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AN OVERVIEW OF INNOVATIVE CONSTRUCTION MATERIALS FOR ENHANCING THE SUSTAINABILITY OF BUILDINGS AND THEIR INTEGRATION INTO BIM

Salima Zerari
Università degli Studi della Campania "Luigi Vanvitelli", Department of Architecture and Industrial Design
Aversa – Italy
https://orcid.org/0000-0001-6176-7158

Rossella Franchino
Università degli Studi della Campania "Luigi Vanvitelli", Department of Architecture and Industrial Design
Aversa – Italy
http://didattica.cressi.unicampania.it/cv/058220-en.pdf

Nicola Pisacane
Università degli Studi della Campania "Luigi Vanvitelli", Department of Architecture and Industrial Design
Aversa – Italy
http://didattica.cressi.unicampania.it/cv/059117-en.pdf

Abstract: The contribution of buildings to the total energy consumption and emission of greenhouse gases has increased. The building sector is responsible for 42% of the total energy consumption. Traditional construction materials such as steel and concrete are creating pressure on the environment. Thus, different innovative construction materials have been introduced to improve buildings' sustainability. The aim of this paper is to give an overview of the relationship between innovative construction materials and the integration of Building information modeling (BIM) in the sustainability process. Particular attention is paid to BIM technologies and certifications.
Keywords: Innovative construction materials, sustainability, BIM.

INTRODUCTION

The contribution of buildings to the total energy consumption and emission of greenhouse gases has increased. There is a necessity for constructing buildings that have high thermal efficiency properties. Which led to a need for innovative construction materials that will address the rising global challenges such as climate change, escalating standards of living, and a growing population; however not many people are aware that there are already sustainable alternatives available which allow building owners to continuously contribute towards minimizing their carbon footprint. Different innovative construction materials such as steel, concrete, wood, plastics, etc. have been introduced to improve the sustainability of buildings and integrate it into BIM. Thus, these innovative construction materials are of great importance in the contemporary construction sector and can revolutionize that industry. Traditional construction materials, such as steel and concrete, are creating immense pressure on the environment with regard to greenhouse-gas emissions and water consumption. The purpose of the present study is to understand the impacts of innovative construction materials on enhancing the sustainability of buildings over the world. Detailing the characteristics of innovative eco-sustainable materials. Then, giving a literature review of different existing software and certifications that have been used to assess sustainability within the framework of BIM.

SUSTAINABILITY AND INNOVATIVE MATERIALS FOR BUILDING CONSTRUCTION

Sustainability is about designing and building so that our buildings last and require as little as possible ongoing spending beyond the initial construction. The construction industry has been scaling at an alarming rate for the past century, and the current model is not sustainable. With the rapid development of technology and innovation, many new construction materials are being developed that can significantly reduce the negative environmental impacts of this industry. Construction industries have been expanding at a fast pace every year. Currently, this trend is unsustainable due to the heavy use of natural resources as a result of its production process. Many new innovative construction materials are being developed now in order to solve these problems caused by natural resource usage. It is also important to emphasize technological advancement.

CHARACTERISTICS OF INNOVATIVE ECO-SUSTAINABLE MATERIALS

The construction industry is characterized by high consumption of natural resources and a very strong impact on the environment and its subsystems: water, air, and soil. The development of materials for construction until recently has been primarily concerned with identifying improved performance in terms of both efficiency and durability, all with control of cost containment. More recently, attention has also been added to the environmental issues determined by both production and use and their final disposal, expanding even to the recycling/reuse.

In order to help create a more sustainable urban environment, it is important that attention also be paid to the materials used, and in this regard, the particular potential seems to be presented by innovative ones that draw on the renewable resources of our planet for their constitution.

The introduction of innovative materials brings about a change in the relationship between building and construction materials in that while traditional ones have always performed a static function, innovative ones are characterized precisely by performing a dynamic function that allows them to adapt to environmental changes. This makes it possible to expand the frontiers of the dialogue between the building and the surrounding environment, which in this way can also take place through the careful use of materials.

Innovative materials by definition exhibit property optimization over traditional materials to enable the achievement of innovative performance by intervening on physical and chemical characteristics. Particular attention must therefore be paid to those materials that allow the improvement of functional performance while also being attentive to environmental effects extended to the entire life cycle. In this regard, it is important to raise awareness in the world of industrial production in order to promote production cycles that integrate material efficiency with environmental compatibility to preserve and enhance ecosystems and the biological cycles of nature. With these premises, it is important to specify that in the field of innovative materials for construction those that assume a particularly prominent role are both natural matrix materials (biomaterials) and smart materials. Biomaterials are totally or partially made up of raw materials of natural mineral or vegetable origin. A whole series of building materials based on wood, kenaf, coconut, cellulose, straw, rock wool, glass wool, etc. are already commercially available. The smart ones are distinguished by their ability to change in response to stimuli from outside and are characterized precisely because they are able to exploit environmental resources by using nature's principles for their operation by stimulating strategies proposed by nature itself.

