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Niels Bartels · Jannick Höper · Sebastian Theißen · Reinhard Wimmer

Application of the BIM Method in Sustainable Construction

Status Quo of Potential Applications in Practice

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What You Can Take from This *essential*

- An introduction to sustainable building
- Basics of operationalization of sustainability in the construction industry
- The most important BIM terms, definitions and standards for sustainable construction
- Currently relevant BIM use cases for sustainable construction
- Methods for implementing these BIM use cases.
- Data exchange requirements for these BIM use cases
- Added value through BIM for the BIM use cases in sustainable construction

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Abbreviations

AIM	Asset Information Model
AIR	Asset Information Requirements
BEG	Federal funding for efficient buildings
BEM	Building Energy Modeling
BEP	BIM execution plan
BIM	Building Information Modeling
BMI	Federal Ministry of the Interior and Community
BNB	Sustainable Building Rating System
BREEAM	Building Research Establishment Environmental Assessment Methodology
DGNB	German Sustainable Building Council
EIR	Exchange Information Requirements
EPBD	Energy Performance Buildings Directive
EPD	Environmental Product Declaration
ER	Exchange Requirement
FM	Facility Management
GEG	Building Energy Act
GHG	greenhouse gas
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IWBI	International WELL Building Institute
KG	Cost groups
LCA	Lifecycle Assessment
LEED	Leadership in Energy and Environmental Design
LOD	Level of Development
MEP	Mechanical Electrical Plumbing

MP	Material building passport
MMC	Multi model container (Multi model concept)
MVD	Model View Definition
OIR	Organizational information request
PIM	Project Information Model
PIR	Project Information Requirements
QNG	Quality Label Sustainable Building
TBS	Technical building services
VeV	Simplified procedure
VoV	complete procedure

1 Introduction

Sustainable development generally aims to meet the needs of the present generation while preserving the livelihoods of future generations [1]. Megatrends such as net zero carbon, circular economy or digitalization play a decisive role in this. The construction and building sector also has a responsibility to respond to these trends and to contribute to achieving national and international sustainability goals by optimizing the use of technologies and improving processes. Particularly with regard to the climate protection targets agreed in the Paris Agreement, the construction and building sector plays a decisive role, as the design, construction, operation, renovation and deconstruction of buildings are responsible for approx. 39% of global CO_2 emissions [2].

In practice, there are already many approaches to increasing the sustainable quality of buildings through optimized operating concepts. As a rule, only purely energy-related measures are focused on, since previous political measures in the building sector have mainly addressed the increase of energy efficiency and the use of renewable energy. Accordingly, only limited attention is paid to holistic, sustainable requirements. However, in order to reduce the use of resources and greenhouse gas (GHG) emissions in the construction and building sector to a greater extent, lifecycle considerations are necessary, which have so far generally been avoided due to excessive complexity and/or additional effort, resulting in additional costs.

At this point, Building Information Modeling (BIM) offers high potential for a more practical implementation of sustainable building requirements. Through the lifecycle, open and transparent exchange of data,[1] the various topics and

[1] In this Essential, the terms “data” and “information” are used. Data describes variables that cannot be interpreted without tools. Information represents data that is placed in a context and can therefore be interpreted.

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assessment methods of sustainable construction can be linked, communicated and documented. In particular, the BIM-based creation of lifecycle assessments, material passports of buildings, the calculation of lifecycle costs, and the performance of simulations already offer many solutions that open up many added values for sustainable design, construction, operation, renovation, and deconstruction.

In this Essential, the current status quo of possible applications in practice with regard to the use of the BIM method in sustainable construction is therefore addressed.[2] The aim is to promote a fusion of BIM and sustainability by highlighting important requirements for BIM processes and models, currently emerging workflows and their added value. In this way, a contribution is made to the coherent implementation of BIM and sustainability, which are still only marginally applied and are also considered very separately.

[2] Based on the expertise of the authors, this Essential presents in particular the status quo in the German construction and real estate industry.

2 Sustainable Construction

The following section briefly discusses the classification of the concept of sustainability within the construction and building sector. Based on legal and funding requirements, it describes the extent to which further sustainability requirements are set by certification systems. This is followed by a description of the basics of relevant methods for operationalizing sustainability in the construction industry in relation to a current application with the BIM method.

2.1 Sustainability Concept

The origin of the term "sustainability" can be traced back to Hans Carl von Carlowitz in 1713. In view of a possible raw material crisis, von Carlowitz stated in his book "Sylvicultura oeconomica" that only as much wood should be felled as can grow again [3]. With the "Brundtland Report" in 1987, the World Commission on Environment and Development of the United Nations (UN) published today's definition of sustainable development [4]. According to this definition, action is sustainable if it does not restrict the choices and options of future generations. Building on the Brundtland Report and the UN Conference in Rio de Janeiro in 1992, the division of sustainability into three dimensions became further established, so that ecological, economic and socio-cultural aspects should be equally important and pursued simultaneously. This guiding principle was further developed by the Enquete Commission in the German Bundestag in 1998. In 2001, this definition was also applied to sustainable construction and published in the Guideline for Sustainable Building [5], which has been consistently updated since then.

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2.2 Requirements for Sustainable Buildings

Since then, the term sustainability has also gained further importance in the construction and real estate industry. Against the backdrop that the industry is a key sector for achieving global climate protection goals and, in addition, in view of economic growth, demographic change and increasing comfort requirements, presents itself as a major challenge in the context of sustainable development, a large number of requirements for and interactions with “sustainability” of buildings have arisen. These must be considered holistically. In concrete terms, sustainable buildings should pay equal and holistic attention to economic, ecological and socio-cultural aspects. However, these aspects are often in a supposed area of conflict, e.g., high environmental quality vs. low cost.

This is one of the main reasons why the concept of sustainable construction is often viewed in a limited way and associated predominantly with energy aspects. This is also reflected in legal requirements. Thus, in the construction and operation of buildings in the context of a sustainability consideration, measures to reduce GHG emissions and environmental impacts with the most cost-effective implementation possible have often been given priority up to now. A multitude of requirements for a building in the sense of the common three dimensions of sustainability are therefore hardly taken into account.

This Essential cannot deal with all topics either and therefore focuses on those topics of sustainability that currently have the most applications of the BIM method (see Chap. 5). The following Fig. 2.1 lists examples of targets within the dimensions of sustainability and their interfaces to the BIM method. The highlighted targets indicate the focus of this Essential. Assessment methods and tools are assigned to the targets, which represent the relevant BIM use cases from a sustainability perspective for this Essential. The rest of this Essential is structured on the basis of these.

In addition, this Essential predominantly considered the status quo for Germany, Austria and Switzerland.

2.2.1 Legal and Funding Requirements

The European Energy Performance Buildings Directive (EPBD) 2018/844 [6], which came into force in 2018 and is currently being revised, obliges the EU countries to transpose the EPBD requirements into national law within 20 months. The German government has responded to this by, among other things, merging

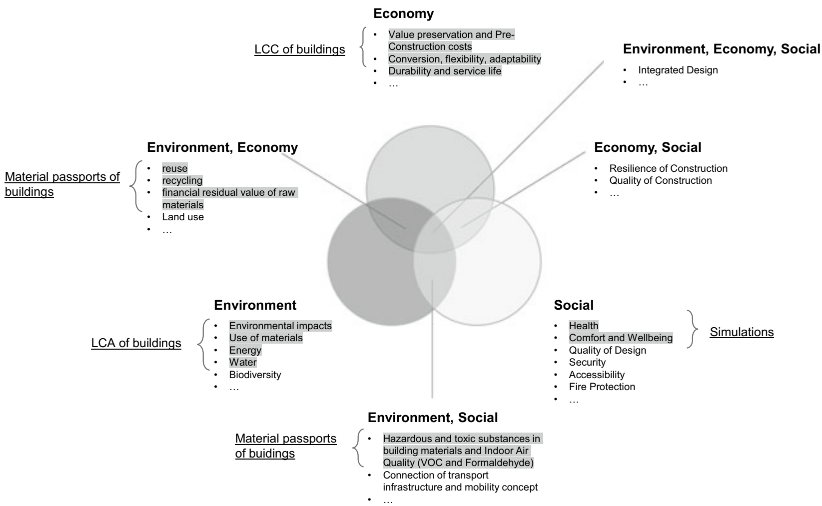

Fig. 2.1 Requirements for sustainable buildings and their focus with BIM in this issue

the Energy Conservation Act, the Energy Conservation Ordinance and the Renewable Energy Heat Act into a "Buildings Energy Act" (GEG). The GEG primarily defines energy requirements in the areas of building renovation and new construction as well as the use of renewable energy. However, there is currently no lifecycle consideration with regard to the other topics of sustainable construction. In 2022, however, an amendment to the GEG will be made, which is expected to be more stringent in this regard.

Within the new "Federal Funding for Efficient Buildings (BEG)", which is possible for all residential and non-residential buildings, the lifecycle approach of sustainable construction has now been given greater consideration for the first time via the introduction of a sustainability class (NH class). The underlying Quality label for Sustainable Buildings (QNG) in the BEG functions as a state seal of quality for buildings, which is issued by the Federal Ministry of the Interior and Community (BMI) as the seal issuer via accredited certification bodies. The structure of the QNG is similar to the well-known certification system for sustainable buildings (see Sect. 2.2.3). As a result, national funding requirements for sustainable construction now go beyond energy efficiency and the use of renewable energy to include, for example, GHG emissions across the lifecycle.

In a similar way to the three dimensions of sustainability, there is a rating system for the financial market and for sustainable (financial) investments based on environmental, social and governance (ESG) principles. Based on this, the EU is now developing a classification system, the so-called EU taxonomy, as part of the European Green Deal for comparability and classification with regard to the sustainability of financial products and economic activities. In concrete terms, the taxonomy is thus part of the "Action Plan: Financing Sustainable Growth," whose objective is to channel financial flows into sustainable investments in order to meet the goals of the Paris Climate Agreement. In this context, evaluation criteria are also being created for the construction and real estate sectors in order to be able to classify investments in this sector in a uniform manner and thus promote the transformation of the sector through decarbonization and the circular economy. This is not the whole sector, but specifically financial products in the form of real estate that want to be considered sustainable according to the EU taxonomy. While six environmental targets with technical screening criteria were initially defined for the "E" in ESG, further standards are to follow for the S and G in the next few years.

The so-called EU Disclosure Regulation defines the legal framework according to which financial market participants, such as financial institutions, investors and companies with "non-financial disclosure obligations", must transparently present the information regarding the defined ESG review criteria for construction of new buildings, building renovation, individual measures and professional services, as well as acquisition and ownership. Specifically, for example, for the activity of new construction, in addition to a certain energy performance for building operation, a lifecycle consideration of GHG emissions is also required. Further requirements are placed on a property in terms of a resource-efficient, circular construction method. Hazardous and toxic building material requirements are also formulated, e.g., volatile organic compound emissions and formaldehyde, which must be taken into account when selecting materials.

2.2.2 Relevant Norms and Standards

Within the construction and building sector, apart from currently existing regulatory and funding requirements, there are numerous standardizations in the form of standards, which often serve as an important basis in legislation and funding. Similarly, these standards also serve as a basis for certification systems. Table 2.1 provides an overview of the relevant standards.

