BIM – TOWARDS THE ENTIRE LIFECYCLE

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ABSTRACT

The goal of Building Information Modeling (BIM) is the integral and comprehensive digital modeling of all properties regarding a building, its planning and construction process as well as maintenance and use. This is combined with the overarching objective within BIM to integrate and support all involved experts aiming towards an improved collaboration. Currently the necessary data often only exists in a very fragmented and uncoordinated way throughout different subsections, as well as planning and construction phases. A lack of organized information management is especially noticeable in finalized built objectives during questions of conversion and refurbishment. BIM tries to mediate between the different views of its users and allows for a coordinated accumulation of data, as well as synchronously keeping the planning status up to date. However, in most cases essential information is missing or not used throughout the complete lifecycle of the building. Consequently, there are clear gaps between the different phases of planning, construction and maintenance.

Within this paper, we give an evaluation of applicable methods for data collection and modeling of the actual inventory of components with regard to position, geometry and semantics (e.g. material) for the purpose of a comprehensive and BIM-compliant as-built documentation. This allows the analysis of missing interfaces and data. Considered from a process automation viewpoint, we identify missing BIM data e.g. for assembly processes within construction in order to create a BIM-aided planning process that continues into actual fabrication and construction. Based on this, we discuss possibilities for the implementation of user requirements in order to develop a comprehensive semi-automated decision support tool for BIM users.

Primary goal is to provide concepts for the integration of construction processes as well as options for conversion planning and construction of buildings. These targets imply a continuous updating of the BIM models (including the semantic parameters) from a continuous 'as-built' acquisition and modeling of the construction progress.

While BIM primarily is being discussed as a cooperative working methodology in the new planning of buildings, we also consider the required information for future conversion and refurbishment of the building and the required level of development, in order to complete the lifecycle approach of BIM.

Keywords: as-built documentation; automation; BIM; decision support tool; existing buildings; lifecycle; model extension; refurbishment.

1 INTRODUCTION

Building Information Modeling (BIM) describes a new method for the digital way of planning and building. BIM aims the entire digital modeling of all features of a building, which are applied by all involved agents and disciplines over the whole life cycle for supporting the building processes (Fig. 1) [1].

Naturally, planning, construction and operation of a building are a high interdisciplinary task of different disciplines (architecture, constructional engineering, surveying and building services). The required exchange and adjustment of information between building construction services often is poorly geared to each other in practical terms (e.g. fragmented data, irregular modeling, media disruption, missing temporal agreement) which leads to errors, delays and finally to higher costs. The consistent use of BIM results in a kind of digital building-database,

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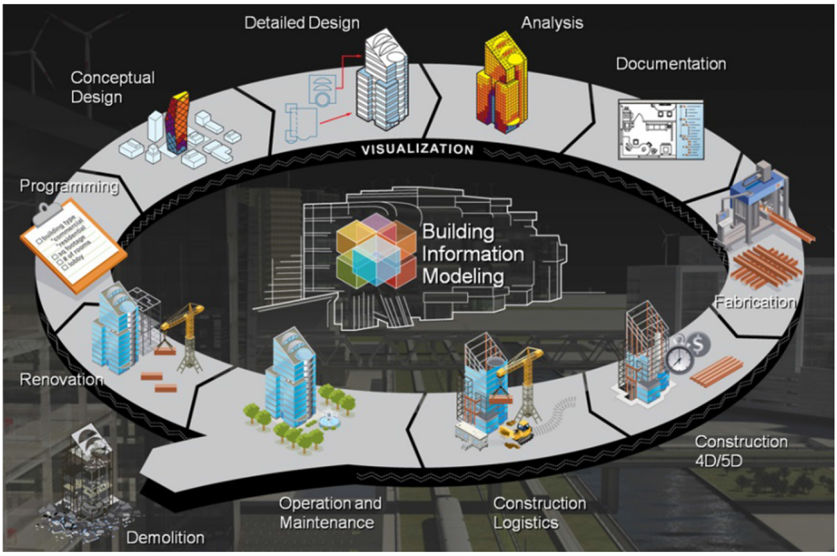

Figure 1: Application of BIM on the building life cycle *(source: NBIM.org)*.

which on the one hand allows a collaborative planning among the construction services and on the other hand, sustainably supports the engrossment and the operation of the buildings. Therefore, BIM enables a high cooperative working method of all involved, especially by supporting of administration and exchanging of all relevant data. The consequent use of BIM does not only focus on the aim of a better data exchange, furthermore it leads to a distinct higher transparency for an optimized coordination between all involved. Discrepancies and errors can be revealed and corrected in an early planning phase, which is a crucial requirement for the security in planning, operation and costs and consequently for an efficient building construction and exploitation. (Significant) missed deadlines and cost overruns concerning a row of large projects trigger intense discussions about BIM in Germany.