At the basis of the choice of material, in addition to the other aspects that are certainly of fundamental importance, it is also necessary to carry out a real "compatibility analysis" of the material that adds to the purpose of saving natural resources also that of mitigating the environmental impact, both seen not so much in their economic value as in their impact on the residual availability for future generations and the possibility of still enjoying a habitat that has not been completely degraded despite having subjected it to repeated transformations. The compatibility analysis makes it possible to be able to define for each material the limitation of the footprint and the identification of the carrying capacity of the same definable as the ability to absorb and control the phenomena of environmental transformations with a sustainable impact on the ecosystem.

INTEGRATION OF BIM

BRIEF HISTORY OF BIM

Rapid advancements in available technology and the move to a new digital paradigm have enabled BIM the fulfillment of its potential. Back to the past, in 1957 the first commercial software known as (CAM), computer-aided manufacturing, was developed by Dr. Patrick J. Hanratty, later he developed DAC (Design Automated by Computer) which became the first CAM/CAD system (KHOCHARE; WAGHMARE, 2018). The rise of innovations facilitated by digital assistance helped in the creation of BIM. Douglas C. Engelbart's published introductory chapter discusses the combined architectural use of object-based design with parametric handling, and a database system in 1962 (Engelbart D 1962). In 1975, Charles Eastman has introduced software called BDS (Building Description System) that combines different architectural elements that could be graphically combined to generate different building drawings (EASTMAN, 1975). It was not till 1982 that Gabor Bojar introduced an innovative software to modeling which he called ArchiCAD (KHOCHARE; WAGHMARE, 2018). This software is based on a concept similar to BDS and is considered to be the first BIM application running on personal computers (GOBESZ, 2020). The main objective at that time was to help resolve data projection problems and schedules of projects. The advancements allowed architects to represent their design and the huge data related to each building element within the entire sequence of design and construction phases as a spatial drawing, without any reference to the sustainability objectives. As a technology, BIM (Building Information Modeling) is a digitally enhanced, 3D representation of a building and its design. It is a powerful tool that helps engineers and planners design smart buildings with the use of 3D models of the site, building, and surrounding areas. This technology is being used in many aspects such as environmental sustainability, cost optimization, project visualizations, and construction performance analysis. BIM is used in almost all large-scale projects nowadays.

BIM SOFTWARE

Since then, a lot of software has been created, as seen in Figure 1. There are many different types of BIM software available on the market today. In each of the BIM dimensions, BIM software may be classed according to its specific application fields: 3D modeling, 4D scheduling, 5D costing, 6D sustainability, and 7D Maintenance &Operation. Some software can also be used for multiple purposes in the process of integration. Some are more popular than others because they have more features or better user interfaces. The requirement for simpler visualization of components that share common connections has led to a significant advancement in BIM 3D modeling software since its introduction. Information can be presented more efficiently to users so that information on all stages in the life cycle of buildings can remain accessible from one software. Autodesk® Revit was used the most. As a result, it can serve as a reference for BIM 3D modeling. For the planning of construction projects, 4D scheduling software is a type of software that is used to create schedules. It includes information about the sequence of construction works, duration, and location. It can be used to plan the project in 3D and 4D. Regarding 5D costing software is a type of software that helps in the estimation of construction projects. It is used to calculate the cost of a project by taking into account all the costs associated with it. 6D sustainability software is a type of BIM software that integrates sustainability into the building design process. It helps architects and engineers to create sustainable buildings by providing them with tools for assessing the environmental impact of their designs, such as Green Building Studio, EnergyPlus, and Ecotect. Lastly, the 7D Maintenance & Operation BIM software also helps with the maintenance of buildings by providing information about how to maintain them to avoid any problems in the future.

OVERVIEW OF THE DIFFERENT BIM TECHNOLOGIES

With BIM integration into the process, developers can better understand the impact of their designs on their projects. They can also make sure that they are complying with specifications and regulations. BIM can be thought of as a collaborative tool for members involved in the design and construction process that allows users to create surfaces and objects using 3D modeling. BIM technologies substantially change the way buildings are conceptualized, assessed, engineered, and constructed. Many different types of integrated building information model technologies are now being used.

INTEROPERABILITY

BIM Interoperability is the ability of different BIM software to work together. It is a key requirement for the success of any project. The interoperability of BIM software can be achieved by using a common data format, such as IFC or DWG. This technology is frequently referred to as being possible thanks to the IFC (Industry Foundation Classes) standard, a developing one from buildingSMART International (SANTOS, 2010). It has been updated several times since then. In addition to IFC, a few lesser-known standards are crucial for achieving BIM interoperability. These include IDM, MVD, and IFD (SANTOS, 2010).