Table 2.1 Relevant standards in the field of sustainable construction

Norm	Designation	Brief description and classification for the evaluation methodology to be developed
Conceptual level		
ISO 15392	Sustainability in buildings and civil engineering works—General principles	This standard defines protection targets that serve to develop evaluation criteria. The guiding principle of sustainable construction relates to protected aspects of the environment, economy and social as protection goals
EN 15643-1	Sustainability of construction works—Framework for assessment of buildings and civil engineering works	The standard provides a system for the sustainability assessment of buildings by applying a lifecycle approach based on the protection goals of ISO 15392. A division is made into the three sustainability dimensions (environment, economy, social) and the two cross-sectional dimensions of technical and process quality. These serve as a basis for evaluating the environmental economic and social quality of a building
Building level		
EN 15978	Sustainability of construction works—Assessment of environmental performance of buildings	The standard provides a calculation method based on lifecycle assessment and other quantified environmental data. For this purpose, the lifecycle approach is used and the environmental impacts to be included are shown in modules
EN 16309	Sustainability of construction works—Assessment of social performance of buildings	The standard provides specific procedures and requirements for assessing the social quality of buildings. As it is a first version, this standard so far only focuses on the assessment of aspects and impacts during the use phase. However, Annex C describes indicators that can be used to assess the origin of materials and the services required for this

(continued)

Table 2.1 (continued)

Norm	Designation	Brief description and classification for the evaluation methodology to be developed
EN 16627	Sustainability of construction works—Assessment of economic performance of buildings	Based on lifecycle costs, and other quantified economic data, the standard specifies calculation methods over the entire lifecycle
Product level		
EN 15804	Sustainability of construction works—Environmental product declarations—Core rules for the product category of construction products	This standard provides basic product category rules for the declaration of construction products and services of all kinds. It standardizes which environmental impacts must be considered in which phases of the lifecycle approach. A total of 35 indicators are defined for environmental impacts, resource consumption, particulate matter emissions, etc. To date, such a concrete orientation at product level only exists in the area of the environmental dimension

2.2.3 Relevant Certification Systems for Sustainable Buildings

About 30 years ago, the first certification systems for measuring and assessing the sustainability of buildings emerged. These systems go beyond compliance with existing minimum standards of existing laws and enable certification of buildings in accordance with the standards of sustainable construction on a voluntary basis. In addition, the certification systems represent a communication tool and steering instrument towards more sustainability in the building sector. They define a variety of assessment indicators that meet the requirements for sustainable building design. The importance of green building certifications has experienced an upswing in recent years, which will continue in the future [7]. The most important systems under consideration on the German market, are

- the Building Research Establishment Environmental Assessment Method (BREEAM) system, which was the first to be developed worldwide in 1990,

- the Leadership in Energy and Environmental Design (LEED) system, developed in 1998 and now the most widely used, and
- the German Sustainable Building Council (DGNB) system developed for Germany in 2009, and
- the Sustainable Building Rating System (BNB) introduced in 2009 for public buildings.

The German systems are based on EN 15643 in their consideration of sustainability and structure the areas and requirements for sustainable construction accordingly. In addition to the above-mentioned systems, there are many other certification systems, but most of them are only used in a national context or have a different focus. One of these systems is the WELL System, which was introduced in 2014 by the International WELL Building Institute (IWBI) and focuses primarily on the health and well-being of humans.

A comparison of the contents with regard to the three dimensions of sustainability shows the consideration and weighting between BREEAM, LEED, DGNB/BNB and WELL. While DGNB and BNB as second-generation certification systems focus on an almost equal weighting, LEED and BREEAM as first-generation systems place a strong focus on environmental content. WELL, with its focus on health and well-being, refers mainly to the socio-cultural dimension (see Fig. 2.2).

2.3 Operationalization of Sustainability in Construction

This section describes the basics of operationalization methods in sustainable construction.

2.3.1 Lifecycle Assessment of Buildings

Lifecycle assessment (LCA) is a method that aims to provide information about the impact of a product or process on the environment over its lifecycle. In this way, environmental impacts in the different phases of the lifecycle can be made measurable and comparable. The ISO 14040 and 14044 describe the main principles and structure for implementation and recommendations on how the procedure for evaluating a LCA should be carried out. The construction industry also uses the LCA method in order to examine the embodied environmental effects of the

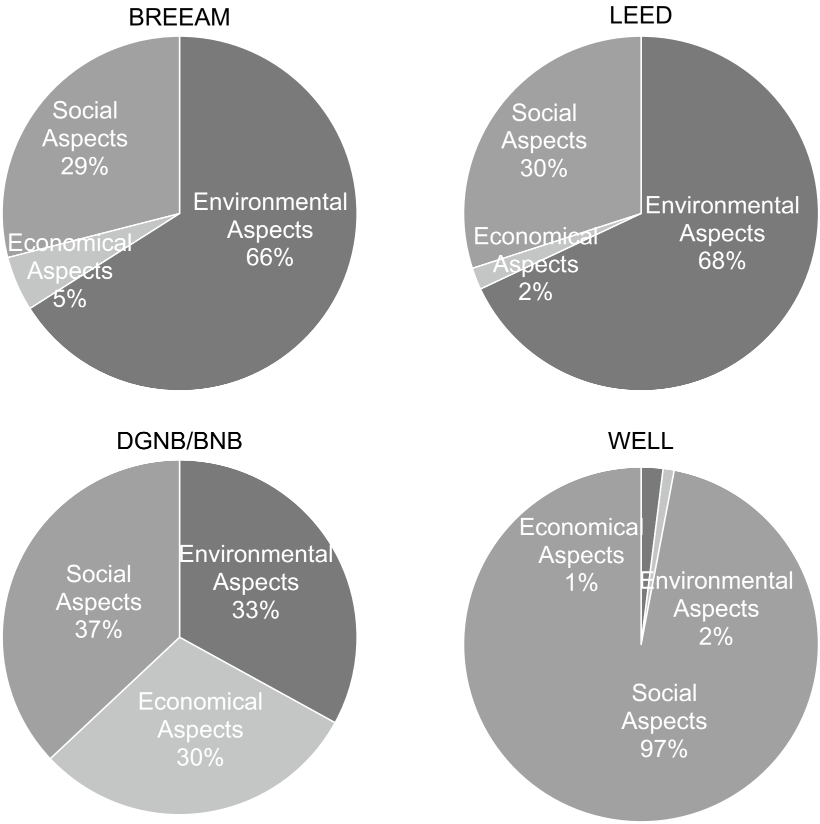

Fig. 2.2 Comparison of the content of the three dimensions of sustainability of selected certification systems (based on. [7])

materials beyond the consideration of the operating phase of buildings, as shown in Fig. 2.3.

The implementation of building LCA can be applied in several project phases, pursuing different objectives. Currently, a state of the art in German research and standardization is emerging, in which building LCA is divided into four sub-use cases along the project phases [8]

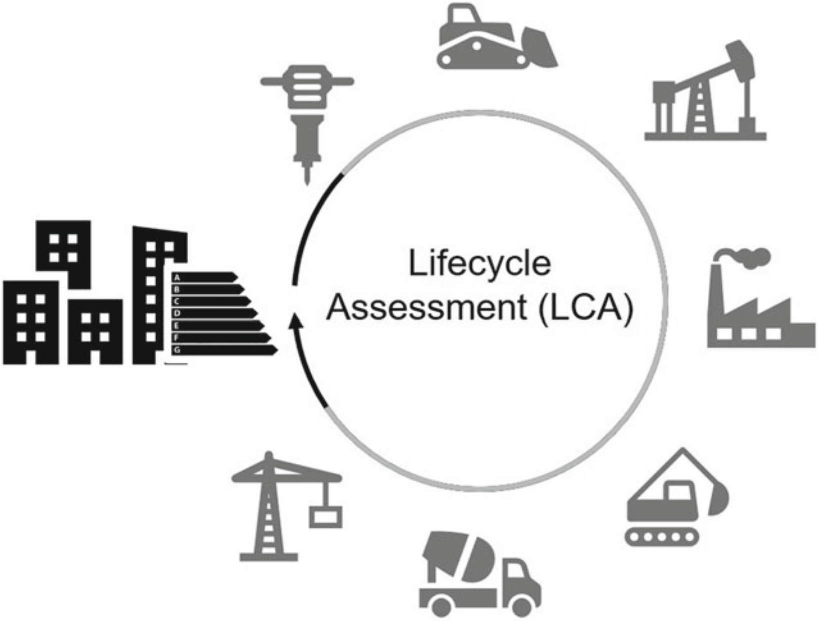

Fig. 2.3 Scope of Lifecycle Assessments in the construction industry

- Preliminary study—definition of requirements: At the beginning, during the requirements specification LCA can be used to investigate and define goals for the GHG budget of buildings. For example, in the study of GHG savings, if the shell of an existing building is to be preserved.
- Conceptual LCA: In preliminary and design, LCA can be used, for example, for variant or concept comparisons of geometry, construction types, building services concepts, or even individual comparisons of components and materials.
- Detailed building LCA: The status of the implementation design provides a basis for a detailed building LCA with concrete information about materials, etc. The building LCA is based on the results of the implementation design. While structural decisions have already been made, the application of LCA here usually only offers optimization potential, for example, in comparisons of materials and manufacturer products.

- As-built LCA: With the completion of the building, ideally an as-built documentation is available that can be used for a building LCA in the context of a green building certification and reporting, e.g., according to DGNB/LEED/BREEAM or the EU taxonomy requirements.

In general, the performance of a LCA is standardized (see Fig. 2.4). While EN 15978 forms the basis for building LCAs, EN 15804 defines product category rules for the environmental product declarations of building products. EN 15804 standardizes, e.g., which types of environmental impact must be considered in which phases of a lifecycle. Overall, various 38 environmental indicators are currently defined, which are used in the lifecycle phases: Manufacturing phase (A1–A3), Construction phase (A4–5), Use phase (B1–7) and Disposal phase (C1–4). [9]. The phases are complemented with a module D (benefits), which includes information on reuse, recovery or recycling outside the lifecycle and the system boundaries (cradle to grave). Module D is not taken into account in the calculation of the environmental impact, but has to be presented for information purposes.

For a building certification according to DGNB, further specific requirements are defined based on 15978 and 15804. According to these, the lifecycle modules A1–A3, B4, B6 and C3–C4 as well as module D must be calculated (see Fig. 2.4). In the LEED system for example, module D is not included. In this system, this module must be indicated informatively. Environmental indicators within the DGNB Market Version 2018 (8. Edition) are the global warming potential, ozone creation potential, acidification potential, eutrophication potential, non-renewable primary energy demand, total primary energy demand and the share of renewable primary energy. Informatively, the indicators ozone depletion potential, abiotic resource use, and water use freshwater must be presented [10]. Data sets conforming to EN 15804 or ISO 14025 are generally permissible as the data basis. Preference should be given to specific product data sets (EPD). If these are not available, generic data sets of ÖKOBAUDAT version 2016-I or newer can be used.

