DOI: 10.24427/978-83-67185-29-5_5

5. BUILDING INFORMATION MODELLING (BIM) FOR SUSTAINABILITY

5.1. Potential of BIM Throughout the Life Cycle of a Sustainable Project

Building Information Modelling (BIM) is transforming the way building is delivered traditionally. The Construction industry is growing rapidly and the demand for sustainable facilities with the least impact on the environment is increasing. Sustainable development has been divided into water conservation, energy use reduction, sustainable procurement of materials, industrial development, recycling, waste reduction, climate change, transport strategies, and biodiversity (Khan & Ghadg, 2019).

Building Information Modeling is based on the idea of the continuous use of digital building models throughout the entire lifecycle of a built facility, starting from the early conceptual design and detailed design phases, to the construction phase, and the long phase of operation. BIM significantly improves information flow between stakeholders involved at all stages, resulting in an increase in efficiency by reducing the laborious and error-prone manual re-entering of information that dominates conventional paper-based workflows. Thanks to its many advantages, BIM is already practiced in many construction projects throughout the entire world (Borrmann et al., 2018).

One of the most important steps in the planning process is to clearly define the potential value of the BIM in the project and to the project team members by defining the overall goals for the implementation of the BIM. Objectives may be based on project results and include elements such as reducing schedule time, achieving higher performance, improving quality, reducing change costs, or obtaining critical operating data for the facility (Videika & Migilinskas, 2020).

The model-based approach increases efficiency within individual organizations and truly shines during coordinated project delivery. Building Information Modelling (BIM) offers the advantage of time and budget savings for building and infrastructure projects.

Here are the top 11 benefits of BIM by Autodesk (WEB-1):

1. Capture Reality: the wealth of information that's easily accessible about project sites has expanded greatly with better mapping tools and images of Earth. Today, a project starts including aerial imagery and digital elevation, along with laser

scans of existing infrastructure, accurately capturing reality and greatly streamlining project preparations. With BIM, designers benefit from all of that input compiled and shared in a model—in a way that paper isn't able to capture.
2. Waste Not, Want Not: With a shared model, there's less need for rework and duplication of drawings for the different requirements of building disciplines. The model contains more information than a drawing set, allowing each discipline to annotate and connect its intelligence to the project. BIM drawing tools have the advantage of being faster than 2D drawing tools, and each object is connected to a database. The database aids such steps as the number and size of windows for quantity take-offs that are updated automatically as the model evolves. The quick, computerized counting of components alone has been a significant labor and money saver.
3. Maintain Control: the digital-model-based workflow involves aids such as autosave and connections to project history so that users can be certain they've captured their time spent working on the model. The connection to the version history of the model's evolution can help you avoid disastrous disappearances or corruption of files that can make blood boil and impinge productivity.
4. Improve Collaboration: sharing and collaborating with models is easier than with drawing sets, as there are a lot of functions that are possible only through a digital workflow. Much of this added project-management functionality is now being delivered in the cloud, such as Autodesk's BIM 360 solutions. Here, there are tools for different disciplines to share their complex project models and coordinate integration with their peers. Review and mark-up steps ensure that everyone has had input on the evolution of the design and that they are all ready to execute when the concept is finalized and moves forward in construction.
5. Simulate and Visualize: another of the advantages of BIM is the increasing number of simulation tools that allow designers to visualize such things as the sunlight during different seasons or to quantify the calculation of building energy performance. The intelligence of the software to apply rules that are based on physics and best practices provides a complement for engineers and other project team members. The software can do much more of the analysis and modeling to achieve peak performance, condensing knowledge and rules into a service that can run with the click of a button.
6. Resolve Conflict: the BIM toolset helps automate clash detection of elements such as electrical conduits or ductwork that run into a beam. By modeling all of these things first, clashes are discovered early, and costly on-site clashes can be reduced. The model also ensures a perfect fit of elements that are manufactured off-site, allowing these components to be easily bolted into place rather than created on-site.
7. Sequence Your Steps: with a model and an accurate set of sub-models for each phase during construction, the next step is a coordinated sequencing of steps, materials, and crews for a more efficient construction process. Complete with animations, the model facilitates the coordination of steps and processes, delivering a predictable path to the expected outcome.

