order to evaluate the maturity of an enterprise in relation to a set target. By developing the sustainable construction maturity model (SCOMM), we have developed a model that enables an assessment to be performed at the building level. In this context, it is essential to have a holistic quality assurance self-assessment tool to evaluate the sustainability of planning practices and control their implications. Furthermore, the transparent and comprehensible communication of information and knowledge is an important part of the evaluation of the building performance.

As in the software industry, researchers have developed several process improvement frameworks for the construction industry over the past decade [34]. Table 1 lists some of the MMs identified in the existing literature that have been developed specifically for the construction industry. The current MMs mainly address the assessment of enterprises in terms of project management.

Table 1. Excerpt of maturity models for the construction industry.

Name	Abbreviation	Source
Project Management Maturity Model	PMMM	[35,36]
Organizational Project Management Maturity Model	OPM3	[37,38]
Change Management Maturity Model	CM3	[39]
Risk Management Maturity System	RMMS	[40]
Program Management Organization Maturity Integrated Model for Mega Construction Programs	PMOMM-MCP	[40]
Public Commissioning Maturity Model	PCMM	[41]
Structured Process Improvement Framework for Construction Environments—Facilities Management	SPICE FM	[42]
Project Management Process Maturity Model	PM2	[43]
Portfolio, Programme, and Project Management Maturity Model	P3M3	[44]
PRINCE 2 Maturity Model	P2MM	[45]
Construction Industry Macro Maturity Model	CIM3	[46]
Maturity Assessment Grid from the Strategic Forum for Construction	MAG	[47]
Standardised Process Improvement for Construction Enterprises	SPICE	[48]
Construction Supply Chain Maturity Model	CSCMM	[49]
Maturity Model for Construction Supply Chain Relationships	SCM	[50]

Some MMs have been developed in the construction industry to support a variety of issues related to project management [40,51]. Many of these address knowledge management [52,53] and risk management [54–56], while other areas frequently addressed include supply chain management [49,50,57], contractor safety [58], and information management [59]. The applications of most of the assessment methods available for use in the construction industry have demonstrated that the MM can be used to identify inefficiencies and weaknesses and highlight performance improvement measures, helping project managers achieve project objectives more effectively [60].

The results of Wendler's extensive literature review on MMs clearly show that the field of the application of MMs in the construction industry still represents unexplored territory;

namely, only ten articles were assigned to the subject area Construction Processes [33]. Other than the MMs models developed in the areas mentioned above, no MM currently exists that can be applied to assess sustainable planning practices. In this context, only the concept of an MM for sustainable construction developed by Goh and Rowlinson needs to be mentioned [61]. However, the construction industry is a highly segmented industry with many actors and disciplines involved, which leads to communication problems due to incomplete and non-transparent planning processes. Therefore, a quality assurance tool is needed—especially in the construction industry—that includes a systemic approach and leads to the reduction of complexity to prevent project deviations from the holistic project goal in the early design phase. Besides quality assurance during the design phase, building owners, planners, and project managers must be presented with a first step to structure and traceably process sustainability requirements from a holistic perspective.

The goal of the research described in this article was to combine the theoretical framework of the maturity assessment method and building certification systems to answer the following research question "What is a holistic quality assurance tool for the early design phase of buildings to monitor (sustainable) planning practices in order to achieve better certification results?". In this study, we took advantage of the Software Process Improvement and Capability dEtermination (SPiCE) model and combined it with the sustainability criteria for the building certification system of the German Sustainable Building Council (DGNB). The proposed hybrid model (i.e., the sustainable construction maturity model, SCOMM) combines the advantages of a classical maturity model and the long-established DGNB certification system to enable self-assessment of (sustainable) planning practices and, thus, the implementation of early project management to achieve the best certification. The application of the developed model was validated based on a first case study. Detailed information on the application can be found in the Supplementary Materials.

2. Materials and Methods

In addition to ensuring quality and supporting the principles of sustainable construction by carrying out a maturity assessment, we specifically considered the Software Process Improvement and Capability dEtermination (SPiCE) and the German building certification system DGNB. Our specific focus was to adapt the fundamental principles of SPiCE for use in sustainable construction based on the DGNB building certification system.

2.1. Software Process Improvement and Capability dEtermination (SPiCE)

The Software Process Improvement and Capability dEtermination (SPiCE) is an international standard applied to conduct maturity assessments of business processes, although it was originally intended for use in software development. It was adopted in 1998 as a technical report in a preliminary version and was replaced by the first version as an international standard in 2006. Currently, it consists of ten parts [23–32], whereby the first two parts were replaced in 2015 by the standards ISO/IEC 33001 [62] and ISO/IEC 33002 [63].

The core elements of SPiCE are the improvement of processes in organizations and the determination of process capability. The assessment of process capability with an MM based on SPiCE is defined by the so-called capability levels. Capability levels highlight the quality achievement of processes derived from single process purposes and process attributes (PAs). Fulfilling a process comprises the satisfaction of an individual process purpose as well as the implementation of relevant PAs. The assessment takes place at six levels (incomplete, performed, managed, established, predictable, and optimizing), which the user evaluates by examining PAs, whereby the process purpose is assigned to PA 1.1 process performance. All in all, PAs represent the measurable properties of a process quality characteristic. In SPiCE, a total of nine PAs (1.1 to 5.2) are assigned to the capability levels, each of which are described by the base practices and generic practices. The former practices represent activities that contribute to achieving a specific process purpose, while the latter encompass activities that contribute to achieving a specified PA.

To fulfil the PA 1.1, the user only evaluates base practices, but the generic practices must be evaluated to fulfil the remaining PAs 2.1 to 5.2. The PAs are shown in Table 2.

Table 2. Process attributes according to SpiCE [62].

Abbreviation	Process Attribute
PA 1.1	Process performance
PA 2.1	Execution management
PA 2.2	Work product management
PA 3.1	Process definition
PA 3.2	Process deployment
PA 4.1	Process management
PA 4.2	Process control
PA 5.1	Process innovation
PA 5.2	Process optimization

ISO/IEC 33002 defines a rating scale consisting of four values (N-P-L-F scale) that can be used to evaluate practices. This scale is a four-level assessment scale, which ranges from N (not achieved) to P (partially achieved) and on to L (largely achieved) and finally to F (fully achieved). N-P-L-F assessments should be performed for each base and generic practice of a process. By using a specific calculation algorithm, conducting an N-P-L-F assessment results in the fulfilment of PAs and, therefore, the achievement of the capability levels of processes. Subsequently, the processes can be grouped into process areas, and the capability levels can be aggregated to a maturity level. Table 3 shows the bandwidths of the calculation algorithm for the target achievement.

Table 3. N-P-L-F calculation algorithm [63].