Technical building services (TBS) can be accounted for within the building LCA of the DGNB system with two different calculation methods: the simplified approach and the complete approach. Whereas the complete approach basically specifies a full inclusion of all components of building structures and TBS, the simplified approach allows a restriction to eight essential building structure component groups and TBS. As compensation for this simplification, the result of the environmental impacts in the individual lifecycle phases must be "worsened" by a factor of 1.2, i.e., with a 20% surcharge. If extensive passive measures are

	Life cycle stages																
	Product			Construc-tion		Use							End of Life				Benefits
	Raw material supply	Transport	Manufacturing	Transport	Construction installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction demolition	Transport	Waste processing	Disposal	Reuse, Recovery, Recycling potential
Life cycle modules	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Cradle to grave	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	O
DGNB-System	R	R	R	/	/	/	/	/	(/)[1]	/	R	/	/	/	R	R	R
BNB/QNG-System	R	R	R	/	/	/	/	/	(/)[1]	/	R	/	/	/	R	R	/
LEED	R	R	R	R	/	R	R	R	R	R	/	/	R	R	R	R	/
BREEAM	R	R	R	/	/	/	/	/	R	R	R	R	R	R	R	R	R

R= required
O= optional
1) only includes the production and disposal of the replaced product, not the replacement process itself (analog to construction process)

Fig. 2.4 Classification of lifecycle phases and lifecycle modules according to EN 15804 and their different consideration in DGNB, LEED and BREEAM credited and recognized in the criterion "TEC1.4 – Use and integration of building technology" in the indicator passive systems, the factor 1.2 can be lowered in the simplified procedure to a factor 1.1 for passive buildings [10]. Within the DGNB requirements, a lifecycle period of 50 years is also specified. Exceptions to this are the utilization profiles logistics and production, for which a deviating lifecycle period of 20 years needs to be applied. In order to be able to consider Module B4 "Replacement", the environmental impacts of building products that have a shorter service life than the specified lifecycle period of 50 years are taken into account again for each replacement. The service lives of the building structure are taken from the literature "Service lives of the Sustainable Building Assessment System" [11]. For the service lives of TBS, the VDI 2067 standard needs to be applied [12].

2.3.2 Material Passports of Buildings

Accessibility and exchange of information of building products and TBS is essential to design buildings according to the principles of a circular economy. One concept that provides this transparency is the Material Passport (MP). The MP combines qualitative and quantitative assessments and optimizations for circularity and harmful substances in building materials as well as an inventory of the material composition and LCA results. [13]. In addition, MP can also be used to estimate and report the financial residual value of raw materials. Currently, however, there is no uniform definition or standardization of the concept of MP and its further terminology or more precise distinction of an MP. Relevant literature analyses show, however, that a differentiation of the functional levels of material passports is useful [14, 15]. Basically, a distinction can be made, for example, between: Building, building element, building component, building product and material passport.

An MP can assume many different functions over the lifecycle of buildings and generate different added values: Building product manufacturers can use material or building product passports to provide important information, for example on the share of recycled materials, in a structured and uniform manner (see Fig. 2.5).

In the design phase, the MP can then serve as an optimization tool with regard to the use of recyclable or circular building materials as well as construction methods.[1] As as-built documentation after completion of the building, the MP

[1] In simple terms, this refers to building materials and building products that on the one hand already contain recycled, reused and/or renewable components during material production. On the other hand, circular building materials and building products are also defined

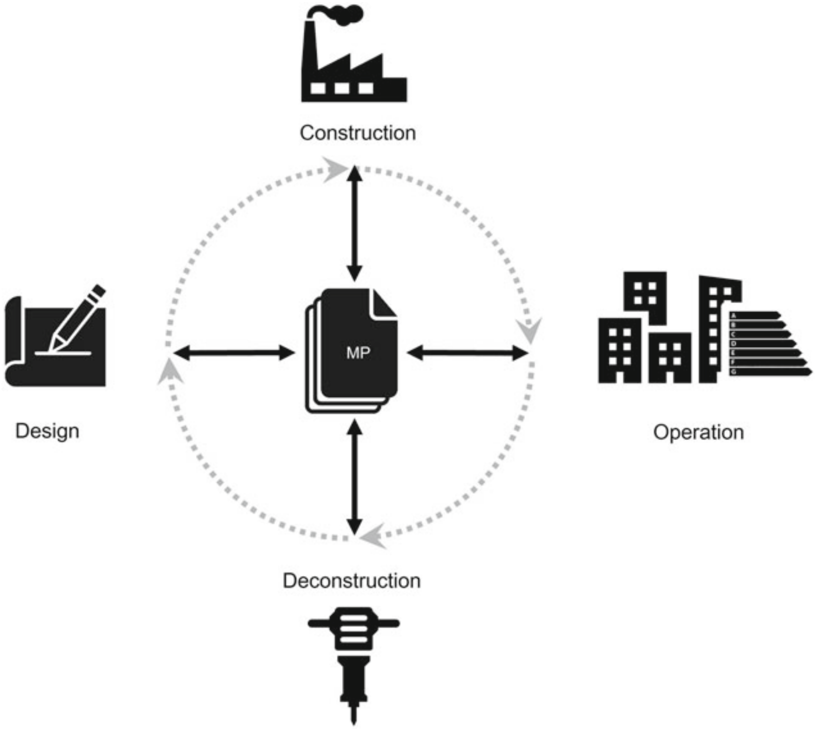

Fig. 2.5 The different use cases of the MP concept over the lifecycle of buildings

contains important information for the operation phase in order to facilitate maintenance and repair processes. At the end of the lifecycle, the MP proves useful as a detailed source of documentation, as it enables more efficient refurbishment, flexibility and adaptability as well as deconstruction in terms of urban mining.

The data that an MP can contain are therefore quite extensive, diverse and currently, due to a still missing standard, depend on the structure and evaluation framework of the individual creator concept of an MP. With regard to the German industry, the following MP concepts are currently represented in particular: The Building Circularity Passport [16], the Concular Material Passport [17]

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by a long service life and direct reuse or high-quality recycling (upcycling). With regard to circular construction methods, attention must be given to design for disassembly.

and the Madaster Material Passport [18]. Further concepts from research are provided by the research projects “Buildings as Material Banks” (BAMB) [19] and “BIMaterial” [13].

In assessing circularity within an MP, these MP concepts are thereby based on different methods to be able to assess circularity at the building, building element, building component, building product and material level. Other methods that assess circularity in construction are, for example, the DGNB TEC 1.6 criterion “Ease of recovery and recycling” [10], the Urban Mining Index (UMI) [20] and the ILEK RecyclingGraphEditor [21]. With regard to a BIM implementation, which this publication focuses on as essential, these are not considered further as they do not have a BIM implementation.

There are very few approaches available in the area of hazardous and harmful substances in building materials assessment of an MP. The Building Circularity Passport, for example, evaluates the extent to which demonstrably improved material ingredients are used compared to the industry standard and whether material ingredients on the Cradle to Cradle Certified Banned List of Chemicals have been excluded [22]. Further considerations and requirements for hazardous and harmful substances in building materials assessment are defined for example by the DGNB and BNB system requirements, and the WELL system. The REACH requirements of the EU as well as existing standards, such as Blue Angel, are also taken into account here. However, so far only one solution approach is known from research, which aims at integrating the DGNB requirements for hazardous and harmful substances in building materials assessment with BIM [23].

Insofar as LCAs are considered in parallel with the circularity and hazardous and harmful substances in building materials assessment within an MP, reference is made to the standards of EN 15978/15804 and the application of the calculation rules of certification systems, e.g., according to DGNB.

2.3.3 Lifecycle Costing

Lifecycle cost analysis considers the entire cost flow in the lifecycle of a property. Through this approach, not only the investment costs at time t_0 are considered, but all costs incurred in connection with the acquisition and use of a building. The lifecycle costs are subdivided into investment costs, utilization costs and costs for deconstruction [5]. Investment costs describe the capital used to construct the property. Occupancy costs include operating costs, maintenance costs and costs for any replacement investments in the property. Deconstruction costs describe the costs of demolishing and deconstructing the property [5]. In general, the cost breakdown for the construction of a building in Germany is carried out according to DIN 276-1:201-128 (Costs in construction—Part 1: Building construction), DIN 18960:20-2011 (Use costs in building construction) [24] and the VDI 2067 sheet 1 (economic efficiency of technical building installations—basics and cost calculation) [25]. However, there is currently no uniform standardization of lifecycle costing in Germany. Internationally, however, ISO 15686-5:2017-07 (Building construction and structures—Lifecycle design—Part 5: Total lifecycle costing) can be applied [26]. In order to obtain a detailed cost calculation for the amount of the investment, DIN 276-1:201-128 is divided into the following cost groups (KG) [27]:

- KG 100 Property
- KG 200 Preparation and development
- KG 300 Building construction
- KG 400 Building technical equipment
- KG 500 Outdoor facilities
- KG 600 Equipment and artworks
- KG 700 Incidental construction costs.

DIN 18960:2020-11 is also subdivided into cost groups [24]:

- KG 100 Cost of capital
- KG 200 Property management costs
- KG 300 Operating costs
- KG 400 Maintenance costs.

It should be mentioned here that the cost groups of DIN 276-1:2018-12 and DIN 18960:2020-11 are not identical and do not refer to each other.

The methods of investment calculation serve as the financial mathematical calculation method for lifecycle cost analysis. There are static and dynamic calculation possibilities for this purpose. The static possibilities include the cost comparison calculation, the profit comparison calculation, the profitability calculation and the static amortization calculation [28]. The dynamic methods include the net present value method, the annuity method, the internal rate of return method, the dynamic amortization calculation and the complete financial plan method [28]. For sustainability certification according to DGNB and BNB, the net present value method is used. In this method, the value of a payment occurring in the future is determined in the present. This makes payments that arise at different points in time comparable. Static methods do not take into account any time influences and, to a large extent, only assess expenses in relation to possible income. Due to the simple implementation of these methods, they are mainly used in practice. The dynamic methods consider a given period of time, e.g., 50 years. All costs incurred in the period under consideration are taken into account. This makes payments at different points in time comparable.

The annuity method is used in VDI 2067 [25]. Here, the capital value is expressed in annual payments. For these annual payments, a so-called annuity factor is calculated. The capital value is multiplied by the annuity factor, resulting in the annual payment. The cost calculation for plant engineering is divided into the following cost groups and is based on VDI 2067 sheet 1:

- Capital-linked costs
- Demand-related costs
- Operating expenses
- Other costs
- Proceeds

The delta between the annuity of revenues and the sum of capital, demand, operating and other annuities of costs is the total annuity (A_N) of all costs of a plant. To assess the profitability of a plant, a distinction is made between two cases:

1. Generating revenue by, e.g., feeding PV electricity into the grid
2. Plants without revenues

In the first case, A_N must be greater than zero (annuity revenues > annuity costs) for the plant to operate economically. In the second case, the most economical plant is the one with the lowest costs ($A_N < 0$).

2.3.4 Simulations

With a simulation, reality is represented sufficiently accurately in a model so that complex systems are simplified and thus become manageable. In addition to static simulations, dynamic simulations in particular are used in the construction industry to model processes and procedures over time. With the help of such simulation models, various problems are investigated, e.g., the compliance with legal boundary conditions or the verification of a hazardous situation (e.g., fire).

Among other things, the energetic, thermal behavior of a building or of complex systems is simulated, e.g., with the aim of fulfilling comfort criteria, optimizing energetic potentials or complying with environmental framework conditions. In most cases, building-physical, energetic processes in components, rooms, delimited zones or buildings are mapped. In addition, moisture simulations are used for assessment, especially for the design or testing of building components. Light simulations (daylight and/or artificial light simulations) are carried out to verify visual comfort before construction. In this way, the electricity demand is usually optimized at the same time and, with simultaneous thermal simulation, the summer heat protection is proven. In addition, Computational fluid dynamic (CFD) simulations are used for a better understanding of occurring flows. Here again, complex interrelationships are mapped using numerical methods [29].