8. Dive into Detail: the model is a great endpoint for a lot of knowledge transfer, but there's also a need to share a traditional plan, section, and elevation, as well as other reports with your project team. Using automation and customization features, these added sheets can save valuable drafting time.
9. Present Perfectly: with all of the design completed on capture and alteration of existing reality, the model is the ultimate communication tool to convey the project scope, steps, and outcome. The fact that the design is fully 3D also means that there are fewer steps to render impressive views and fly-throughs that can be used to sell commercial space or to gain necessary regulatory approvals.
10. Take it with You: having a model that's tied to a database is an added benefit of BIM, granting you a great deal of intelligence at your fingertips. Combining this capability with a cloud, there are, means that you have access to the model and project details from anywhere, on any device.
11. Reduce Fragmentation. In the days before BIM, getting a truly global view of a project proved difficult—with thousands of unconnected documents in play, sometimes it took years for design teams to see the forest for the trees. By pulling all of a project's documents into a single view, BIM enables teams to collaborate and communicate more effectively.

A building information model can be used for the following purposes (Azhar, 2011):

- Visualization: 3D renderings can be easily generated in-house with little additional effort.
- Fabrication/shop drawings: it is easy to generate shop drawings for various building systems, for example, the sheet metal ductwork shop drawing can be quickly produced once the model is complete.
- Code reviews: fire departments and other officials may use these models for their review of building projects.
- Forensic analysis: a building information model can easily be adapted to graphically illustrate potential failures, leaks, evacuation plans, etc.
- Facilities management: facilities management departments can use BIM for renovations, space planning, and maintenance operations.
- Cost estimating: BIM software(s) have built-in cost estimating features. Material quantities are automatically extracted and changed when any changes are made in the model.
- Construction sequencing: a building information model can be effectively used to create material ordering, fabrication, and delivery schedules for all building components.
- Conflict, interference, and collision detection: because BIM models are created, to scale, in 3D space, all major systems can be visually checked for interferences. This process can verify that piping does not intersect with steel beams, ducts, or walls.

Building information modeling facilitates collaboration throughout the entire life cycle of the project. BIM improves communication and information management due to a more efficient exchange and updates of project data. Project participants need to collaborate using BIM-based processes and procedures. However, all members have to put effort into collaboration while utilizing a BIM system from the initial stages. The collaboration of different stakeholders within the project is based on principles that include trust, transparency, efficient communication, open information sharing, risk-taking, equal reward, value-based decision making, and the use of all technological and support capabilities. Finally, BIM offers the potential to produce a high-quality and performing construction project, faster and cheaper, along with reducing errors and the waste of time and cost (Savari et al., 2020).

The sustainability implementations using BIM in the construction sector are creating a healthy built environment and satisfying social, environmental, and economic concerns in a balanced way. The three classical dimensions in which BIM is promoting sustainability are (Khan & Ghadg, 2019):

- **Social sustainability** – Creating healthy and livable communities by providing tools to improve building operations in aspects such as water conservation, energy use reduction, industrial development, recycling, climate change, and waste reduction.
- **Environmental sustainability** – targeted environmentally-conscious decisions throughout the life cycle. Energy consumption, waste management, carbon footprint, etc. – BIM enables users to minimize environmental impact.
- **Economic sustainability** – assuring financial feasibility, reducing waste, and increasing productivity. BIM helps accomplish economic benefits by clash detection at an early stage, better technical decisions, and precise cost forecasting throughout the life cycle of a project.

5.2. BIM in Supporting the Design, Construction, Operation, and Retrofitting Processes of a Sustainable Building

The choice of a building technique, components, and construction material is generally based on criteria such as functionality, technical performance, architectural esthetics, economic costs, durability, and maintenance. Nevertheless, this choice doesn't have to take into account the impact on the environment and human health. Building sustainably ensures that the social, economic, and environmental aspects were taken into account throughout a building's life cycle: from the extraction of raw materials to design, construction, use, maintenance, renovation, and demolition.

BIM technology can be integrated into every point of the project and at any stage of the life cycle (Fig. 5.1).