Degree of Achievement	Bandwidth	Meaning by Words
N—not achieved	0–15%	Evidence of fulfilment of the PA is not available or very scarce.
P—partially achieved	>15–50%	An attempt was made to meet the PA, and this was partially achieved. However, some points of the process attribute are difficult to verify.
L—largely achieved	>50–85%	A systematic approach has been used to integrate the points of the PA. Despite some remaining weaknesses, this has been largely achieved.
F—fully achieved	>85–100%	The PA has been fully implemented within the process. A systematic approach is used to ensure that it is implemented correctly and evidence of this is available. There are no significant weaknesses.

This PA assessment forms the bedrock of the evaluation of the process capability level. To achieve a capability level, all PAs on the previous levels must be evaluated as F (fully achieved). The PAs of the capability level to be achieved must be evaluated as L (largely achieved) or as F (fully achieved).

2.2. Building Certification System DGNB

The European evaluation concept that is generally applied to assess the sustainability of buildings—the so-called second-generation certification systems—considers technical and functional qualities, as well as the classic three pillars of sustainability (environmental, economic, and social). The German building certification system DGNB of the German Sustainable Building Council is one of these systems.

The DGNB has developed its own certification system to make sustainable construction practically applicable, measurable, and comparable. First launched in 2009, construction industry actors have steadily improved the system. Today, it is not only the most advanced certification system worldwide, but it is also recognized internationally as a Global Benchmark for Sustainability. The certification system exists in several schemes for buildings, districts, and interiors. Within this system, a distinction is made between the categories of office, education, residential, hotel, and consumer markets. To develop the SCOMM, we used the DGNB system for "New Construction—Office", as different building typologies have different criteria weightings. The structure of this scheme, including the criteria weighting, is shown in Table 4.

Table 4. Structure and weights of DGNB scheme "New Construction—Office" [64].

Quality Sections	Criteria	Weights	
Environmental quality	Building life cycle assessment	ENV1.1	9.5%
	Local environmental impact	ENV1.2	4.7%
	Sustainable resource extraction	ENV1.3	2.4%
	Potable water demand and wastewater volume	ENV2.2	2.4%
	Land use	ENV2.3	2.4%
	Biodiversity at the site	ENV2.4	1.2%
Economic quality	Life cycle cost	ECO1.1	10.0%
	Flexibility and adaptability	ECO2.1	7.5%
	Commercial viability	ECO2.2	5.0%
Social and functional quality	Thermal comfort	SOC1.1	4.1%
	Indoor air quality	SOC1.2	5.1%
	Acoustic comfort	SOC1.3	2.0%
	Visual comfort	SOC1.4	3.1%
	User control	SOC1.5	2.0%
	Quality of indoor and outdoor spaces	SOC1.6	2.0%
	Safety and security	SOC1.7	1.0%
	Design for all	SOC2.1	3.1%
Technical quality	Fire safety	TEC1.1	2.5%
	Sound insulation	TEC1.2	1.9%
	Quality of the building envelope	TEC1.3	2.5%
	User and integration of building technology	TEC1.4	1.9%
	Ease of cleaning building components	TEC1.5	1.3%
	Ease of recovery and recycling	TEC1.6	2.5%
	Immissions control	TEC1.7	0.6%
	Mobility infrastructure	TEC3.1	1.9%
Process quality	Comprehensive project brief	PRO1.1	1.6%
	Sustainability aspects in tender phase	PRO1.4	1.6%
	Documentation for sustainable management	PRO1.5	1.1%
	Urban planning and design procedure	PRO1.6	1.6%
	Construction site/construction process	PRO2.1	1.6%
	Quality assurance of the construction	PRO2.2	1.6%
	Systematic commissioning	PRO2.3	1.6%
	User communication	PRO2.4	1.1%
	FM-compliant planning	PRO2.5	0.5%
Site quality	Local environment	SITE1.1	1.1%
	Influence on the district	SITE1.2	1.1%
	Transport access	SITE1.3	1.1%
	Access to amenities	SITE1.4	1.7%

The DGNB was not developed to distribute certifications to gain market advantages, but to promote and ensure holistic building quality with reference to established certification criteria. However, to obtain certification, certain minimum requirements must also be met, which are known as knock-out criteria (K.O. criteria). These include indoor air quality (SOC1.2), design for all (SOC2.1), and fire safety (TEC1.1). Such criteria can vary depending on the scheme and are specified in the individual schemes.

3. Results

3.1. Development of a Sustainable Construction Maturity Model (SCOMM)

Most MMs consist of a rating system that can be applied to evaluate the degree of maturity. However, the structure of MMs can differ from model to model. Proença and Borbinha indicate that most MMs include the following elements: (i) name of the maturity model, (ii) number of maturity levels, (iii) classification and number of process areas, and (iv) maturity level or capability level definitions [65]. Caralli et al. see the following elements as additionally important components of MMs: (v) domain of the maturity model and (vi) description of the assessment method [66].

3.1.1. Name of the Maturity Model

Since the developed MM includes the assessment of sustainable planning processes and, thus, the early assessment of the overall building quality, the model was named the sustainable construction maturity model (SCOMM).

Figure 1 shows how the SPiCE nomenclature was transferred to the nomenclature in SCOMM using the DGNB building certification system. The example of the process thermal comfort illustrates this transfer. Once the relevant planning practices to satisfy individual stakeholder preferences have been identified, SCOMM can be used to perform quality management of planning in the design phase.

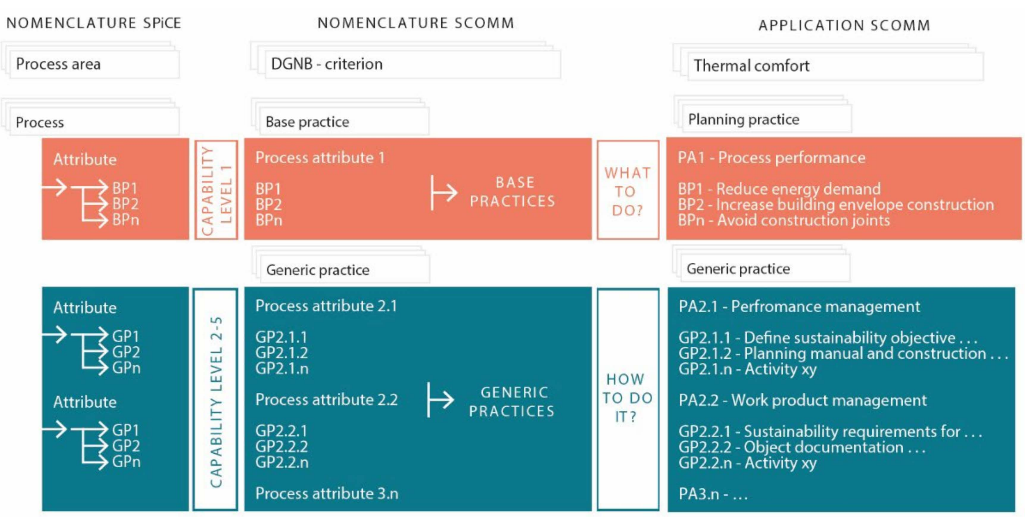

Figure 1. Transfer of SPiCE nomenclature to SCOMM.