In order for these models to be built, extensive data must be available. Depending on the target value, data from all disciplines must be aggregated and combined expediently. Mostly, besides the geometry of the architecture, the building physical values of each material are needed. Furthermore, the external loads and conditions are fixed by the location. The rooms contain information like internal loads and requirements. In addition to this information, building services usually require energy, acoustic or thermal data for the simulation. These and other information serve as input variables for the simulation [30].

Simulations are limited to local standards and guidelines (e.g., DIN 18599, VOB), which is why specialized tools (mostly from national manufacturers) are only used for Germany. In the U.S., standards of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), among others, are required as a basis for calculations, but these are not valid in Germany [31].

3 Building Information Modeling

This section presents the basics of the Building Information Modeling (BIM) method. The focus here is on the aspects of the BIM method that are relevant with regard to the link between BIM and sustainability. This section therefore deals with general definitions and related terminology. In addition, the Industry Foundation Classes (IFC), which represent a recognized and open data format, are described, as they make a significant contribution to the integration of sustainability aspects into the BIM method.

3.1 Basic Terms

The term Building Information Modeling is currently defined in different ways [32]. This is particularly due to the fact that the individual disciplines and software manufacturers emphasize different aspects that are relevant for their respective service provision [33]. For software manufacturers, for example, the technological approach, which refers to the use of software products, is in the foreground. For design offices, the focus is particularly on the use of BIM for design aspects, e.g., three-dimensional, architectural representation. Facility Management (FM) companies, on the other hand, emphasize the data that accumulates over the lifecycle. In research and teaching, the focus is again on the representation of processes and open interfaces.

When looking at the various definitions, the following commonalities emerge: BIM describes a method that operates over the entire lifecycle. With the help of various technologies, BIM links individual building models with each other in such a way that an interdisciplinary exchange is made possible between all those involved. The individual building models are referred to as specialist models and are created by the respective discipline and brought together at regular intervals

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in a coordination model. This creates a cooperative way of working together, which results in a digital building model that contains all relevant data over the entire lifecycle and can be accessed at any time.

3.1.1 Open and Closed BIM

The BIM method integrates various software systems. In addition to the classic BIM software systems, digital building models are regularly combined with other software products, e.g., with building information systems, global positioning systems or radio frequency identification. This requires data exchange between the individual software systems. Against this background, a distinction is made between different forms of collaboration within the framework of the BIM method:

- Open BIM—This BIM deployment method uses only published formats to exchange data between different programs. This is to ensure that no manufacturer-specific application restrictions prevail in the projects.
- Closed BIM—This BIM deployment method, on the other hand, uses only proprietary formats to exchange data.
- Little BIM—This BIM deployment method is only used in a specific subject model. There is no cross-discipline or cross-lifecycle use of BIM.
- Big BIM—In contrast to Little BIM, this BIM deployment method is used across different specialist models. This results in a cross-discipline and cross-lifecycle use of BIM.

The aforementioned deployment methods can be combined, as shown in the matrix in Fig. 3.1, which result in four different concepts for the use of BIM.

In practice, it is currently apparent that closed BIM methods are used above all. The reasons given by practitioners are that

- Closed BIM systems are often associated with less data loss,
- the coordination of the individual specialist models and thus the creation of the respective specialist model is optimized, since data losses due to misinterpretation are avoided due to the identical data format and
- processes and workflows have already been tested.

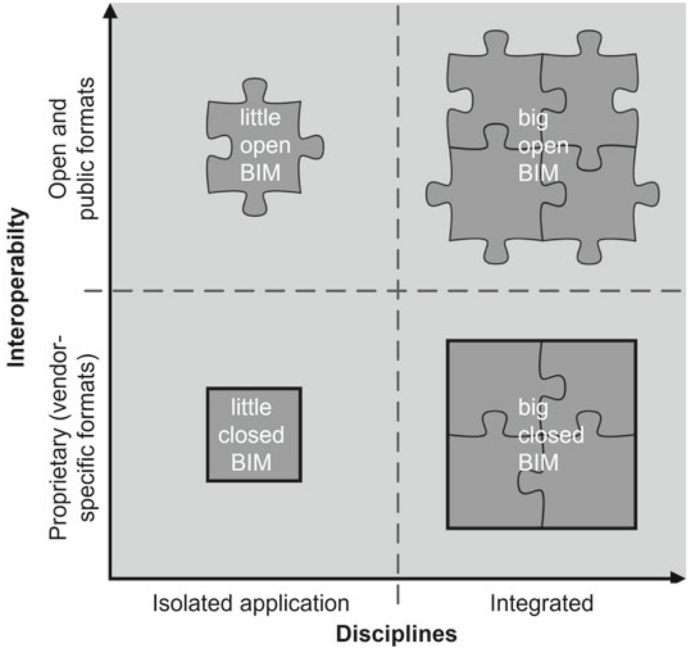

Fig. 3.1 Distinction Open and Closed BIM (based on. [30])

However, in the literature and research, Open BIM is considered the ideal BIM method. In particular, the open data formats for Open BIM enable data accessibility across different software products. Furthermore, Open BIM creates the basis for the project team and the associated cooperation to be set individually and related to the construction project. Another major advantage of Open BIM is that it avoids market power (vendor lock) by individual software manufacturers [34]. Open BIM also plays a decisive role for public clients, since a vendor-neutral invitation to tender must be issued.

3.1.2 (multi-) Modeling

The multi model container (MMC) generally describes a concept in which the models are divided according to individual disciplines. This approach makes it possible for the individual disciplines to work in their specialist models. This leads to an increase in efficiency, which results from the fact that

1. too much data can be avoided, because only a part of the model is processed at a time,
2. changes remain more traceable and
3. the individual disciplines display only those classes, objects, attributes and parameters that are relevant.

The multi model concept makes it possible to combine a large number of specialist models. In particular, this means that, in addition to the classic specialist models, such as structural design or building services engineering, aspects of sustainability can also be integrated into the overall process as a specialist model. Figure 3.2 illustrates the MMC method. For example, specialist models (e.g., structural design or architecture) are derived from an overall model. These are in turn subdivided functionally-specifically into so-called sub-models (e.g., construction sections or floors) [30].

There are different views on how an MMC method can be implemented.

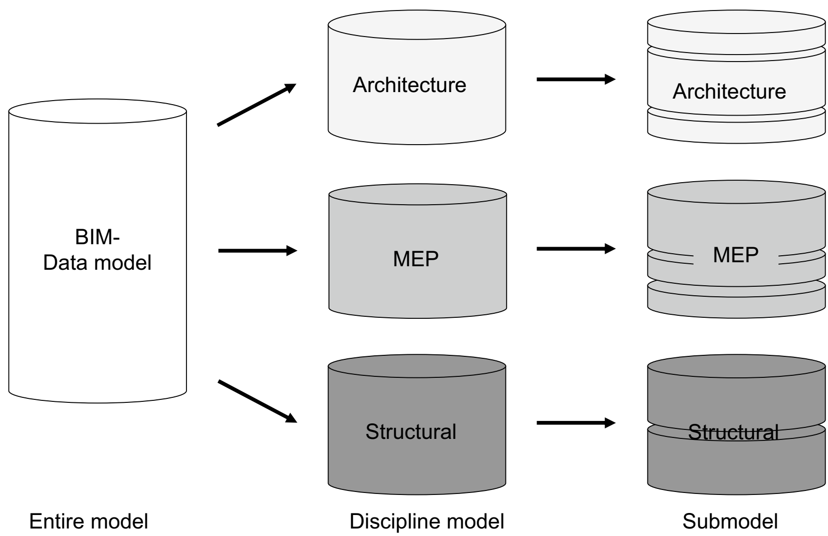

Fig. 3.2 Structure of entire model, specialized models and submodels (based on [30])

3.1.3 Industry Foundation Classes (IFC)

In order to exchange different building models, data exchange formats are necessary. The basic data model for the open BIM method is the vendor neutral data exchange format IFC, which is standardized in ISO 16739. [35]. Simplified, the IFC data format can be interpreted like the PDF format. If different formats (e. g. Word and Pages) are used to create text files in a project, these texts can be exchanged and read using the PDF format. To enable this exchange, the attributes and relationships are defined in IFC. The first IFC version (IFC 1.0) was published in 1997 [36]. Since then, IFC has been updated and extended by buildingSMART, currently IFC 4 Add2 TC 1 exists (as of 15.10.2021).

IFC describes a hierarchically structured and object-oriented data format, whereby attributes can be inherited by subordinate layers. The IFC data format is divided into four layers in its architecture, which specify a corresponding clustering for the functional delimitation of the individual classes. The layers in turn contain specifications for domains (concepts for use cases, e.g., architecture or structure), elements (physical products), extensions (control, product and process extension) and resources (entities).

3.1.4 Classes, Objects and Attributes

The data models on which the BIM method is based are object-oriented and, in addition to the geometric data, also contain additional functional and physical data for the correct interpretation and complete definition of the represented objects. Figure 3.3 illustrates the difference between the conventional CAD representation and the current BIM method.

In CAD, objects are visualized by vectors. The data are mostly only geometrical. These are made clear by line widths, hatchings, colors, etc. In the BIM method, on the other hand, an object is represented that can be used in such a way in a BIM model. This object is completely described geometrically, has a unique class and can be interpreted accordingly by the respective program. In addition to the geometric data, alphanumeric data is also present. In practice, these are usually clustered and functionally grouped by dimensions beyond the third dimension.

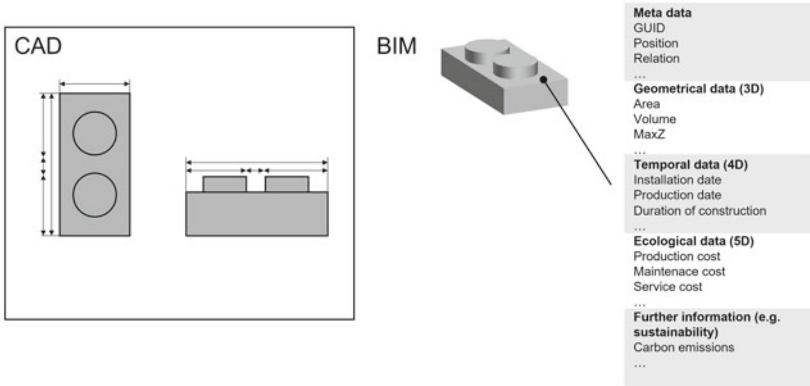

Fig. 3.3 Comparison of CAD objects and objects of BIM models

3.2 Processes and Information Requirements

In the context of Open BIM, information requirements need to be defined. The basis is the Information Delivery Manual (IDM), an ISO standard used by the International buildingSMART Organization [37]. An ISO standard is used [38], which formalizes the information requirements in the collaboration process between the different project participants in a purpose-bound manner. The aim of the IDM is to capture processes in the construction industry and provide a uniform structure for the information flow in the form of BIM use cases [39]. It specifies where and why a process takes place by listing who is involved and what information is created and exchanged and how.