Apart from the constructive features of a building, BIM is also supposed to depict the technical, functional and mercantile aspects. This aims on integrating all essential construction phases. This paper pursues the goal to explore, On the basis of the described basic functions of already existing BIM systems the goal of this project is to examine its adaptability and its options to further development including the renovation processes of buildings. The examinations also aim onintegral building progress analysis and supported BIM informed automation of processes by manufacturing robotics. Therewith BIM should not limited on constructions of new builds. Moreover, it should be used as a decision-supportive tool for architects, technical planners and investors. This tool allows the creation of scenarios for the adaption of new usages including the determination of structural-constructive possibilities and cost assessments as well as the usage as a master tool for automated alteration processes.

The bases of the integrated digital BIM are *object-oriented three-dimensional models* (Fig. 2). BIM is infrequently used as an acronym for *Building Information Management* or *Building Information Model*. The first term implies the challenge of the digital management and the exchange of all specialist data, meanwhile the second description deals with the new way of modeling with applying semantic building models. However, in this chapter BIM

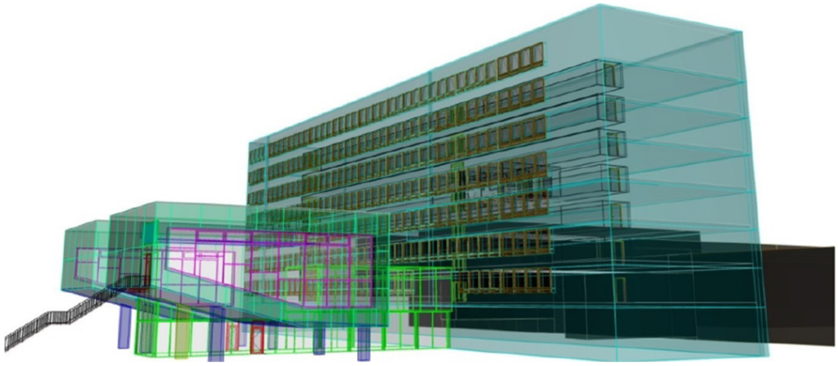

Figure 2: BIM – (architecture) model of the faculty for civil engineering of RWTH Aachen *(Source: gia, RWTH Aachen University).*

represents Building Information Modeling, which includes both, the model and the management of and the work with the data.

2 MODELING FOR BIM

The accurate description of the main body has always been the basis for creation by the building contractors. The description in the pre-digital era took place with analogous plans in layouts and basic patterns. With the occurrence of appropriate computer performances, layouts and patterns they were, with the usage of CAD-systems, transferred into a digital form, whereas people stayed with the two-dimensional depiction of layouts and patterns. The semantics (=meaning) were marked with signatures and divided into themes with layer or surface techniques. With the increase of object-oriented programming techniques, the pure character-oriented CAD converted to *object-oriented models.*

In building models for BIM, the objects or components are the essential information carriers. In contrast to drawing-oriented CAD-models, which merely consist of geometrical primitives (points, lines and surfaces) arranged on different layers, in BIM the geometry is only one feature of a component. Further crucial properties of the objects are their descriptive semantics and their relations to each other (Fig. 3). Objects or components portray instances of predefined object or component classes. The definitions of the components result in the model – and in special case of buildings in building models (Fig. 3). The object-classes result from the underlying (object-oriented) data model.

The definitions of the object-classes, i.e. their semantics (including the descriptive characteristics) and relations, are included within the BIM. One relation serves as the geometrical representation that is usually provided with an own geometrical class. Which geometrical classes are permissible is set within the object classes. Components consist also of integrity rules the instances can be validated with.

The specific characteristic of a component (e.g. concrete characteristic of a window) usually is set in the software by a range of predefined component catalogs. However, these can be enhanced by an own or a third component definition. Geometry only describes one feature of the objects in BIM models. Nevertheless, it is a central basis for the multi-dimensional description of structures and with that linked analysis. For the geometrical description of edges, surfaces and bodies, there do exist different models to which this respective literature [2] is worth mentioning [3].