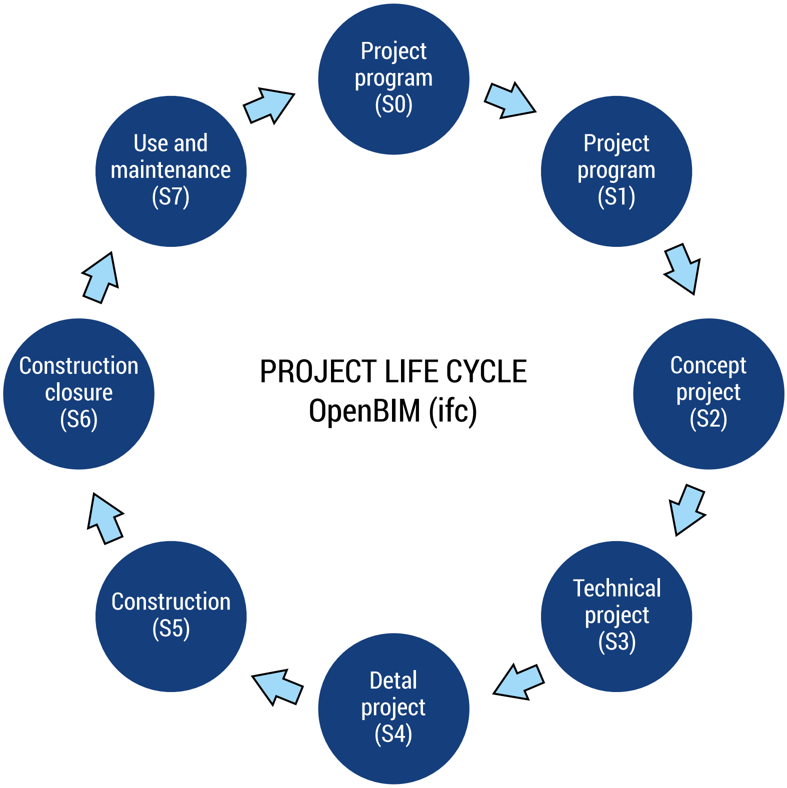

FIG. 5.1. Project life cycle (Source: own elaboration)

The use of BIM in projects also addresses the issue of sustainability.

The most important BIM use cases in the life cycle stages of a building are presented in Table 5.1.

TABLE 5.1. Fragment of stages and BIM Use Case structure (Source: own elaboration based on WEB-2)

BIM project development stages (RIBA approach)	**S0**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
	Feasibility Study	**Project program**	**Concept project**	**Technical project**	**Detail project**	**Construction**	**Construction closure**	**Use and maintenance**
Economic / quantity take-off and cost calculations	S0.1	S1.1	S2.1	S3.1	S4.1	S5.1	S6.1	S7.1
Development of current conditions model		S1.2	S2.2	S3.2	S4.2	S5.2	S6.2	S7.2

BIM project development stages (RIBA approach)	**S0**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
	Feasibility Study	**Project program**	**Concept project**	**Technical project**	**Detail project**	**Construction**	**Construction closure**	**Use and maintenance**
Land plot analysis		S1.4	S2.4	S3.4				
Functional, volumetric, and planning layouts development (S2)		S1.5	S2.5					
Design / Modeling (S3-S4)			S2.7	S3.7	S4.7			
Energy analysis			S2.9	S3.9	S4.9			
Sustainability Assessment			S2.10	S3.10	S4.10			
Structural analysis and design			S2.11	S3.11	S4.11			
Lighting Analysis			S2.12	S3.12	S4.12			
Analysis of engineering systems			S2.13	S3.13	S4.13			
3D coordination				S3.16	S4.16	S5.16		
Health and safety planning					S4.18	S5.18	S6.18	
Building Logistics Planning						S5.21	S6.21	
Technical supervision of construction works						S5.24	S6.24	
Fill-in model (as-built)						S5.25	S6.25	
Planning for building maintenance								S7.27
Analysis of structural (engineering) systems								S7.28
Energy Cost Analysis								S7.29
Asset Management								S7.30
Spatial management and monitoring								S7.31
Sustainability monitoring and analysis								S7.32
Accident Prevention								S7.33

BIM process allows multidisciplinary information to be superimposed with an integrated model, which makes environmental impact evaluation precise and efficient. In applying the BIM methodology, it is important to properly articulate the objectives, requirements, and scope of the building model. Documenting a set of standard procedures in a BIM Execution Plan (BEP) and setting out procedures for coordination in Employer's Information Requirements (EIR) as part of a project's contract documentation is crucial. So too are the BIM Execution Plans authorized by suppliers. During the design and construction process, design team interface managers should assess design decisions and clashes to see if they can resolve them internally, and where this cannot be done, separate models may be combined for review by a design lead (WEB-3).

In the Concept stage of the project (S2), comparable measures and comparable calculations of the cost of the building design must be developed and agreed upon based on which decision can be made regarding the future energy performance class and other important aspects of the building. Initial and intermediate project proposals should be agreed upon with the Customer. At least 2 solutions for the installation of the main structural structures and engineering systems of the assembled building and a comparison of their prices should be provided (WEB-3, 2021). At this stage it is possible to assess which degree and in which sense the type of land use is changed by the construction project. The area is not "consumed", but a usage change of the area takes place. The implementation of compensatory measures can be identified based on the available documents: it is checked if a green roof is planned and if it can be approved as a compensation measure. As well the type, extent, and direction of change of the actual use of the area are recorded and evaluated according to measuring specifications – change from the near-natural toward the built-up. One important design aspect is determined by the integration of technical structure, either outside or inside the building. The integration of the roof in the design of the building and its surroundings shall enhance the development of a three-dimensional urban surrounding. Utilization of this area can reduce CO_2 emissions and can improve the microclimate. Besides the designed integration of the technical structures, the roof can improve the general welfare with suitable areas. Such areas are green roofs, solar-active areas, socio-cultural utilizations such as roof terraces, and historical references to the direct surroundings such as the choice of material and color of the roofing in historical city centers.