If the entire lifecycle of a building is considered, there are two levels: the requirements level and the implementation level. The requirements level is defined in DIN EN ISO 19650 and includes the following components:

- AIM (also at the implementation level): The Asset Information Model (AIM) represents the digital image of the asset and is used by the developer to evaluate, analyze, and operate the asset.
- OIR: These Organizational Information Requirements (OIR) map the organizational concept of the client (asset owner). As the client-side formal definition of information management, the OIR are fundamental for all other requirements and models based on them. Based on this, asset-related information

requirements and the asset information model can be generated. The OIR are developed together with BIM management and the client as a guiding perspective.

- PIR: The Project Information Requirements (PIR) are used to define the respective requirements during the realization of a new, specific asset. They are derived from both operational and (project) design processes (Parts 2 and 3 of DIN EN ISO 19650). The PIRs are defined by the client as strategic BIM objectives, which are broken down to specific information requirements in the form of exchange information requirements (EIR).
- AIR: The Asset Information Requirements (AIR) represent the asset-related precision of the OIR. It prepares the relevant digitization strategies and information management objectives for operations, design, and production/construction of the asset. These objectives are used by the project team to delineate the project horizon and by operations to capture operationally necessary information. The long-term project goals must be identified in order to enable the short- to medium-term goals to be derived from them.

The level of implementation is defined, among other things, in the standards specified in ISO 19650 [40], ISO 29481 [38] and ISO 16739 [35] and deals with the following components:

- EIR (also in the requirements level): The exchange information requirements (German AIA) define when, in which geometric and alphanumeric level of detail, in which format, for which BIM target and by which project participant the required information is to be delivered. The EIRs are drawn up together with the client in the form of a consultation during the tendering process (see ISO 19650 Parts 2 and 3).
- BEP: According to the principle of requirement specifications and functional specifications of a classic project implementation, a complementary relationship exists between EIR and the BIM execution plan (BEP). The BEP defines the guard rails of the digital routes with milestones to answer the EIR.
- MVD: A Model View Definition (MVD) represents the use case specific implementation of exchange requirements in software technical interfaces. The method of the MVD was developed to be able to filter the information of a digital building model and thus to specialize it for a specific purpose. The relevant data and information for the respective interface (e.g., transfer of FM-relevant information) are defined.
- PIM: The Project Information Model (PIM) represents the BIM data model in project processing. The PIM thus contains all data and information of the

entire consortium for the design and construction of the project. Likewise, the PIM represents the relevant data and information for handover to operations and thus for generation of the AIM.

The Information Delivery Manual (IDM) is the basis for deriving the Exchange Requirements (ERs) on which the Model View Definition (MVD) is based. The IDM represents, among other things, a process diagram with details on the stakeholders, roles, responsibilities, deadlines, interfaces and the associated information deliveries involved in the process (see Fig. 3.4). In general, an IDM should answer the five W-questions: What is missing **W**ho needs **w**hat information from **w**hom, **w**hen and in **w**hich quality.

Using this method, the diagram can provide a quick overview of the process and the associated subprocesses for a particular use case. Thus, only the necessary processes are defined. The ERs are derived from the IDM. After the process and associated information supply chains are defined, the required information to be exchanged can be specified. The ER can also be understood as a data requirement specification. Here, a detailed specification of information is made and which role, or project-specific, which stakeholder must supply it. In addition, the mapping of the building information with the IFC and a class- and parameter-related definition of the Level of Development (LOD) of the data model used can also take place [30].

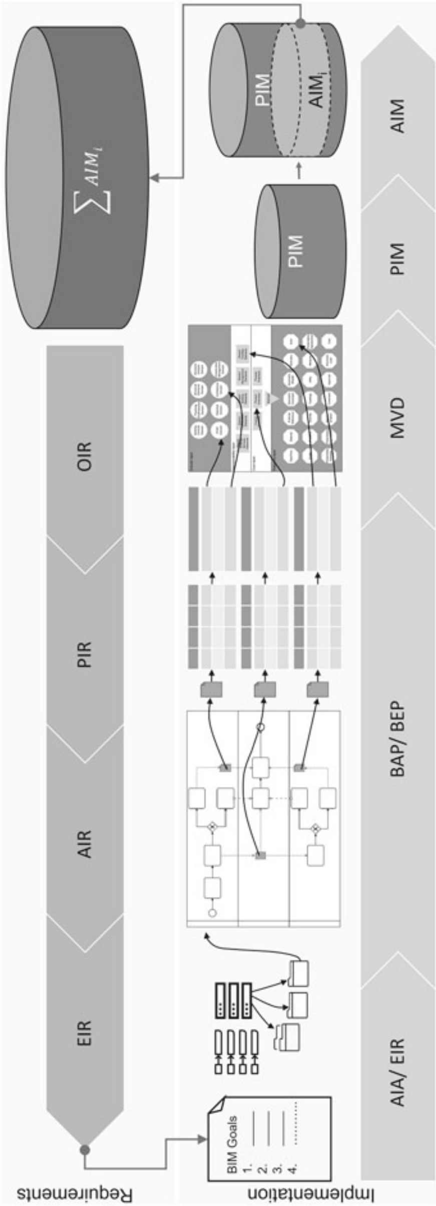

Fig. 3.4 Process classification of information requirements

4 Requirements for EIR and BEP to Implement Sustainability

The requirements in the EIR, derived from the client's internal BIM strategy, comprise the client's content-related, technical and organizational requirements for the implementation of the BIM method. The requirements relate in particular to:

- specified BIM goals of the client,
- the structure and contents of the subject-specific BIM models as BIM delivery objects,
- defined BIM roles for project planning and construction and quality assurance,
- the process and ensuring coordination between project participants using BIM and
- the technologies and data interfaces to be used.

The EIR define how the BIM method must be applied in the project in terms of information management. The contents defined by the client for the project and asset information requirements are part of the information exchange requirements [41, 42].

Essential components of the EIR are the BIM objectives, which describe the specific requirements of the client for the application of the BIM method. For FM, for example, the data requirements, the type of data transfer, and the times of data transfer (so-called data drops) for the FM systems must be recorded in the EIR. This can ensure data transfer and data consistency throughout the entire lifecycle.

The EIRs are provided to the potential contractors with the tender documents. The requirements described therein are viewed by the design consortium and answered with a BIM Execution Plan (BEP) for submission of the bid. The BEP

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describes the collaborative, digital processing of the project and thus the application of the BIM method. In order for the contents to be elaborated, the software architecture, its interfaces and the processes must be examined with the help of a conformance test model [43] be examined.

The BIM objectives listed in the EIR are detailed and elaborated into BIM use cases. The use cases are elaborated as IDM (see Sect. 3.2). The elaboration of the BEP has the following contents:

- Software architecture, including definition of data formats
- Description of the BIM use cases
- Definition of data and information requirements
- Role definition
- Establish coordination meetings, including test reports.
- Conventions and applicable BIM standards and guidelines

With the help of the EIR, sustainability goals and the associated data basis as well as the requirements for BIM models can also be contractually stipulated. Currently, the focus of EIR is more on defining the requirements for operation, but sustainability criteria are currently increasingly in focus [44]. Particularly with regard to the more efficient implementation of sustainability aspects, the following aspects can be stipulated in the general BIM objectives with the help of the BIM method:

- Commitment to cooperative collaboration to ensure the project objectives in application of the BIM method.
- Complete derivation of 2D documentation from the BIM models
- Comparison of design variants optimized by collision check and data reconciliation
- Model-based communication and decision-making (e.g., approvals, changes, or decision templates) based on digital methods
- Involvement of users and operators already in early phases of the project (at the latest from the pre-authorisation phase)
- Cross-lifecycle data collection and data exchange in one model (avoidance of redundancies)
- Structured processes in design, construction and operation

The definition of these criteria already leads to the fact that efforts for the procurement and preparation of information can be avoided, since all information is consistently maintained in a model and is available in a structured form. In many respects, this allows automation potential to be generated in the subsequent processing and evaluation according to sustainability criteria.

In addition, project-specific BIM targets can be named; especially in the case of high requirements for sustainability criteria or criteria to be met with regard to certificates. In this respect, in order to ensure the correct information delivery and handover times between the process participants with the respective necessary data and levels of detail, ERs should be defined early at the beginning and integrated into the EIRs [45]. Currently, the first standardization activities in Germany are ongoing within the standardization process of VDI 2552 Sheet 11.4 "Lifecycle Assessment and BIM". [8] as well as the buildingSMART German chapter "Expert Group BIM and Sustainability" [46].

5 BIM Use Cases in Sustainable Construction

This section is dedicated to the interrelated consideration of BIM and the predefined methods and calculation tools for operationalizing sustainability in construction. Finally, an overview of the associated data exchange requirements and selected databases is provided, which provide important data bases for the implementation of the BIM use cases focused on sustainable construction.

BIM use cases describe the purpose for which data is created and processed within the framework of the BIM method. They are usually defined as part of the EIR and detail the services that the contractor must provide to the client. This makes it easier to define the work packages that are to be carried out using the BIM method. In addition, the BIM use cases can be used to better calculate and plan the efforts and also the knowledge required for the provision of the respective services.

The BIM use cases can be divided along the lifecycle. One significant focus of BIM use cases is currently on the design phase. Here, BIM use cases such as inventory recording or the support of design and construction design through simulations, measurements, approvals or design implementation play an essential role. In addition, there are BIM use cases for the construction of real estate. In the construction phase, the focus is primarily on construction progress control, the billing of construction services, defect management, and building documentation with the help of BIM method [47].

In operations, for example, the transfer of data into FM systems and the use of data for cleaning, maintenance and operation represent BIM use cases. In the area of operation, there are use cases for the implementation of model-based sustainability and energy management as well as model-based operation of building automation for generating savings potentials with the help of the BIM method [48]. However, the focus in the area of sustainability has so far also been significantly more in the area of the design and construction phase. In the field of

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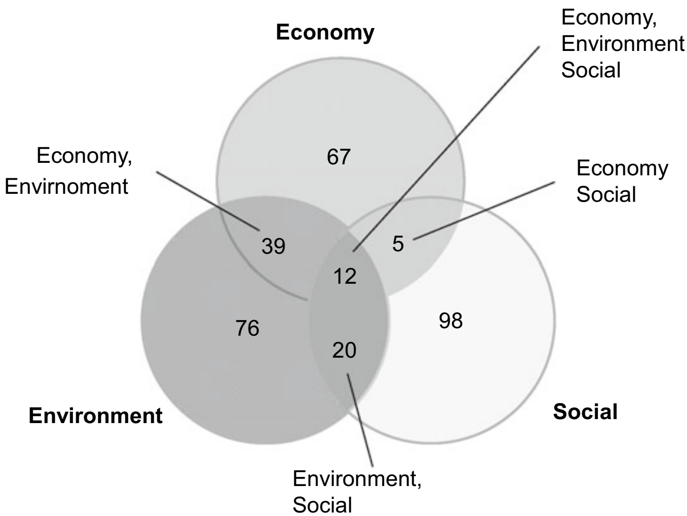


Fig. 5.1 Application of the BIM method in the field of sustainable construction (number of publications mentioned) (based on. [49])

research, it can be seen that specifically for the optimization of sustainable quality and its more efficient implementation during design, solution approaches are being researched and developed in connection with BIM. For example, Santos et al. [49] studied 317 journal papers from 2008 to 2017 regarding the application of BIM in the context of sustainable construction. Among them, most of the papers addressed the design phase. Within their evaluation, Santos et al. also assigned the papers to the three sustainability dimensions or interfaces, among others (cf. Fig. 5.1).