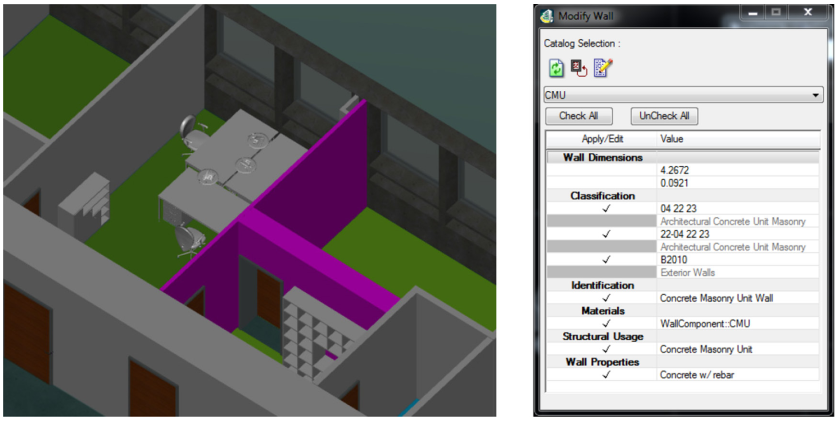

Figure 3: Component 'wall' with descriptive features of the BIM-software (here: Bentley Building Designer).

Various disciplines with very diverse requirements to building models take part in the life cycle. This necessarily leads to specific models (architecture model, supporting framework models, technical building services (TBS) models). Also in BIM the various technical planners create their discipline-specific object models with a discipline-specific software. Furthermore, they can (depending on the work phase) be present in different levels of development (LOD) [4].

Every single model is a representative for the discipline-specific model of the building structure. In BIM these single models are fused together to a complete model, whereby this can be accomplished in different ways. In the most consequent construction all single models are immediately saved in a central model server or in the 'Cloud' and directly revised online by involved people. Nevertheless, up to now more practical is the decentralized local management of the single models by various planning specialists. Then the single models will be fused at given times. The creation of the fused model has a very crucial meaning for BIM because only that allows a transparent planning and an early detection of discrepancies.

At least the system relevant or the components depending on each other and the ones, which influence each other have to be fused in order to perform conflict analysis between the single models. With the help of software supported collision checks one can detect and solve conflicts between the planning's of the different disciplines and their interfaces at an early planning phase (e.g. between TBS- and structural engineering).

3 WORKING WITH BIM

BIM involves working with the models, besides digital modeling and data exchange. Thus scale plans (e.g. floor plans), sections, dimensioning or three-dimensional visualizations in different render modes (wireframe to photo-realistic depictions) models can at the touch of a button be derived automatically and consistently from the BIM models. That also provides a very useful functionality for the visualization of planning varieties. With the usage of 3D geometry, analyses such as escape route plans, lighting analyses or the collision check between components of different discipline-specific models can be performed.

The component descriptions that go beyond geometry make ongoing evaluations possible. For instance, these can be the derivation of component lists (e.g. number of doors of a certain type) or surface and quantity calculation (e.g. needed amount of concrete). The fact that component descriptions can also include technical and physical features of the objects makes likewise building physical and structural design analyses (e.g. energetic simulations or simulations for support structure optimization) viable.

With the extension of 3D models to the fourth dimension (4D BIM), e.g. with inclusion of time and schedule plans, BIM can above that be a central tool for the construction process planning. With the extra link to temporal documentation information and adjustment of the construction process planning, a BIM-based progress monitoring can occur. If the components are additionally linked to costs as a fifth dimension, further calculative analyzes, such as a BIM-based cost calculation, and deliberate variations in planning can be used to calculate costs. These form the basis of risk analyses or financing concepts that can occur as the template for financing credit institution [5]. Besides the geometrical and semantic aspects, legal accessibility issues to the data, specified on the user role, have to be considered.

4 ADVANCED BIM – REQUIREMENTS AND CHANCES

This chapter will provide a conceptual overview on ways of innovative BIM model extensions. This is achieved by significant examination for the usage of BIM methods for the conversion planning and reconstruction of buildings. While BIM is currently discussed especially as a cooperative working method in the new planning of buildings, the intention therefore aims at a completion to further phases of the life cycle of existing buildings.