In the Technical stage of the project (S3) stage, an intermediate comparison of the modeled main solutions (at least 2 variants) and prices of the modeled main building systems and elements must be envisaged. The variants of the final design solutions and their estimated cost must be agreed upon with the Customer before the completion of the detailing of the S3 stage of the project. The information for the calculations must be taken from the model and linked to the model using an information classification system. (WEB-3, 2021) One of the goals of sustainability at this stage can be to reduce the need for heating to condition the building areas while ensuring high thermal comfort and avoiding structural damage. The following aspects can be assessed of the building envelope in the building model: thermal transmittance coefficients of building components, thermal bridges, air permeability class (window air-tightness), amount of condensation inside the structure, and if necessary solar heat protection.

The BIM model aims to increase the ease of deconstruction, recycling, and dismantling – to avoid waste, in particular by reducing its quantity and hazardousness. Between 40% and 50% of waste in Europe can be assigned to the building sector. The amount of accumulated waste is to be reduced and is to be led into the recycling system. Due to the comparatively long expected useful lifetime, many of the materials that are used today will not accumulate as deconstruction material or potential waste until 50 or 100 years after construction. These materials can serve as important resources for future construction materials. The ability to recapture homogenous deconstruction materials and extract high-grade recycling materials is very important for the evaluation of ease of deconstruction and ease of recycling.

During the process of developing the model for current conditions, the model must include the adjacencies of the structure related to the project, including adjacent buildings, project area, and area for the transport system and engineering communications. It is also necessary to assess the direction, depth, purpose, material, and protection zones of the various other communications which cross the project area.

If the building is being renovated or repaired, a scan of the building should be provided as well.

A scan plan should be produced after the project objectives have been clarified. A scan plan is a set of information that outlines the scope and approach that will be taken to capture the data on-site. Often, a scan plan starts with a detailed analysis of precisely which elements need to be captured. When scanning a new work, most scanners will capture the position of each element that will be geo-referenced. In case of renovation work, scanners will often have the specific objective to gather more information. Identifying the exact scope of elements to be scanned helps the on-site team to prioritize their efforts and mitigate time spent capturing unnecessary elements (Gleason, 2013).

When the project team is preparing a building model for all parts of the project, all systems and elements must be modeled to a sufficient level of detail required to achieve the objectives and implement one or another application for the BIM, to prepare project documentation from the model and to link it to the model.

The project team develops BIM architectural (Fig. 5.2), structural (Fig. 5.3), or other parts of the model (as needed) that can be exported to open format and can be merged, reviewed, analyzed, and used for other BIM purposes.

The model must provide the necessary and harmonized amount of information that is gradually developed throughout the project.

Modeling of natural and artificial lighting is performed in the BIM model. At the same time, the influence of sun glare on workplace comfort must be assessed. Through early and integral daylight and artificial light planning, high quality of illumination can be created with low energy demands for illumination and cooling.

Furthermore, a high degree of daylight use can enhance workplace sustainability and compliance with health requirements and reduce operational costs. Lighting control integrated with daylighting is recognised as an important and useful strategy in energy-efficient building designs and operations. Proper daylighting schemes can help reduce the electrical demand and contribute to achieving environmentally sustainable building development.

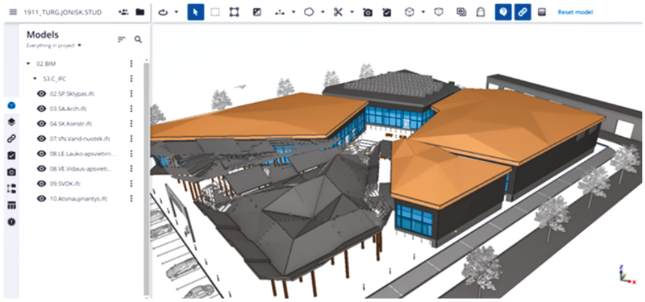

FIG. 5.2. Architectural model of the market building (Source: own elaboration)

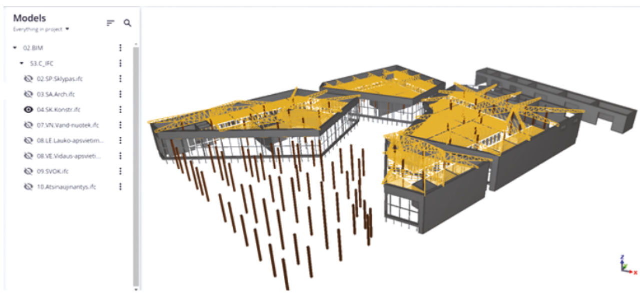

FIG. 5.3. Structural model of the market building (Source: own elaboration)

The visualization of the building helps to assess the integration of the building into the environment (Fig. 5.4) or to evaluate interior solutions (Fig. 5.5).