Whereas the socio-cultural dimension shows the highest number of published papers in a single consideration of sustainability dimensions, a consideration of the interfaces shows a higher interest in the interrelated consideration of ecology and economy. The most use cases here were focused on LCA, LCC, and the performance of different types of simulations, such as CFD or energy simulation [49]. Other recent evaluations confirm these results and also show that the use cases for the creation of a material passport of buildings, including the assessment of circularity, are also gaining in importance [50, 51]

One reason for the increased use of the described use cases is also the possibilities for automation. Ege [52] and a study at the University of Aalborg by Gade et al. found, for example, that with ideal modeling and consistent data storage in BIM models, 60–65% of the evaluation criteria of a DGNB certification can theoretically be automated. LCA and LCC in particular showed a high automation potential.

5.1 BIM Based LCA of Buildings

Building LCAs are complex to apply because the necessary information gathering from the many project stakeholders and databases is unstructured and predominantly based on 2D design documents [54]. Performing LCAs using the BIM method offers much more efficient (automatable) processes and earlier as well as more comprehensive assessment results for environmental decision making.

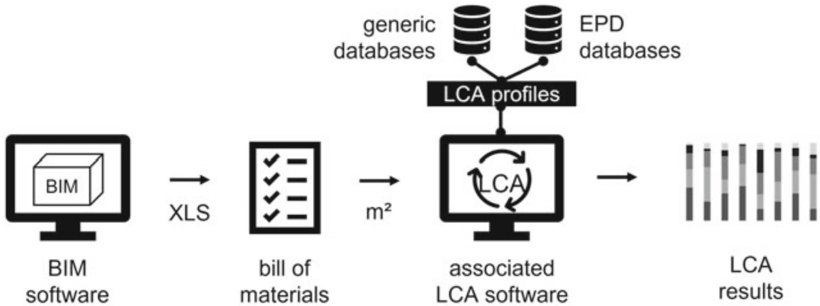
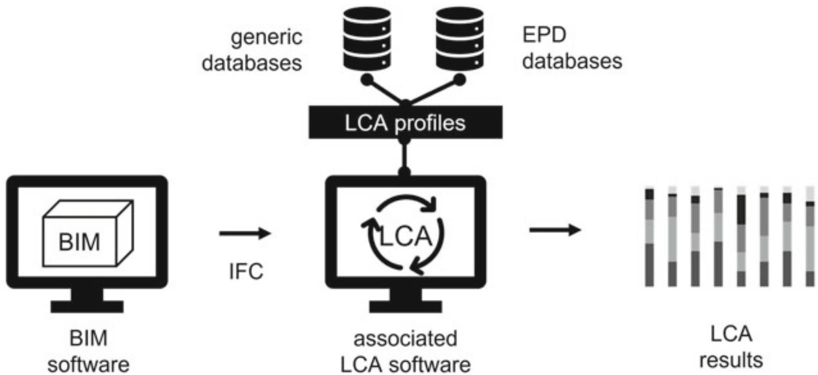
5.1.1 Methods for Implementing BIM

There are many different workflows with which the linking of LCA and BIM can be implemented. Depending on the software and tools used, these can be roughly classified. According to the classification scheme developed by Wastiels and Decuypere , there are five workflows for the integration of LCA into BIM (cf. Table 5.1).

Schumacher et al. [56] conducted a potential analysis for evaluating embodied environmental impacts in the digital building design process, including a survey of approximately 200 German practitioners in sustainable and digital construction. Based on the five workflows from Wastiels and Decuypere [55], the practitioners were asked which of the workflows are currently used in practice. Of the 200 respondents, only 12 initially stated that they were already calculating LCAs with the help of BIM. Workflow 1 is the most commonly used, followed by 4 and 2, and finally workflow 3. Workflow 5 has not yet been used.

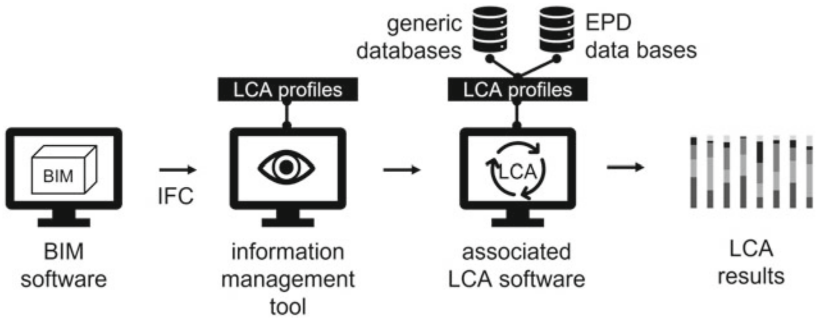
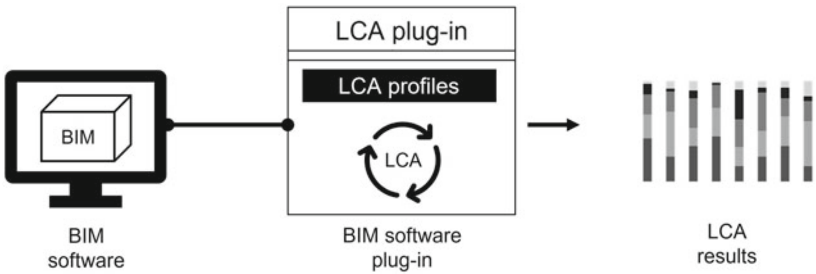
Finally, it should be noted that the choice of the right approach or workflow may differ depending on the use case and the objective. It may well be that an LCA plug-in is better suited for an early streamlined initial assessment of design variants, for example for the supporting structure, than an IFC export to a BIM tool and the linking to LCA data sets that takes place there. However, for a detailed LCA of the building and the fully comprehensive consideration of the technical building services, it seems to make sense to use a workflow that follows the open BIM approach. This is essential in order to be able to link different specialist models and at the same time to maintain manufacturer neutrality and to

Table 5.1 Strategies for integrating building lifecycle assessment into BIM, (adapted from [55])

1	**Masses and quantities export** In the first workflow, a volume/mass/quantity export (Bill of Quantities) is exported from the BIM authoring tools and imported into the building LCA software, in which the building LCA is created after manually linking the LCA data	
2	**Geometric IFC import** In the second workflow, the BIM model is imported as a "whole" into the LCA software via a suitable file exchange, vendor-neutral or native. Subsequently, the linking of the LCA data sets also takes place manually	

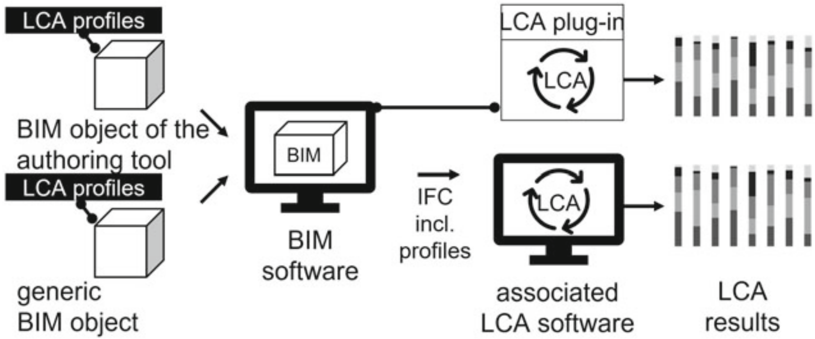
(continued)

Table 5.1 (continued)

3	**BIM tools for linking the LCA data sets** In the third workflow, the BIM model is first transferred to a BIM information management tool, in which the LCA data sets are assigned to the components and materials. This is followed by a further transfer to the building lifecycle assessment software, with which the calculation can usually be automated	
4	**LCA plugin for BIM software** In the fourth workflow, the LCA is performed directly via a plug-in within the BIM authoring tools. Depending on the software and plug-in, the link to the components and materials can be (partially) automated as far as possible	

(continued)

Table 5.1 (continued)

5	**BIM objects enriched with LCA dataset information** In the fifth workflow, the strategy is to integrate the LCA information into BIM objects or libraries of the BIM authoring tools. In this way, the linking of components and materials can also be almost completely automated, either with the help of a plug-in or after file export to a building lifecycle assessment software	

do justice to the diversity of the different modeling and design software systems used depending on the specialist discipline.

5.1.2 Added Value Through BIM

These solution approaches that combine BIM and building lifecycle assessments are useful for reducing, for example, additional manual efforts in re-entering data, compared to the 2D-based workflow in performing a building LCA. This results in time and cost savings that help implement the method in practice [56]. Another decisive criterion for the application of building LCAs with BIM is also the earlier and iterative or design-accompanying application as well as their better possibility for communication and visualization of the results. Specifically, the uniform structuring of the information required for the calculations and its easier accessibility within the BIM models provides a better basis for obtaining real-time feedback on results [57]. For example, the 3D models can be used to colorize different components or materials to identify "environmental hotspots". This supports the intuitive understanding of LCA results and can support decision making much better, especially for non-experts. In addition to workload reduction of early applications and visualization benefits, BIM also offers the potential to cover a larger or more detailed scope of the building LCA. For example, BIM models make it more feasible to fully integrate TBS and HVAC systems as well [58].

5.2 BIM-based Material Passports of Buildings

The creation of an MP requires the compilation and linking of many different pieces of information. In order to more efficiently manage and coherently evaluate the large amount of information that arises over the lifecycle of buildings and materials, BIM and open exchange formats, such as IFC, offer the possibilities to integrate, link and exchange data in the 3D models with a high degree of semantics.

5.2.1 Methods for Implementing BIM

Currently, there are different approaches for creating BIM-based MPs (cf. Table 5.2). While software tools available on the market offer IFC file uploads [18], there are also other individual solutions from research work, which work with native data formats. For example, workflows have been developed in the research project Buildings As Material Banks (BAMB) [19] as well as by Mombour [59] and Honic [60], which can be generally described below by workflow 3. In general, the methods used to create BIM-based MPs are very similar to those used for BIM-based building LCA. However, so far there are significantly fewer available software solutions on the market or solution approaches from research.

BIM plug-in solutions for the creation of MPs are not yet available. Furthermore, none of the available solutions considers the TBS BIM models when creating MPs.

5.2.2 Added Value Through BIM

BIM-based MPs result in various benefits along the lifecycle phases of buildings. In the few solution approaches in which the creation of MP is implemented with BIM, the focus is predominantly on the use case of documentation in order to avoid additional manual effort in the renewed integration and compilation of information for MP. However, BIM-based MPs offer many other added values that need to be tapped in the future.