3.1.2. Number of Maturity Levels

The SCOMM is based on SPiCE and involves the capability dimension approach. This approach provides a framework for the measurement, including six capability levels and the associated nine PAs. To determine a capability level, the underlying planning practices (base practices and generic practices) in the respective processes are evaluated and summed up using the N-P-L-F evaluation algorithm described in the section entitled Software Process Improvement and Capability dEtermination (SPiCE).

Once the assessment is complete, the user can check the quality of the individual planning practices. In addition, the user can obtain maturity levels for individual process areas after aggregating the process evaluation. Similarly, the user can merge process areas and check the maturity level for the overall quality of a building. The SCOMM includes six capability levels for the evaluation of planning practices and five maturity levels for the measurement of the maturity of the process areas and the overall building quality.

3.1.3. Classification and Number of Process Areas

To apply MMs, the user must define the goals that are to be achieved. These include the desired maturity level and the definition of the areas to be evaluated [18]. Some MMs assign processes to higher-level process areas, which should facilitate the evaluation to the desired extent. This means that only those process areas that are relevant for achieving a desired objective need to be included in the evaluation.

Based on the DGNB building certification system, we defined six process areas. These six process areas are defined by the six quality sections of DGNB (environmental quality, economic quality, sociocultural and functional quality, technical quality, process quality, and site quality).

3.1.4. Maturity Level and Capability Level Definitions

To evaluate planning practices, the N-P-L-F evaluation algorithm based on SPiCE is used. After evaluating the planning practices, the user can calculate the capability levels for the superordinate process areas. In the SCOMM, the user applies six capability levels as proposed by SPiCE. Table 5 shows the numbered levels and the corresponding capability level. Extensive definitions of the individual capability levels are given in the Appendix A.

Table 5. Overview of capability levels.

Numbered Level	Capability Level
Level 0	Incomplete process/planning practice
Level 1	Performed process/planning practice
Level 2	Managed process/planning practice
Level 3	Established process/planning practice
Level 4	Predictable process/planning practice
Level 5	Optimizing process/planning practice
Level 0	Incomplete process/planning practice
Level 1	Performed process/planning practice
Level 2	Managed process/planning practice

After the achieved capability levels are merged, a maturity level can be reached (e.g., for the six DGNB quality sections or the overall building quality). The five maturity levels are shown in Table 6. Extensive definitions of the meanings of the individual maturity levels are given in the Appendix B.

Table 6. Overview of maturity levels.

Numbered Level	Maturity Level
Level 1	Performed
Level 2	Managed
Level 3	Established
Level 4	Predictable
Level 5	Optimizing

3.1.5. Domain of the Maturity Model

The SCOMM has been specifically developed for the quality management of planning practices related to the implementation of sustainable construction in an early building design phase. The systemic interactions of the processes (i.e., of the DGNB certification criteria) are included in the SCOMM. Moreover, especially the systemic interdependencies among the planning practices are highlighted and explained. The domain of the MM, thus, covers the systemic consideration of planning practices in the early building design phase to improve the DGNB certification results.

3.1.6. Description of the Assessment Method

As proposed in ISO 33001, SCOMM involves the N-P-L-F assessment. These N-P-L-F assessments should be performed for each planning practice (base practice and generic practice). Using a specific calculation algorithm, the N-P-L-F assessments result in the capability levels of the superordinate processes. By aggregating the processes to process areas, the user can obtain the maturity level for six DGNB quality sections and the design quality for the whole building.

The user only evaluates base practices (BP) to achieve the PA 1.1 process performance. BP are activities which—when consistently performed—contribute to achieving a specific process purpose. In the SCOMM, these include the planning practices designed by the planners. Exemplary BPs are listed in the Appendix C.

To achieve the remaining PAs, we defined generic practices (GP). GP are activities which—again when consistently performed—contribute to achieving a specific PA. All GP developed for the SCOMM can be found in the Appendix D.

Figure 2 provides a schematic view of the assessment method. The SCOMM structure follows a hierarchical structure derived from the DGNB building certification system and SPiCE. Accordingly, the lowest level of the hierarchy represents the building quality or the certification result, respectively. This building quality is further divided into the six process areas corresponding to the six DGNB quality sections; the areas also contain their weighting based on the DGNB scheme "New Construction—Office". The next level displays the individual processes, which correspond to the 37 DGNB certification criteria. The last level of the SCOMM illustrates the subdivision of the processes into the BPs and GPs.