FIG. 5.4. Visualization of the market building (Source: own elaboration)

FIG. 5.5. Visualization of the market interior (Source: own elaboration)

Dynamic energy demand modeling must be performed when preparing the energy analysis of a building. A comparison of energy efficiency solutions, analysis, and presentation of cost-effectiveness options, and a report for choosing the right option must be provided.

The energy efficiency of buildings pursues as its ultimate goal – the saving of natural resources, the reduction of the carbon footprint, and, ultimately, the preservation of the global balance of our planet. The decisions to be taken in the construction process, such as business decisions, must also correspond to the criteria of business efficiency, i.e. reduction or, at least, compensation of costs. The BIM methodology offers us the tools so that these decisions can be made based on reliable data obtained instantaneously. The reduction of uncertainties is one of the greatest achievements of the BIM methodology. It allows the best possible decisions to be made at the most appropriate moments of the construction process.

Sustainable development is maintained throughout the whole life cycle of the building and should:

- Reduce consumption of resources (save water and energy);
- Reuse of resources during the refurbishment or disposal of existing buildings or use of recyclable resources of new buildings. The wrong environmental management of the site encourages the generation of waste that could have been avoided;
- Eliminate toxic materials and ensure the healthiness of buildings, applying nature protection (climate change mitigation, biodiversity, ecosystem services);
- Emphasize the quality of the buildings, maximizing the durability because generally, it is more sustainable to renovate existing buildings than to demolish and build new;
- Use eco-efficient materials (without processing) and local materials;
- Increase the comfort of life (increase the quality of outdoor areas and indoor air).

The planning and design of high-energy buildings require an efficient process of their assessment, which includes methods for modeling and optimizing building properties.

5.3. Data Required for Simulations of Sustainable Building

Digital models can be used to test combinations of solutions by testing their behavior over the years to select rational solutions.

Energy Models: These building information modeling models deal with all the big questions. The energy model will often be used during the earliest stages of the analysis. The energy model helps to interpret the basic information. Often, only basic geometry will be used to build the models. More realistic and defined specifications come with later energy models. The energy consumption of a building depends significantly on the architectural, structural, and engineering solutions.

Lighting Models: These are all about the presentation because the lighting model handles the visual aspect. They tend to contain many more details than energy models. Geometry and the use of this model will define the properties of the materials. This is the model that helps to figure out exactly what is needed, as well as how everything should fit together. Generally, the finished lighting model is similar to the one that will be presented to clients.

When imported into the energy simulation tool, the model would assume the default values for the location given when creating the digital model. In order to discern that the information related to the selected material used in the model has been completely transmitted over to the energy simulation and analysis tools, new material could be assigned to the 3D model of the building (Fig. 5.6).

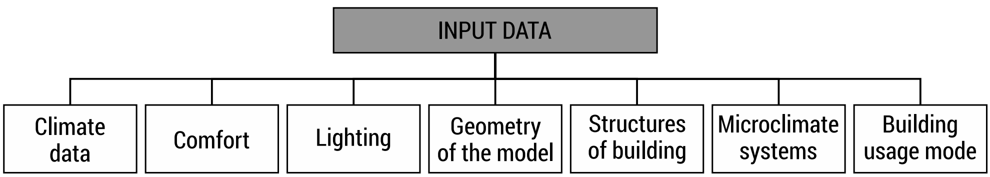

FIG. 5.6. Input data for sustainable building simulations (Source: own elaboration)

Application of building information model during the stages of building development, design, and construction, facilitates transfer of all the information about the building from the architectural models to the building modeling tools, which allow the designer to:

- evaluate alternative solutions,
- make a rational decision according to the chosen functions of the goal,
- reduce the likelihood of ineffective solutions,
- implement the requirements for high-energy efficiency buildings.

The newest feature of building information model is the ability to calculate light levels in space from the sunlight and skylight on a given day and time, e.g. The All-Weather Sky method uses historical weather data to better approximate the sky conditions for the selected day and time.

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