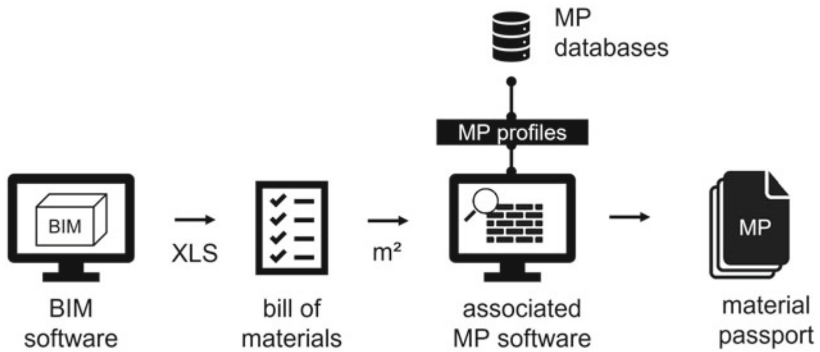
For new construction, the various stakeholders involved benefit from MPs in different ways. Construction product manufacturers can provide digital material or building product passports, which can be directly referenced in BIM-based material passports of buildings.

Architects, planners, sustainability experts, building owners and contractors can use these material and building product passports to have information on circularity available at an early stage during design and thus are to carry out optimizations. Furthermore, the information from the design can be directly integrated and documented in a BIM-based MP, e.g., for the detachability of two material layers. This results in advantages not only for reporting purposes in terms of sustainability certification or the EU taxonomy. Important added values are also generated for the operational phase by creating a transparent basis for efficient building product traceability or maintenance and repair phases of buildings. This can be ideally used for design material replacements and repairs.

MPs also simplify “leasing models” in which manufacturers take back their building products after their service life and exchange them for a new one.

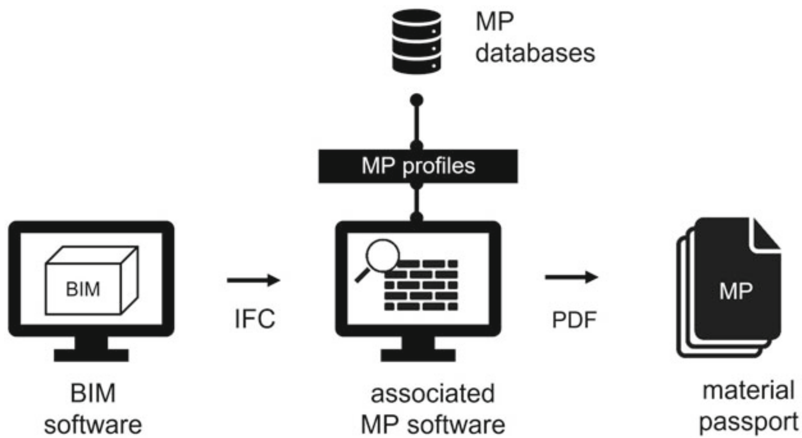
Furthermore, refurbishments can be planned efficiently or, in the case of a deconstruction, the dismantling and demolition design can be carried out in a targeted manner, since it is known which materials can be reused, recycled or

Table 5.2 Strategies for the creation of material passports of buildings through BIM

1	**Masses and quantities export** In this workflow, information on quantities and masses as well as material information can be exported from a BIM model and then imported into the MP software. Based on the imported information, the MP software performs a mapping with stored or linked databases in order to calculate the circularity and further statements, e.g., on the financial value in case of reuse or recycling	

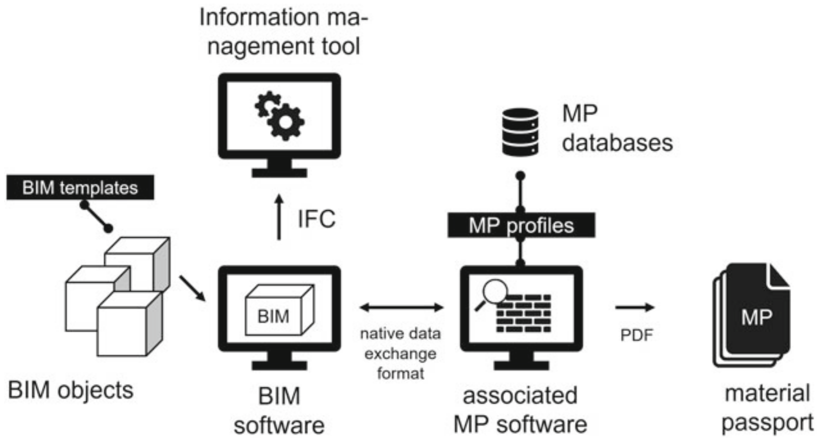
(continued)

Table 5.2 (continued)

2	**Geometric IFC import** This workflow involves IFC imports into the associated MP software. During modeling, certain requirements have to be taken into account. An example would be using a classification method according to DIN 276, so that a location of the materials can be carried out. Furthermore, it is essential to integrate material information so that automated material links to data sets of circularity can be carried out with the BIM objects as far as possible	

(continued)

Table 5.2 (continued)

3	BIM tools for linking the MP data sets This workflow provides for the use of information or links from a prefabricated library during modeling in the BIM software. Via a data exchange, e.g., via IFC, it can optionally be checked in an information management tool whether, for example, all information from the prefabricated library has been used correctly. Afterwards, a data exchange is carried out with the associated MP software. In addition to the quantities and masses, this software also recognizes information from the prefabricated BIM objects, e.g., via a Globally Unique Identifier, and compares these with the stored MP database in order to perform evaluations with regard to circularity. Subsequently, results of the MP can be visualized in the model and/or provided as a PDF file	

disposed of and what expenditure is associated with this. On the one hand, this supports material marketplaces and building component exchanges in order to be able to provide detailed information on the renewed availability and financial values of components and materials. On the other hand, construction projects in the vicinity can be planned with reusable raw materials that become available.

In the case of existing buildings, where there is usually no documentation or only very incomplete documentation, 3D laser scans and building inspections can be used to subsequently create BIM models, on the basis of which BIM-based MPs can be created. With the basis created in this way, the added values described above can then be used in equal measure, e.g., for future refurbishment processes.

5.3 BIM Based LCC of Buildings

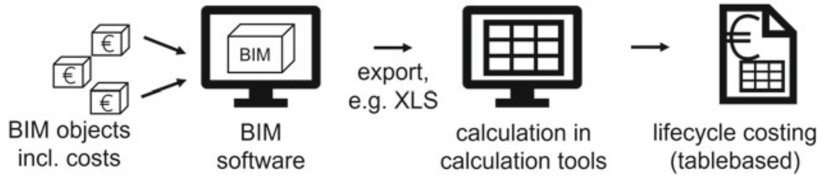
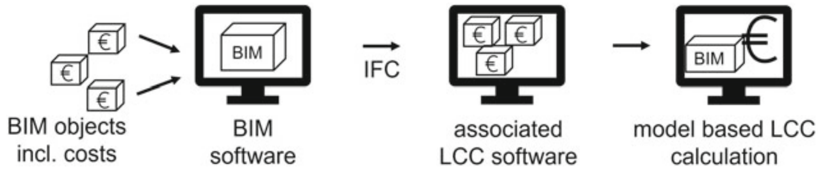
BIM offers the possibility to optimize lifecycle costs. Due to the cross-lifecycle approach of BIM, it is possible to think holistically about design, construction and operation. This provides both opportunities in design through cost estimates and opportunities to use information from operations to validate the cost estimates. This is particularly relevant given that building services now account for 35–45% of construction costs [61] and that TBS is also one of the cost drivers in the operation of modern buildings [62].

5.3.1 Methods for Implementing BIM

With the help of the BIM method, there are various possibilities for integrating lifecycle costs by extending the software environment. These are shown in Table 5.3.

The advantage of workflow 1 is that new columns can be added individually in the spreadsheets, so that adjustments to the calculations and their bases are possible. However, it is to be noted here that an exact assignment of the attributes in the tables takes place. The advantage of workflow 2 is that all information and calculations are stored in the model. In contrast, however, there are only limited options for calculating lifecycle costs in open data formats, such as IFC. In addition to the two aforementioned variants, there are software tools that enable the integration of tabular calculations and visualizations.

Table 5.3 Strategies for integrating lifecycle costs in BIM

1	**Use of specific calculation software** In this workflow, based on the BIM objects and the costs contained in the attributes, the BIM software first determines the masses from the building model and then transfers them into a tabular structure for costs, which can be used to perform calculations	
2	**Calculation within the model** Researchers are investigating approaches to perform the calculations directly on the objects in the digital building model [63]. The basis for this is formed by the attributes for the costs of the respective objects, which are stored in the digital building model. For example, databases of manufacturers can also be used for this purpose	

5.3.2 Added Value Through BIM

By using the BIM method, added value can be achieved for design and construction as well as for operation with regard to lifecycle costs. In design, for example, model-based energy management can be carried out. This leads to the fact that optimization possibilities for the reduction of lifecycle costs can already be shown on the design model. In addition, collision checks and construction process simulations can be carried out on the basis of the model-based working method. [64] and construction process simulations can be carried out, enabling problems to be identified at an early stage. This leads to a reduction of time and costs in design and construction, which can reduce design and construction costs [65].

Furthermore, simulations and pre-calculations for the operating and lifecycle costs can be carried out in design [66], so that optimizations for the lifecycle costs can be planned at an early stage. In the utilization phase, the use of the BIM method enables the continuation of model-based energy management. With this, various lifecycle considerations and the determination of lifecycle costs through real-time analysis can be carried out [65]. In addition, the BIM method offers the possibility to create forecasts for the development of lifecycle costs based on TBS maintenance costs.

5.4 BIM Based Simulations of Buildings

Simulations represent an essential component for increasing the sustainable quality of buildings. They can be used for various aspects over the entire lifecycle of the real estate, so that optimizations with regard to sustainability criteria can be implemented with BIM during design, construction and operation [67].

When running a simulation, several factors have to be taken into account with the aim of eliminating uncertainties. The timing of the simulation is an important aspect. The trade-off between the validity of the information and the influence of the simulation results on the current design status must be weighed. The later in the project the simulation is carried out, the more valid the project-specific information is, but then some decisions cannot be revised or can only be revised uneconomically. In contrast, the earlier in the design progress a simulation is performed, the more uncertain the input of data (“garbage in, garbage out.”), but the design changes are more economical to implement.

There are various BIM use cases in the area of simulations. In the field of energy simulations, simulations of building orientation, building mass, daylighting analysis, simulation of possible use of renewable energy or energy modeling can be mentioned in particular. The energy-relevant BIM use cases are also referred to as Building Energy Modeling (BEM). By integrating BIM and BEM, there are already possibilities in the early phases of the project to compare different options by simulations with regard to energy efficiency and comfort. [68].

In the field of comfort simulation, the focus is particularly on thermal, acoustic or visual simulations as well as simulations of air quality or fluid mechanics. Here, there are also relationships to the aforementioned use cases of energy simulation. The BIM method offers the possibility to holistically relate the different aspects of building services, architecture and building physics through simulations and thus to optimize the design.

5.4.1 Methods for Implementing BIM

The goal of using BIM for simulations is that optimizations in design, construction, and operation can be generated by incorporating geometric and alphanumeric data [69]. These optimizations are generated in particular by the fact that the data and models of the various disciplines, such as architecture, structural design or building services, are available as a whole and can be exchanged and used.

The models are initially used conceptually for design. At the latest from the construction design stage, all models have a high degree of granularity of geometries and information, so that the uncertainties already mentioned are minimized as far as possible.

The individual use cases in the field of simulations concern ecological aspects as well as economic and socio-cultural aspects. A sharp delimitation of the use cases is not always possible, e.g., the daylight analysis concerns ecological aspects (especially energy saving) and socio-cultural aspects (especially comfort factors in buildings).