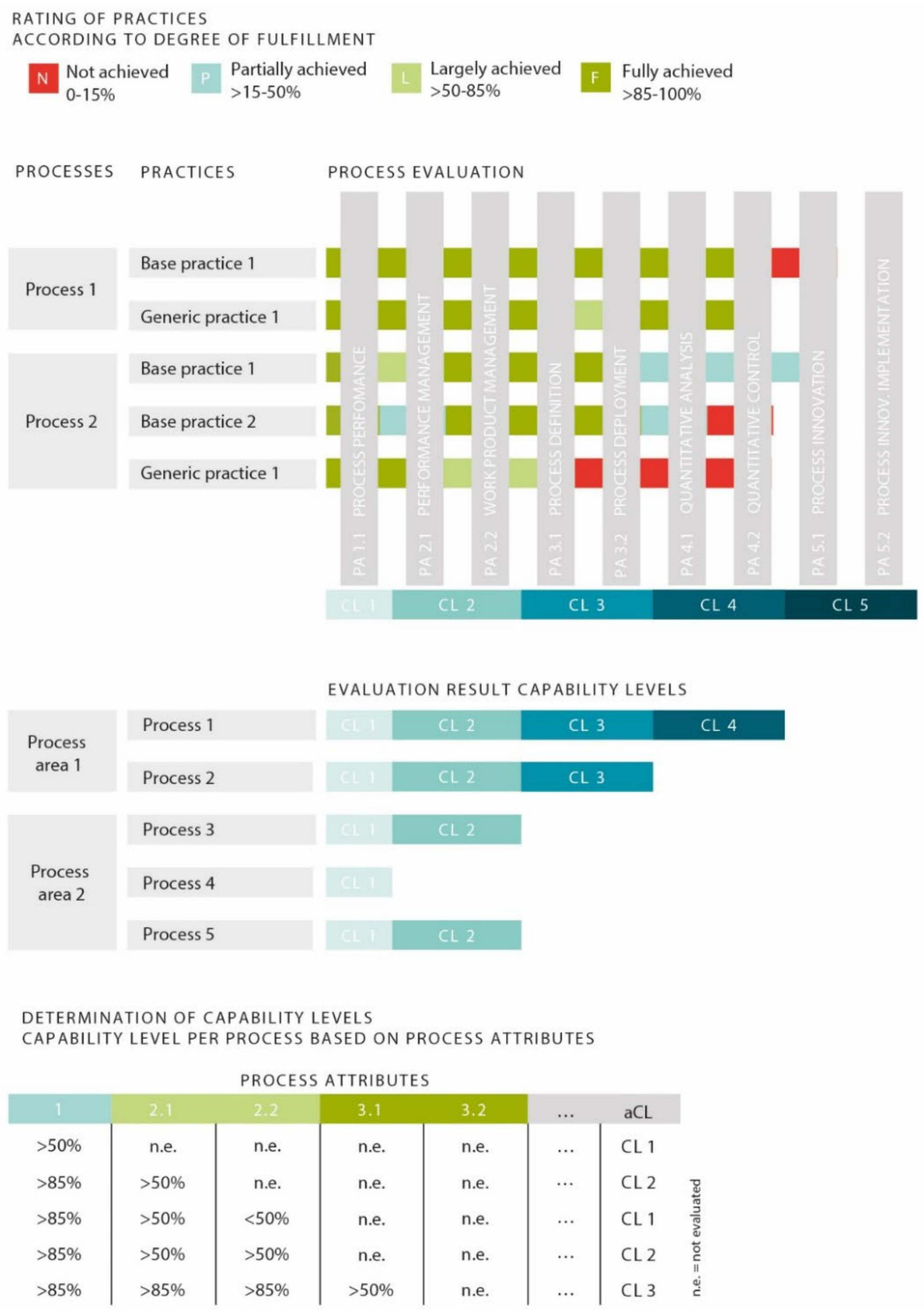

Figure 2. Schematic view of the assessment method.

These practices are finally assessed using the N-P-L-F assessment scale, resulting in capability levels for processes or in the case of aggregation for process areas.

3.2. Application of SCOMM

Although planning buildings based on recurring procedures and processes may not always be ideal, because many buildings are unique, the SCOMM developed in this work provides an effective quality-assurance tool that guides the user through the planning process based on a flowchart defined in the early building design phase. Figure 3 shows the flowchart that illustrates the SCOMM workflow.

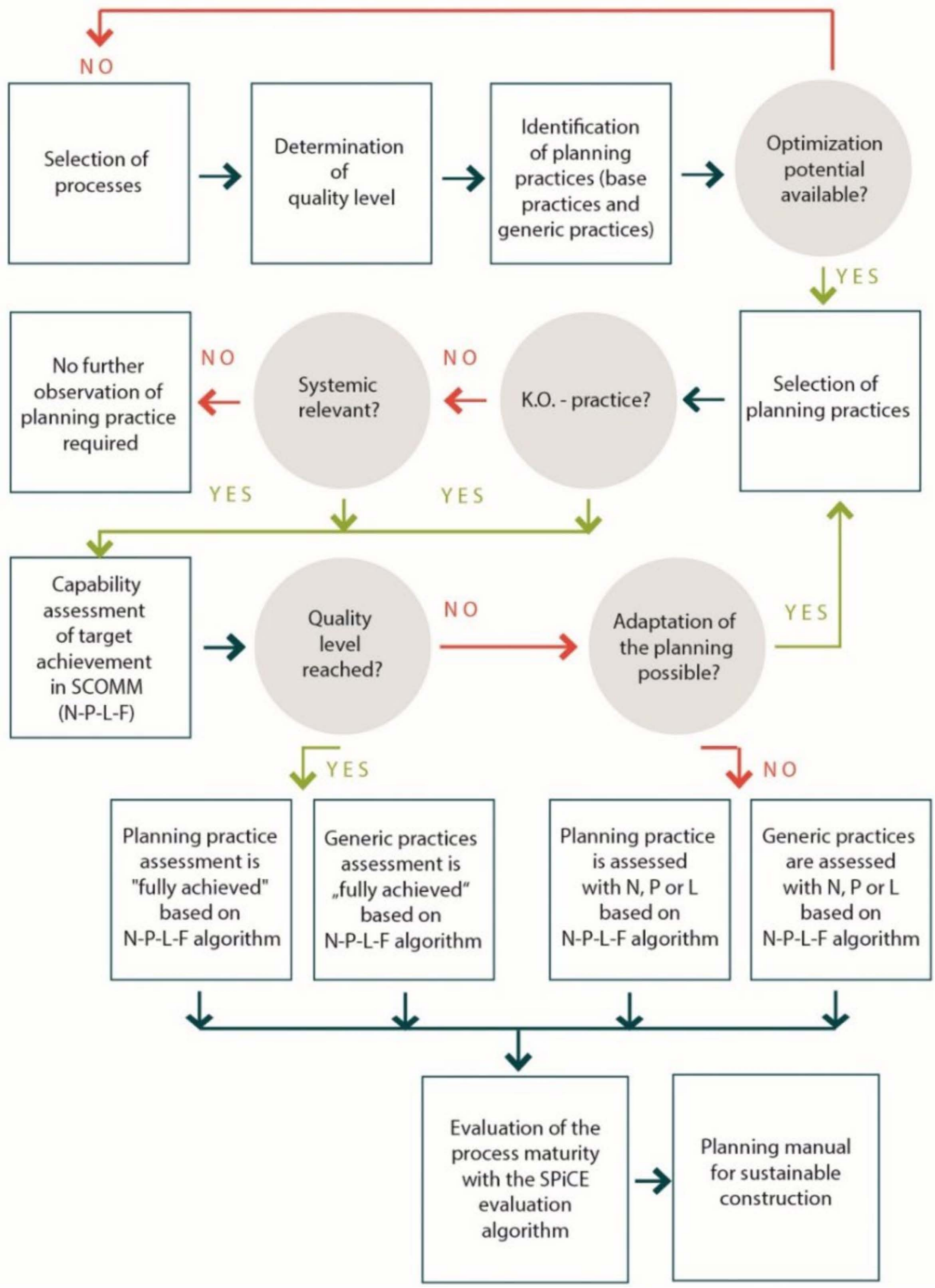

Figure 3. Flowchart practical application of SCOMM.