The ideas, which will be further described in the following, provide a preparation of basics for designing BIM model extensions in different phases of the life cycle, which result inpossible follow-up projects with the creation of new interfaces as a cross-sectional task. Single examinations should be deepened with the help of specific issues, which are determined by means of sample scenarios.

4.1 Model extension of usage requirements

Considered as the first BIM extension of the ‘classic’ BIM, including architecture-, static and TBS-models, the completion of architecture models offers to new usage database. This form of a BIM database shall link certain BIM applications, such as collision tests or mass determinations and performance images for components with central information requirements, in accordance with the step plan for digital building of the Federal Ministry of Transport and Digital Infrastructure (BMVI). A functional classification and the classification of the components, which lists the functional characteristics of components in a feature database is necessary in this context [6].

A variety of usages in the living and office areas are standardized concerning their surface, their required connections to the TBS as well as the room layouts and lighting requirements. By the German Institute for Standardization, standardized spatial cuts and standard measures were developed as guidelines for construction plans (above all DIN 18011 and DIN 18022), which were partly replaced and extended by specific measures of countries (Regional building regulations, Model building regulation).

With the DIN SPEC 91400: 2015-01, a uniform classification and description system for BIM objects such as walls, windows or sanitary equipment is offered, which is compatible with the standard performance book for construction (STLB construction) as well as to the international standard ISO 16739 [7]. These are minimum- and regulation measures for sanitary facilities, working places or sleeping areas. Beyond these minimum requirements, there are mostly recommended standard gauges and sizes of relevant outline and planning help. These indeed vary in personal equipment wishes or equipment demands (e.g. heights, barrier liberty and movement spaces) and financial options, which nowadays lead to widely spread individualizations. Indeed, there are typologies that appear in hotels, medical- and nursing facilities or office buildings, which can be gathered in databases concerning their surfaces, disposals, alignments and integrated within a BIM. With such a procedure the danger of reducing the individuality of outlines (and so the creativity of architectures) can come up. Contemporaneously, these investors and planners repose in an early stage in the opportunity, through the integration and variation of different typologies, to prove the frame of feasibility studies options for further and reuse of single building-parts or the whole object.

Varieties of guides provide planning recommendations on further topics such as sustainable or barrier-free building [8]. At this point, the question arises as to which rules and other planning aids in the first four performance phases of §34 HOAI are based on decision making aids or foundations which of these have already been found in the BIM-based database of various manufacturers. To provide interfaces especially at data transfer points in the individual service phases, these databases should also contain information on the typical BIM requirements and LOD.

If the implementation of usage requirements in the form of standardized minimum requirements and guidelines, however are extended to parameters of common outline- and planning helps and further qualitative decision criteria, then even an increase of architectural overall quality can be aimed. In addition to technical problem solving and cost aspects, planning, licensing, logistical and architectural-historical issues also play a role here [10]. As a result, further research needs can be identified: the question of the identification of further relevant qualitative decision-making criteria and the associated requirements for implementation in BIM systems. One example is the aspect of the recyclability of building materials (see section 4.3).

With this approach, the goal is to provide architects, project developers and professional planners with comprehensive, digital support in the form of a semi-automated tool and (in extended version) a variant evaluation of individual modification interventions. According to the basic principle of a value analysis as a qualitative analysis method for the evaluation of alternatives, such complex problems could be rationally supported. By means of BIM, such an assessment can refer firstly to the fundamental feasibility, the matter of aborts, extensions and rebuilding's and punctual or larger extensions. First results can be the naming and description of interventions of support structures or of TBS. In order to maintain and delineate which aspects have to be taken into account in the different stages of completion to be defined (see section 4.2) the different planning phases should be differentiated.

If standardized usage data basis for product- and cost catalogs or income database for different applications are completed, BIM can be extended to a decision-supporting and assessing tool for usage options of components or buildings in the life cycle. This raises further research questions on requirements and the implementation of appropriate assessment systems, such as the question of prioritizing, weighting or filtering the various decision criteria. Proceeding like that, the degree of consideration of individual criteria should be left to the respective planner. In countries where BIM has already been established as a cooperative method, e.g. so-called 'Solibri Model Checkers' are already being used as tools for model-based quality testing for ongoing quality control in larger construction projects. They are used to check moving surfaces, opening radii, minimum dimensions or other sources of errors [11].