The models with the inherent information serve here as input for the simulation. Interoperability plays an immense role here. The simulation tools currently available on the market are not designed to process complex models. For this reason, simplified processing models are usually extensively remodeled especially for this application and only serve as input. The results are then fed back into the overall model so that all project participants have access to the results. The following Table 5.4 outlines the existing, commercially available workflows for implementing use cases with the goal of performing a BIM-based simulation.

Table 5.4 highlights in particular the interfaces and the associated transformation processes. The transformation processes depend on multiple factors:

- Transformation of the native model into the exchange model (export)
- Transformation of the exchange model into the native model (import)
- Geometric structure of the objects present in the model
- Interpretation of attributes and parameters

These complex relationships must be investigated and understood so that no loss of information or misinterpretation distorts the results during transmission.

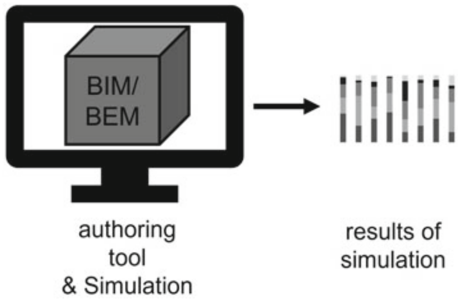
5.4.2 Added Value Through BIM

The large amount of information needed for a simulation (of any kind) can be very diverse and complex at the same time. In conventional, non-model-based design, this often results in time-consuming and resource-intensive searches for the input data. By applying the BIM method and the associated centralization of the information, the search results are made available, making manual aggregation obsolete. The goal is that the relevant information is available within the models for the entire design consortium, either by direct specification or by linking the information. The communication of the results is again centralized by providing them via the models. The extensive information can be visualized with the models and thus communicated in an intuitively understandable way and used for plausibility checks.

5.5 Data Exchange Requests

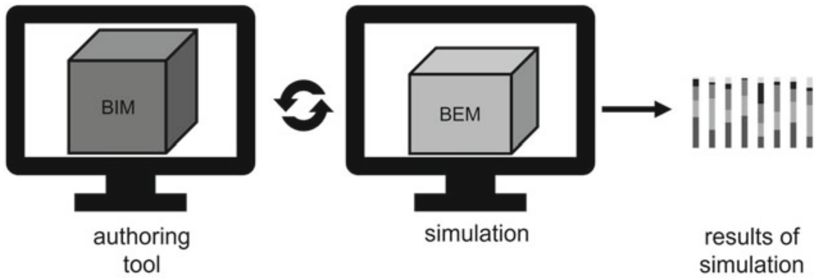
The exact design of the data exchange requirements for the calculation of the building LCA, LCC as well as the preparation of MP and the execution of simulations varies depending on the present project phase, methods used and further requirements, e.g., certification systems. The following Table 5.5 represents general information requirements. The table clearly shows the object-related content required by each of the listed use cases.

Table 5.4 Strategies for integrating simulations into BIM

1	**Simulation in the authoring tool (closed BIM deployment method)** In this example, the simulation is performed in the authoring tool. Here, the relevant information is used directly from the native model. So far, this workflow is only possible for simple, mostly static simulations, since the common authoring tools have not (yet) implemented such functions and defined them according to national standards. With this approach, the results are stored directly in the BIM model and the results are generated based on this	

(continued)

Table 5.4 (continued)

2	**Simulation within the software environment of the authoring tool (closed BIM deployment method)** The BIM model is converted to a BEM model within the (usually proprietary) software environment and used for simulation in a tool specifically designed for this interface. In this context, the BEM model represents a specialized interpretation of the BIM model for the respective use case. This workflow usually allows more complex simulations, which are also dynamic. In this approach, the results are generated from the BEM model and can be fed back into the BIM model if implemented appropriately	

(continued)

Table 5.4 (continued)

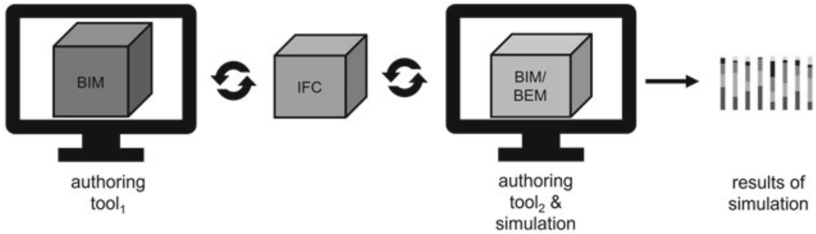
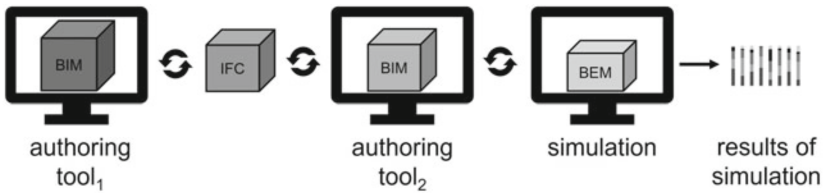
3	**Simulation with a non-proprietary simulation tool (big open BIM deployment method)** This workflow envisages that, based on the native model of the first authoring tool, a data exchange to a manufacturer-independent second authoring tool and associated simulation tool is established using the IFC model. Two transformation processes must be mastered for a successful exchange. The results are generated by the simulation tool on the basis of the BEM model and must be specially configured for integration in the BIM model of the first authoring tool	
4	**Simulation with an authoring tool independent simulation tool (big open BIM deployment method)** This workflow is comparatively identical to workflow 3, but here an additional interface to another independent simulation tool is integrated after the second authoring tool. Within this interface, further exchange formats specialized for the mapping of BEM models (in addition to the IFC model) could be integrated	

Table 5.5 Subject models and their objects with relevant data and information for the focused BIM use cases in sustainable construction

Subject models	Objects and parameters	LCA	MP	LCC	Simul.
Architecture	Space enclosing objects				
	Component layers	x	x	x	x
	Material properties	x	x	x	x
	Geometry	x	x		
	Quantity take-off	x	x		
	Space objects				
	Typification (e.g., DIN 277)			x	x
	Requirements (specifications)			x	x
	Geometry			x	x
	Location				
	Weather data				x
	Shading due to environment				x
Load-bearing structure design	Space enclosing objects				
	Component layers	x	x	x	x
	Material properties	x	x	x	x
	Geometry	x	x	x	x
	Quantity take-off	x	x	x	
TBS	Technical building services for distribution, storage, generation, transfer				
	Material properties	x	x	x	x
	Geometries	x			x
	Quantities and masses	x		x	
	Final energy demand (electr., therm.)	x			
	Requirements			x	
	Maintenance intervals			x	
	Lifetime			x	
	Costs (e.g., maintenance)			x	
	Component parameters (e.g., emissions)			x	x
	Control types				x

5.6 Relevant Data Sources in Sustainable Construction

The following Table 5.6 provides an overview of databases that can be used for linking with BIM models or BIM objects in the context of the BIM use cases described. The thematic assignment of a database is symbolized by an "x" to one of the four BIM use cases in sustainable construction.

Table 5.6 Relevant data sources in sustainable construction

Data base	Description	LCA	MP	LCC	Sim
ÖKOBAUDAT [70]	ÖKOBAUDAT is a platform provided free of charge by the BMI. The lifecycle assessment data for building products provided there are standardized in accordance with EN 15804 and are checked against other quality features before being made available. In addition to the focus on building materials, construction, energy, disposal and transport processes are also described in terms of their ecological impact. The more than 1000 data records are predominantly generic	x	x		x
WECOBIS [71]	The WECOBIS building materials information system represents an accumulation of information on environmental and health data of building product groups. In contrast to the ÖKOBAUDAT, this includes data on material ingredients and the extent to which they contain risk substances. In addition, WECOBIS offers further specific building material information, which is primarily intended as a design and tendering aid for specialist planners	x	x		x
EMMy [72]	EMMy—Ecological material mini library is a database developed by a research group of the Chair of Resource Efficient Construction at RWTH Aachen University. It contains about 200 materials and provides information about circularity, lifecycle assessment, material ingredients and other individual information about the application	x	x		

(continued)

Table 5.6 (continued)

Data base	Description	LCA	MP	LCC	Sim
Building material Scout [73]	Building Material Scout provides an overview of around 40,000 building products. Depending on the manufacturer, in addition to technical and safety data sheets as PDF files, other data formats such as BIM objects are also available. In addition, classifications are provided regarding the fulfillment of requirements according to certification systems, such as DGNB, LEED, among others	x	x		x
IBU.data [74]	The IBU.data database is provided by the Institut Bauen und Umwelt e. V. It provides access to EPDs for construction products registered worldwide according to DIN EN 15804. In addition to the mainly generic data sets in ÖKOBAUDAT, IBU.data provides product-specific data sets for about 1000 construction products	x	x	X	x
Material library [75]	The Material Library is a cooperative project of the Münster School of Architecture (MSA) and the Bergische Universität Wuppertal. This database currently contains 636 product-specific data records on materials used in buildings. The data includes information on origin, material ingredients, use, service life, recyclability and lifecycle assessment	x	x	X	x
DGNB Navigator [76]	The DGNB Navigator database currently contains 1128 data records, which, in addition to general manufacturer information on building products, provides information on their assessment of certain DGNB criteria, such as risk substances. So far, 297 building products can be found with a verified preliminary assessment by the DGNB, which provides values for the environmental indicators required in a DGNB lifecycle assessment in addition to service life, lifecycle costs, material specifications, recycling percentages, and risk materials	x	x	X	x
Cradle to Cradle certified [77]	The Cradle to Cradle certified database currently lists around 700 products that have been certified in accordance with the label of the same name. Among other things, 233 building products are available, which also provide information on material ingredients as part of their detailed evaluation based on the five Cradle to Cradle criteria	x		X	
BNB service lives [11]	Within the framework of the BNB, 296 data on service lives of building products are made publicly available by the BMI	x	x	X	x

What You Can Take Away from This *essential*

- The BIM method supports use cases of sustainable construction through the central provision, maintenance and transparency of information.
- BIM data for sustainable construction is generated in design, construction and operation and exchanged with BIM models.
- EIR and ER—as standardized definition of processes—therefore represent important contributions to more efficient BIM project execution and efficient sustainability assessment.
- However, it is currently apparent that many of the approaches to BIM-based sustainability assessments in closed BIM environments are applied on the basis of proprietary software systems. Standardized and open data exchange formats as import formats are not yet sufficiently offered.
- Standardization activities in the area of modeling guidelines, the definition of use cases, and information exchange requirements will be of great importance in the future to increase the degree of automation in BIM-based sustainability assessment.
- With regard to building LCA, there are many solutions and standards already available for calculating environmental impacts that accompany design, such as CO_2-emissions, and communicating them using digital building models.
- In the area of BIM-based material building passports, there are significantly fewer solutions and no standard so far. In the future, great progress in development can be expected here, since MPs document all necessary data for a functioning urban mining system and simplify reporting purposes for sustainability certification and the EU taxonomy.

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- In the context of LCC, the cost attributes and quantities represent relevant data from the BIM model. These are generated and updated during design, construction and operation.
- Simulations support the sustainable optimization of buildings in many ways with regard to the dimensions of sustainable construction. Based on the BIM method, applications can be carried out better already in earlier phases.

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