First, the user selects the processes (e.g., thermal comfort, visual comfort, sound insulation) and determines their desired quality level. Using the SCOMM, the user can identify relevant planning practices (base practices and generic practices) for all processes. If the planner identifies a potential for optimization within the relevant planning practices, the user can examine this potential in more detail in the following steps of the developed MM. After selecting a planning practice, two further questions arise: (1) Whether the planning practice is a knock-out (K.O.) practice (i.e., whether this planning practice addresses a knock-out criterion as defined by the DGNB building certification system) and (2) whether the planning practice has a systemic influence on other processes. K.O. criteria, as defined by the DGNB building certification system, can prevent successful certification in any case, but K.O. practices also can be essential conditions that are defined by the stakeholders or planners themselves and must be implemented.

While SCOMM can be efficiently used to identify relevant planning practices, it can also be used to highlight the systemic relevance of a planning practice. If the user answers the two questions described in the previous paragraph with "no", the planning practice is identified as not systemically relevant; therefore, the user learns that it has no systemic relevance with respect to the overall planning quality of the building.

However, if the planning practice is a K.O. practice or is identified as systemically relevant, this practice will be evaluated with the N-P-L-F assessment algorithm. Once this evaluation has been carried out, the result is compared with the previously defined quality level. The user must decide whether this level has been achieved. If the defined quality level has not been fully achieved (evaluated as "not achieved", "partially achieved", or "largely achieved"), planners can consider whether they can adapt the design so that the planning practice is evaluated as "fully achieved". If the planners can create such an alternative design, the user checks the newly developed planning practice again for its systemic relevance. This receives an evaluation result of "fully achieved" if—and only if—the defined quality level has been fully achieved.

Once the user has applied SCOMM to assess all the planning practices for the various processes, they need to take the next step and assess the generic practices. After all processes have been assessed, the user applies the calculation algorithm to determine the capability levels of each process and the maturity level of the six DGNB quality sections or the overall building design quality. After applying the SCOMM, the results can be presented in the form of a sustainability report, which can serve as a planning manual for the early design phase of sustainable construction.

3.3. Exemplary Output of the SCOMM

Figure 4 shows an extract of the SCOMM which concerns the capability assessment of a selected process "thermal comfort". SCOMM automatically displays all possible synergies and trade-offs based on the deposited interactions for the selected planning practice "reduce energy demand". The SCOMM mainly contrasts with current systemic approaches (e.g., Vester's paper computer model, which places a focus on the identification of systemic effects of overarching subjects [67]) in that it can be used to visualize the systemic effects of individual subjects (here, planning practices). Thus, the systemic interactions among individual planning practices and indicators of the DGNB's sustainability criteria become visible. This ability to visualize and evaluate planning practices provides users with a holistic view of the entire planning process, supporting quality-assured planning.

On the left-hand side of Figure 4, the base practice (i.e., the selected planning practice) within the selected process area is shown. The exemplary output shows the process "thermal comfort", which is to be assigned to the sustainability quality "socio-cultural and functional quality" of the DGNB building certification system. One possible planning practice to improve thermal comfort is described by the reduction in energy demand, which can be achieved if different specific measures are applied. If, for example, solar radiation is reduced by means of shading to reduce the energy demand, this measure also has positive effects on the indicator "sun protection", which should be assigned to the process area "visual comfort". On the other hand, the installation of shading systems can also have a limitation (i.e., a trade-off) with respect to the indicator "daylight factor", which is also assigned to the process area "visual comfort".

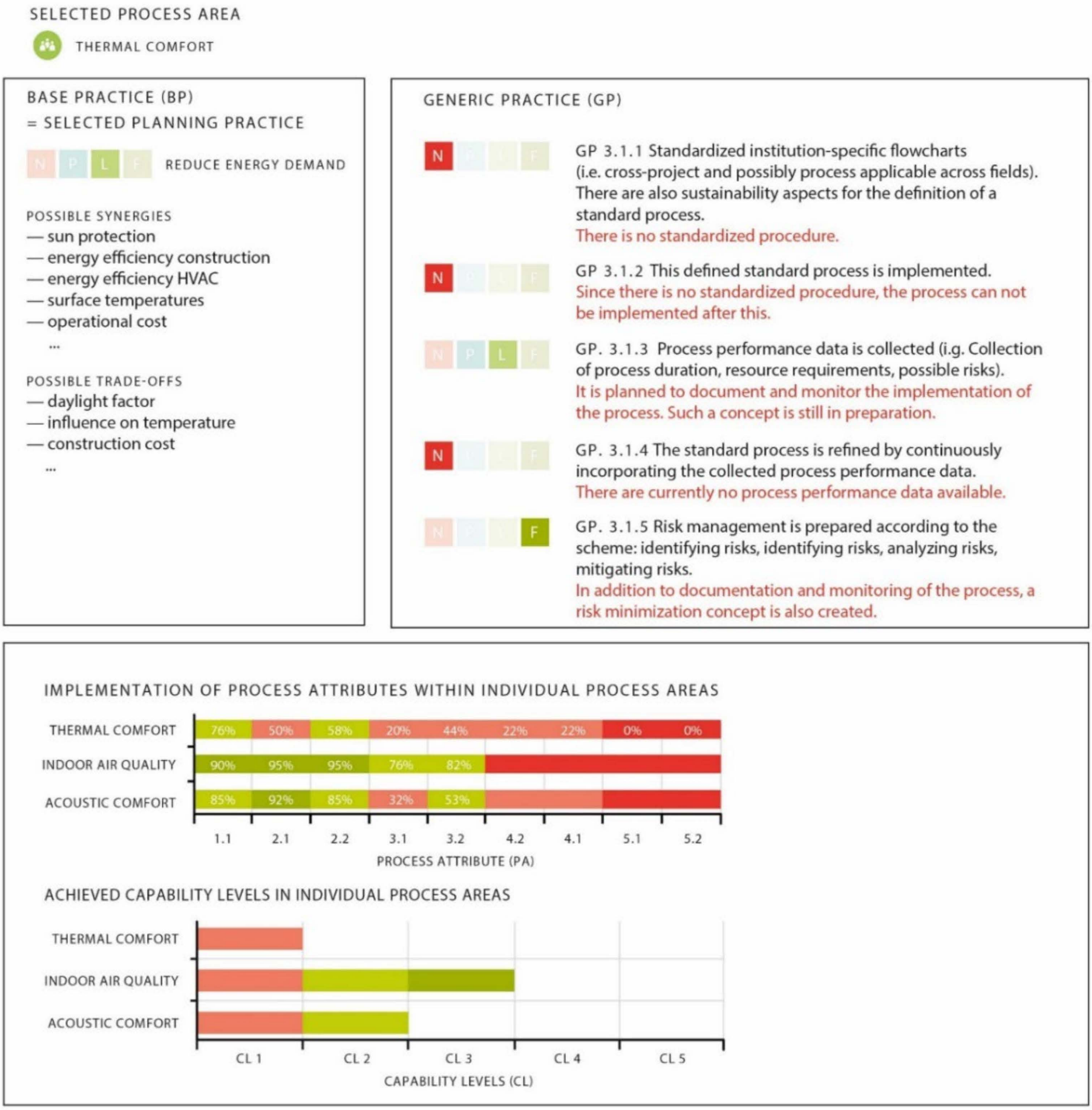

Figure 4. Exemplary assessment with the SCOMM.