Since for a number of years political governance has increased the volume of existing buildings compared to new construction investments by means of subsidy programs as well as changing demands on the number of existing buildings the need for expertise in the existing area, esp. the assessment and recommendation for stockpiles will gain in importance. As a result, the project a-BIM aims to record typologies for residential uses in existing buildings (for room types and building elements) and to develop a concept for integration into BIM, including the LODs. This covers issues concerning examinations of categorization, updating, user guidance and extension, besides the implementation of several decision criteria.

Another important aspect linked to successful decision support, is an extension to a model-based communication between all actors involved in use planning. In order to optimize model-based communication and coordination in BIM-supported projects, different BIM software features different approaches, including classic graphical features in the project levels, as well as mini-tools that enable Skype-like chat windows and model-bound comments and cloud-like platforms. With the BIM Collaboration Format (BCF), a file format that stores textual comments, camera positions, affected objects, etc., the exchange of model-based comments between different software is possible [11]. The need for research exists at the level of the actors involved and their model-based communication esp. at the level of their requirements for an optimal digital information flow.

After the evidence of the fundamental feasibility of such usage requirements and their connectivity as well as their applicability and their usage for the construction- and planning process involved, the approach can be extended in further extension levels to other usages e.g. office use.

4.2 Model extension for acquisition, detection and modeling of changes

As it is shown in chapter 2, BIM is based on semantic and component-oriented building models, which i.e. contain information of component structures as well as materials. In the case of more recent or new buildings, to which covering information can be available or updated, material information are extended above the sheer surfaces to 'covert information'. However, a particular challenge nowadays is, especially the reliable status plan and even the information about the components for existing buildings, how to acquire layer structures and materials 'beyond the surface'.

Measurement methods by means of laser scanning, photogrammetry, radar, radiography etc. fundamentally seem to make it possible that inventory data can be collected to the purpose of a BIM-friendly as-built documentation for the conversion planning. However, this field of research is partially at the outset. Distinct measurement methods are available. However, these methods need a structured, comprehensive and automated data collection. A calibration and validation of the derived knowledge from single applications in terms of a generalizability and transferability is necessary. As well coupling and automatized processing of the just acquired data to the integration in BIM must be guaranteed.

For as-built data collection of buildings various measurement techniques are used. The four basic common techniques are photogrammetry, terrestrial laser scanning (TLS), tachymetry and electronic devices for manual measurement. Data collection using 3D point clouds is the most common method for generating BIM compliant as-built models. The point clouds can be produced solely from imaging methods such as Structure from Motion (SfM) or TLS [13]. TLS is the most common approach for point cloud generation with the purpose of as-built documentation. This process is known as 'Scan-to-BIM'. The category

IMMS (Indoor Mobile Mapping Systems) covers systems especially developed for indoor usage. They combine various sensors such as laser scanners and inertial measurement units (IMU) for mobile point cloud acquisition [14, 15]. To determine the position of the system simultaneously to the data collection the so-called SLAM-methods (Simultaneous Localization and Mapping) are often applied [16]. The result of the mentioned data collection methods, the high-resolution point cloud in combination with the images, enables flexible modeling in various levels of developments and serves as a basis for some approaches of automation [18–22], Additional sensors (e.g. for thermography) can be used to enrich the geometry with further semantic information [23]. Besides these systems for point cloud generation, single point based measurement and modeling systems are offered. These systems require but also allow to collect much more information by the user during the in-situ measuring [24, 25].

In the frame of the project a-BIM the existing methods for measurement and registration of the as-built situation concerning position, geometry and material shall be first classified comprehensively. On this basis a concept for an *integrated* data collection and modeling will be developed. The project aims at, for example, extending the model component for structure planning or initiating a model component concerning materials and to integrate these model parts into BIM. First step is the analysis of accurate data collection and integration into a BIM.

The needed abstraction and accuracy depend on the intended purposes (e.g. technical, ecological or economic valuation methods for reuse of single building components). They are crucial for the applied data collection and modeling methods and their methodological improvements. Therefore, in BIM the already in chapter 2 mentioned term *LOD* is used. LOD describes the level of completion in five main levels, starting with a conceptual (LOD 100) up to an as-built model (LOD 500) (Fig. 4) [4, 26, 27].