Another measure that can be applied to reduce the energy demand is to optimize the U-value of the building envelope. This could be achieved by, for example, increasing the material thicknesses or providing additional thermal insulation. These measures have a positive influence (i.e., synergies) on the indicator "heat transfer", which should be assigned to the process area "quality of the building envelope". In addition, the application of these measures can subsequently lead to an increase in the storage mass and an improvement in the indicator "surface temperatures", which is assigned to the process area "thermal comfort". In terms of reducing the energy demand by applying efficiency measures, more efficient technical building equipment could be planned, which, in turn, would have positive impacts on the indicators "passive systems" and "adaptability of the distribution system to suit operating temperatures to enable the use of renewable energy services", which are to be assigned to the process area "use and integration of building technology". Another measure to reduce the energy demand, and that can be derived from the sufficiency strategy, would be to reduce the indoor air temperature. However, this reduction could lead to a trade-off with the indicators "temperatures during the heating period" and "temperatures outside of the heating period (cooling)", which should be assigned to the process area "user control". From an economic perspective, some measures also have both positive and negative effects. While reducing the energy demand lowers the operating costs, which has a positive effect on the indicators "life cycle cost calculations in the planning process", "life cycle cost optimization" and "building-related life cycle costs", which belong to the process area "life cycle cost", the measures described above can also increase construction costs, which has a negative effect on the indicators mentioned. These exemplary descriptions of the interactions clearly show the complexity underlying sustainable construction management.

As shown in Figure 4, the user has rated the planning practice "reduce energy demand" as largely achieved (L). This means that the user largely rates the quality of his planning measure positively, even after considering all interactions with other process areas. The likelihood that this planning practice will jeopardize other project objectives, therefore, is considered low.

The evaluation of all base practices in the respective process areas (i.e., several planning practices can also occur within the same process area) then results in the implementation probability of PA 1.1. After the N-P-L-F assessments of all base practices have been carried out, the user takes the next step and evaluates the generic practices for the selected processes.

The N-P-L-F assessment of the base and generic practices results in a degree of implementation for all PAs associated with a process. The additive combination of the implementation degrees for each PA, which are based on the assessment method, provides the capability levels for each process. Similarly, the capability levels of the processes can be aggregated to the maturity levels for the six DGNB quality section or for the overall design quality of the building.

4. Discussion

Maturity models are already in use in the construction industry; however, they are primarily applied in a broader sense to project management and in a narrower sense to risk management and knowledge management. The quality management of sustainable construction—supported by existing maturity level models—can currently only be achieved by improving the management processes [61].

Actors in the construction industry have been searching in vain for a maturity model that could be used to assess the quality of planning practices or processes and, thus, the quality of planning for sustainable construction. Our work resulted in the development of just this type of maturity model for sustainable construction (SCOMM), which enables the users (i.e., the individual planners) to monitor their design and increase the quality of planning without investing valuable additional time.

As general advantages of using maturity models, the user can identify the strengths and weaknesses of individual processes; therefore, they are given the opportunity to improve these directly and strategically [8,10]. In turn, this enables companies to achieve higher standards in various areas [21]. By providing the opportunity to improve and develop processes, maturity models reduce the number of (inevitable) errors in the company/planning office and avoid unnecessary additional costs and delays [68]. Another advantage of using these models is that processes can be analyzed before they are executed, rather than simply being improved after a potentially costly error has occurred [13].

If a company/planning office exhibits a high level of maturity, which is also communicated externally, the office can enjoy further advantages on the market, as the level of maturity differentiates it from its competitors. A weakness of maturity models is that introducing maturity models requires the investment of too many resources and that the benefits of their use are not always clear [20]. The introduction of a maturity assessment often fails because the employees display a resistance to the conversion of tried-and-tested processes for the purpose of process optimization due to their lack of understanding [69]. In such situations, management needs to inform employees about the purpose and benefits of such assessments, so that everyone can work together to improve processes [70]. Furthermore, the time required for maturity assessment can be reduced by integrating SCOMM into methods such as Building Information Modeling (BIM) [71].

Assessing the maturity level of a company/planning office can also be problematic, as this is often done by self-assessment due to the additional effort involved. This means that some entrepreneurs may try to position themselves advantageously in the comparison by falsifying the assessment. This problem could be remedied by contracting an external evaluation, but this would involve additional costs [22]. These advantages and disadvantages apply analogously to the maturity model developed for sustainable construction.

Regardless of whether the planning is carried out by a single planner or by several planners in a larger planning office, the planners must be convinced of the usefulness of the maturity model. They also need to be made aware of the fact that a certain amount of additional time will be required for planning due to the execution of the maturity assessment and to accept this fact. When carrying out such discussions, management should clearly emphasize the advantages of using the maturity model. Evaluating individual planning practices engenders a certain degree of self-control in a positive sense. Planned practices are repeatedly scrutinized and specifically checked for their degree of goal achievement. In addition, the synergies and trade-offs related to individual planning practices within the maturity model become apparent. By identifying the synergies and trade-offs, a clearer picture of the systemic understanding emerges, and unexpected short, medium, and long-term effects can be avoided [8,72,73]. By determining the capability levels of individual processes, the user can recommend the application of the necessary control measures already in the early building design phase.

By reducing their planning errors, planning offices can gain a better reputation as compared with their competitors. In this way, the application of the maturity model can also result in an increase in the number of planning contracts. To achieve this purpose, actors in the construction industry should consider including the application of a maturity assessment when tendering and awarding in the future. This compensates for the resulting additional expenditure during the design phase. As one way to receive compensation, the maturity assessment could be included in the schedule of services and fees for architects and engineers (HOAI).

In addition, clients should be made aware of the added value of maturity assessments; the planner should clearly indicate how the assessment helps to avoid planning errors and unexpected additional costs. These unexpected additional costs are significantly higher than the additional planning costs in most cases.

Finally, it should be noted that an extension of the system boundary from the building level to the district or urban planning level is feasible. In this context, the DGNB certification system already offers a certification system for the planning and certification of sustainable districts. Thus, the proposed methodological approach could also be applied to urban planning, unless the underlying sustainability criteria are adapted, the interactions of urban planning practices are identified, and the generic practices for the assessment of the process attributes are adjusted.

5. Conclusions

The design of sustainable buildings is crucial to meet our climate goals. From a current perspective, it appears as though Austria can only meet its international climate commitments and align with European strategies by investing a substantial amount of effort (i.e., by applying much more ambitious, specific, and resilient measures). The steadily increasing complexity of planning and construction processes calls upon those individuals involved to take what is essentially a new approach to creating (more) sustainable construction. We recognized that a further step was urgently needed to ensure the development of a resilient built environment. We addressed this problem by combining the theoretical framework of the maturity assessment method and building certification systems to provide a holistic quality assurance tool for the early design phase of buildings to monitor (sustainable) planning practices in order to achieve better certification results. This resulted in the development of a new maturity model (SCOMM) that enables integrated sustainability assessment in the early design phase of buildings by providing a self-assessment tool for (sustainable) planning practices and, thus, the implementation of early project management to achieve best certification. The main points of the developed model can be summarized as follows:

- Combination of Software Process Improvement and Capability dEtermination (SPiCE) model and the building certification system of the German Sustainable Building Council (DGNB).
- The proposed process-based approach ensures a holistic consideration of all required planning practices by a systematic assessment process.
- Assessment of planning practices (i.e., base practices (BP)) and identification of their synergies and trade-offs by applying the proposed maturity model.
- Development of generic practices (GP) to evaluate process attributes and, thus, foster sustainable construction.
- Determination of the maturity level of individual planning practices or of the fulfillment of DGNB criteria or their quality sections.

This new maturity assessment method was developed to enable quality management throughout the early building design phase to ensure a holistic perspective. However, this holistic view can only be achieved if the function of the individual process steps is guaranteed. If individual process steps fail or if interactions are overlooked, the entire sustainable construction management and the entire sustainability certification are at risk.

The stakeholders and planners involved in this project have taken the first step towards structuring sustainability requirements, processing them comprehensibly and carrying out monitoring. When used in combination with the principles of building certification systems, this newly developed model can serve as an important tool that enables users to achieve better building certification results and, thus, better sustainable construction.

In summary, the advantages of the SCOMM can be described in five principal areas:

(1) it increases the user's knowledge of the essential planning practices (K.O. practices and systemic relevant practices);
(2) it increases the user's knowledge and ability to visualize the interactions that occur among planning practices and processes;
(3) it increases the user's knowledge of the maturity level achieved as compared to the planned process maturity and, thus, the implementation of quality management from a holistic perspective;
(4) it offers the user the possibility of preparing a sustainability report as a basis for a planning manual; and
(5) by combining all of these advantages and by taking into account the maturity model's workflow, the user has a higher chance of achieving a higher certification result.

People who choose to implement SCOMM can visualize the possible effects of decisions in the early building design phase by carrying out three simple steps: define the target, analyze the system, and assess the maturity. Our intention in developing SCOMM was to raise awareness among the involved stakeholders and planners for the potential inherent in this new mode, as well as for various influencing factors in the context of holistic building optimization. The fact that the user can apply SCOMM to visualize interactions and gain knowledge about critical processes or planning practices are decisive factors that help them achieve sustainability goals. The resulting synergies can be consciously considered in further planning process steps, as the possible trade-offs due to diverging target preferences become evident.

Supplementary Materials: Supplementary data related to this article can be found at https://openlib.tugraz.at/sustainable-design-process-integrated-facades-2019.

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Appendix A. Capability Levels

Table A1. Capability levels.

Capability Level	Definition	Process Attribute
Level 0: Incomplete process/ planning practice	The process does not achieve its purpose or is not implemented. Little evidence is available.	Level 0 is the only process to which no process attributes are assigned.
Level 1: Performed process/ planning practice	The process is implemented and fulfils its process purpose. Input and output work products are in place and ensure that the process purpose is achieved.	**PA 1.1: Process performance** This attribute is a measure of the degree to which the process purpose is achieved. Indicators are work products and measures that convert input work products into output work products.
Level 2: Managed process/ planning practice	The process is planned, monitored and adjusted if necessary. The main differences to level 1 are the management of the execution and the work products. The result of the processes is measured by target-performance comparisons.	**PA 2.1: Execution management** This attribute describes to what extent the execution of a process is planned and controlled. The application of basic management techniques is affected. PA 2.2: Work product management This attribute describes how well work products are planned and controlled in the process. It is used to check the effort put into identifying, documenting, and managing work products.
Level 3: Established process/ planning practice	The applied and controlled process is now also defined to achieve the desired process result. The established process is a standard process that is defined and adapted.	**PA 3.1: Process definition** This attribute indicates how far a process is described. A process becomes a defined process, if a certain degree of customization under consideration from the outside. With regard to the desired process result a process description created. **PA 3.2: Process deployment** The degree to which a defined process is used as a standard process is determined by of the attribute process usage is described. Aspects that are described in the attribute are described, which contribute to the effectiveness of the implementation.
Level 4: Predictable process/ planning practice	The process runs as a standardized process to achieve the desired process results. The process is consistently implemented within defined limits. Deviations are recorded together with their causes.	**PA 4.1: Process management** This attribute reflects how well measurement results are used in the assurance process to perform processes. The measurement results are used to determine the degree to which business objectives are achieved. **PA 4.2: Process control** This attribute reflects how far a process is controlled. It can be used to predict whether a process is running within predefined limits. The purpose of control is to detect deviations and determine the causes of these deviations.
Level 5: Optimizing process/ planning practice	The existing process is continuously optimized to achieve current and future business objectives. The execution of processes is continuously improved by introducing new ideas and techniques and changing inefficient practices.	**PA 5.1: Process innovation** This attribute describes the degree to which process changes are implemented based on measurements, deviations, new innovations, and new ideas. Recognizing and understanding the causes of change is an important factor. **PA 5.2: Process optimization** The extent to which changes are made to the definition, control, and execution of processes is reflected by this attribute. The effects of changes are estimated in order to achieve the best possible improvement. Optimization must be planned carefully to minimize disruption.

Appendix B. Maturity Levels

Table A2. Maturity levels.