The main elements of BIM model are on the one hand the geometry and on the other hand the semantic information. In the initial LOD definition by and the geometric level of completion (level of geometry, LOG) is basis for the classification into the different completion levels. There are no declarations concerning a level of develoment of the additional semantic information (Level of Information, LOI). In fact, the LOI content depends on the particular purpose of the BIM model An example for such an LOI concept is explained in Therefore, one aim of the project is to analyse and to define LOG and LOI concerning themes such as reuse, automated production processes and usage requirements.

4.3 Model extension of interfaces to production and automation processes

The current degree of automation within the construction industry is still low especially compared to industrial production. Nevertheless, a number of previous attempts at automation

Figure 4: LoD summary *(Source: NATSPEC 2013).*

were made using specialized machines for specific tasks [30]. These approaches however failed for a number of reasons. Specialized machines are often low in flexibility, while construction tasks can be highly complex, especially if only single tasks are automated while the rest are manually executed. This leads to necessity for construction work being adapted towards automated processes, which causes additional cost and can be time consuming. In addition to the small lot sizes within construction, high tolerances and variation are very common especially when working with natural materials. Building components are therefore often fitted manually on-site. Efforts are made to mediate this through tighter process control and detailed digital representation within BIM.

The information from the several planning levels accumulated by the various actors within the BIM planning is currently only used to a limited extent in the actual construction process. Even if in rare cases at least the foreman has an insight into this planning, this information is not applied directly at the actual level of construction. In order to investigate the gap between planning level and construction and to develop initial concepts for a consistent flow of information, a digitally controlled workflow without the loss of information is to be analyzed in furture research by the help of automation. Within this process, the information required from BIM is to be identified in order to reduce the partial additional documentation effort in the long term.

Similar to the approaches of the 'Production Immanent Design' [31], information or parameters from the BIM planning are extracted and used to inform a semi-automated construction process. In a first proof of concept, a small-scale example scenario will be used for the planning of a semi-automated construction process. Further process data, which can be obtained in the BIM are examined and existing interfaces are used for a transfer of the process control. This approach is also used to identify additionally required information within the available BIM.

The progress of the planned construction processes is captured by sensor technology in analogy to an as-built model for a completed construction and fed back into the existing BIM model. This serves both to investigate possible reconstruction scenarios as well as to inform of the semi-automated Construction process. This however additionally requires a matching of scan data, BIM and other on-site sensors for automation, in order to synchronize data within a consistent frame of reference. Considerations from the area of construction logistics are left out at the moment. In the process, the consistent information flow from model to reality as well as back through a continuous as-built survey is to be investigated.

Required parameters are identified and transferred to an (semi-)automated process. This allows first conclusions to be drawn from the BIM for the information necessary for construction production. In addition, the workflows carried out are systematically recorded and a first continuous information flow to the BIM is considered.

Within the field of green-field construction material information can still be concluded from the given BIM, which in turn creates planning possibilities for possible automation. This in turn is often used for the area of prefabrication. However, for reuse planning this information is often not available especially from a material point of view, increasing the difficulty of using the available data for planning construction processes. This leads to a certain degree of unpredictability, which increases the cost for refurbishment process. In the following the aspects of employing BIM for refurbishment and recyclability is further discussed.

4.4 Model extension of recyclability

Recyclability in the building context is indicated by the material flow, which is linked to the material and the construction details. BIM offers the integral evaluation of what is commonly done in separate steps: first exporting the information about the building (bill of quantities based on volume and density) and secondly allocating environmental indicators to it.

Methods for the quantification of the environmental indicators based on the cubature and the material are increasingly observable [32], and categories of recycling in construction were presented by different scientific actors (among others [33]); however, the application in BIM is relatively new. The first mapping is IFC based and indicates the type of joints (e.g., [34]). The combination of both parameters, environmental indicators like Global Warming Potential and recyclability are currently investigated in a-BIM. Only the combination of both parameters – material and jointing – can provide information about the ecological quality and thus provide the basis for planning decisions. During the planning process, in the new building as well as in the collection of existing buildings, the evaluation of the construction can be judged by the link with a material library.

Environmental impact can be quantified on different levels (material, component, building) by linking materials and component information to a database. This informs the planner about possible planning scenarios (further use/ refurbishment, re-use, recycling). This sets the requirements for a material library, which is defined by semantic parameters. The structure of the material library is led by building components starting with the most typical types. In variants of the components, the impact of material selection is presented with its ecological effects, prepares the interface to the information model and hence provides an informed planning decision.

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