Maturity Level	Definition
Level 1: Performed	The process purpose is met, based on training, experience, or work procedures following generally accepted guidelines. Company-wide process management does not exist, performance depends largely on personnel and differs from project to project. The results of the process execution are available, but the process execution relies only on the know-how of the project team members. Guidelines, if used, could be building certification systems, for example. However, their application is not consistent throughout the organization and planning measures, management measures, and repeatability measures are generally not implemented.
Level 2: Managed	The process execution is planned and guided. Resources, responsibilities, and instruments are planned according to realistic experiences. The project goals are defined, and the work is monitored, managed, and checked. The guidelines to be applied at project level are known and are applied. Additionally, the work is planned and executed at the individual project levels. Management of requirements and quality assurance are in place. Moreover, sub-processes (e.g., monitoring of milestones, costs, and project progress) are specified and implemented. Project-specific guidelines are planned.
Level 3: Established	Where appropriate, the standard processes are standardized throughout the company. Additionally, their execution is standardized using application guidelines and/or by adapting processes. This provides the foundation for standardized project management, project control, and project planning. The process is person-independent and institutionalized. There is a model for the standard procedure (process model), which has been documented and standardized on an organizational level. Simulations (e.g., LCC or thermal simulations) are performed.
Level 4: Predictable	The performance indicators derived from the measurements and analyses and their ongoing monitoring are capable of systematically identifying any weaknesses. This results in an improved forecasting accuracy. The qualities are quantitatively known, and the risk management is well-established. The process has been quantitatively understood and is being monitored at project level. Productivity and quality are measured, and the relevant parameters are identifiable. Effort estimations are performed methodically, and a PLAN-ACTUAL analysis is conducted. Possibilities for analysis and management can be specified.
Level 5: Optimizing	The information and knowledge gained from level 4 is then used to launch an optimization process. New methodologies and workflows are developed, simulated, and implemented as a prototype. If they are successful, they will be institutionalized. A systematic collection and re-use of empirical values and an error analysis is carried out. Opportunities for optimization resulting from new concepts and new technologies are explored. Long-term optimization goals and visions can be specified.

Appendix C. Base Practices

Table A3. Exemplary base practices.

Exemplary Base Practices	Influenced Process Area (s)	Influenced Quality Section (s)
Slender design of building envelope	Quality of building envelope, thermal comfort, sound insulation, visual comfort, building life cycle assessment, life cycle cost	Environmental quality, economic quality, sociocultural and functional quality, technical quality, process quality
Increase window surface area	Visual comfort, thermal comfort, sound insulation, acoustic comfort, ease of cleaning building components, building life cycle assessment, life cycle cost	Sociocultural and functional quality, technical quality
Increase sound insulation	Sound insulation, building life cycle assessment, life cycle cost,	Sociocultural and functional quality, technical quality,
Reduce S/V-ratio	Land use, building life cycle assessment, life cycle cost	Technical quality, environmental quality
Use triple glazing windows	Thermal comfort, sound insulation, acoustic comfort, building life cycle assessment, life cycle cost	Sociocultural and functional quality, technical quality
Use heat pumps	User control, building life cycle assessment, life cycle cost	Technical quality

Appendix D. Generic Practices

Table A4. Generic practices for PA 2.1 Performance management.

Abbreviation	Generic Practice
GP 2.1.1	Define sustainability objective and plan sustainability needs
GP 2.1.2	Planning manual and construction schedule are available, taking into account sustainability aspects throughout the planning process and in preparation for execution (tendering and contracting)
GP 2.1.3	Competencies and responsibilities related to the process are included in the performance specifications
GP 2.1.4	Processes for supporting "sustainability" controls are defined
GP 2.1.1	Define sustainability objective and plan sustainability needs
GP 2.1.2	Planning manual and construction schedule are available, taking into account sustainability aspects throughout the planning process and in preparation for execution (tendering and contracting)

Table A5. Generic practices for PA 2.2 Work product management.

Abbreviation	Generic Practice
GP 2.2.1	Sustainability requirements for results/products are clearly defined
GP 2.2.2	Object documentation "sustainability" with regard to the use phase is prepared
GP 2.2.3	Potential qualitative trade-offs/synergies resulting from sustainability optimization of a process area are identified
GP 2.2.4	Results of ongoing monitoring of the process from a sustainability perspective are documented

Table A6. Generic practices for PA 3.1 Process definition.

Abbreviation	Generic Practice
GP 3.1.1	Standardized institution-specific flowcharts (i.e., applicable across projects and possibly across process areas) are available to consider sustainability aspects to define a standard process
GP 3.1.2	This defined standard process is implemented
GP 3.1.3	Process performance data are collected
GP 3.1.4	The standard process is refined by continuously entering the collected process performance data
GP 3.1.5	Risk management is prepared according to the scheme: identify risks, analyze risks, mitigate risks

Table A7. Generic practices for PA 3.2 Process development.

Abbreviation	Generic Practice
GP 3.2.1	Roles, responsibilities, and required skills in relation to sustainability requirements are defined (e.g., performance charts with responsibilities and accountabilities, DEMIA-RACI diagrams)
GP 3.2.2	Requirements for the (construction) project infrastructure (e.g., project references, personnel know-how, experience with the application of methods and tools for sustainable construction, site conditions with regard to the use of renewable resources) for the implementation of a sustainable planning and construction process are identified and documented
GP 3.2.3	Resources for implementing the sustainability processes are provided, allocated, and used (e.g., use of sustainability-qualified personnel)
GP 3.2.4	An appropriate (construction) project infrastructure (e.g., tools, documentation) exists on site (in the planning office, on the construction site) for the process

Table A8. Generic practices for PA 4.1 Process management.

Abbreviation	Generic Practice
GP 4.1.1	Objectives and related measurands are defined (Objectives: process area level and applicable planning practices; measurands: LCCA, LCA, critical and active planning practices)
GP 4.1.2	Measurements are collected (evaluation LCCA and LCA for a process or individual planning practices)
GP 4.1.3	Analyze trends from key performance indicators (LCCA, LCA)

Table A9. Generic practices for PA 4.2 Process control.

Abbreviation	Generic Practice
GP 4.2.1	Process control variables (LCCA, LCA) are analyzed
GP 4.2.2	Sustainability process is managed using measurands

Table A10. Generic practices for PA 5.1 Process innovation.

Abbreviation	Generic Practice
GP 5.1.1	The definition of the standard sustainability process is changed as necessary
GP 5.1.2	Impacts of proposed changes are evaluated
GP 5.1.3	An implementation strategy for the changes and process flow diagrams for change management exist
GP 5.1.4	The effectiveness of a process change is assessed

Table A11. Generic practices for PA 5.2 Process optimization.

Abbreviation	Generic Practice
GP 5.2.1	The objectives for improving the process towards sustainability are established. Change in method through innovation has occurred and the objectives for improvement are set
GP 5.2.2	The potential for improvement is analyzed. Systemic SWOT analysis of the process improvement has been performed and sources of actual and potential problems have been identified
GP 5.2.3	Changes are introduced according to the implementation strategy and process improvement flowcharts exist
GP 5.2.4	The benefits obtained are quantified. Quantitative evaluation of the improvements of the changed process in relation to the pre-defined objectives

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