SCAN TO BIM

The process of scanning the physical environment and converting it into a BIM 3D model is known as Scan to BIM(BOSCHÉ et al., 2015). Light detection and ranging (LiDAR), which estimates the distance to a target by emitting a laser beam and detecting the reflected laser signal, is another name for 3D laser scanning(WANG; GUO; KIM, 2019). The laser scanner is used to scan the physical environment to create point cloud data. The point cloud data is then converted into a gbXML (green building eXtensible Markup Language) file which can be imported into BIM software (e.g., Revit, Bentley, ArchiCAD) for further processing as shown in figure 2.

INTEGRATION OF BIM AND GIS

BIM and Geographical information systems (GIS) are two different technologies that have been around for a while. Geographical information systems (GIS) are computer-based tools that allow users to analyze and map data. This system of digital mapping is used for various purposes such as urban planning, disaster management, and environmental protection. CityGML and other SIG 3D tools could aid in the creation of large-scale models (GRÖGER; PLÜMER, 2012). However, building information modeling (BIM) can combine the information from both sources to create a more accurate representation of the project on the urban scale as shown in figure 3. The field of architecture, engineering, and construction (AEC) can now be integrated more effectively thanks to advancements in both the social sciences and information and communication technologies (ICTs) (WANG; PAN; LUO, 2019).

REAL-TIME BUILDING PERFORMANCE MONITORING

The use of real-time building performance monitoring is becoming more and more popular. This is because it can help to identify problems before they become major issues. It can also help to reduce the cost of maintenance and repairs. It does this by collecting data from sensors that are installed in the building, such as temperature, humidity, and air quality sensors. The data collected by these sensors is then analyzed by software to identify

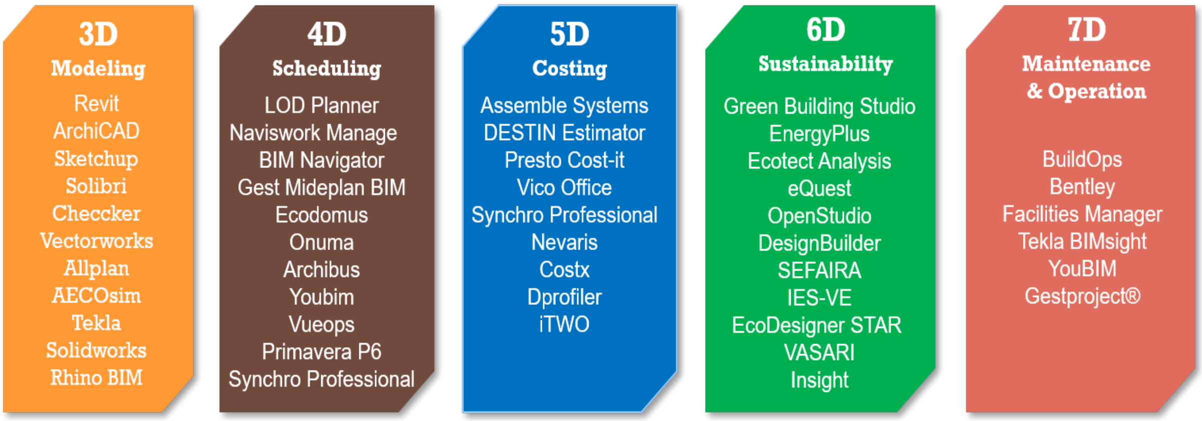

Figure 1. Categorization of BIM software

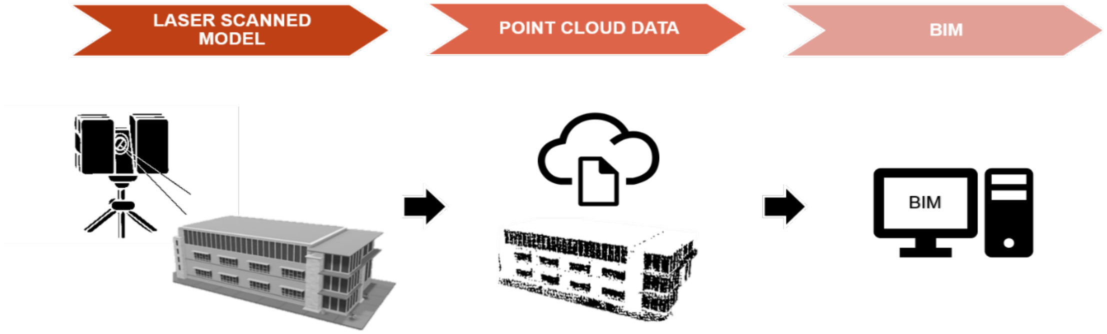

Figure 2. From 3D Laser scan to BIM software.

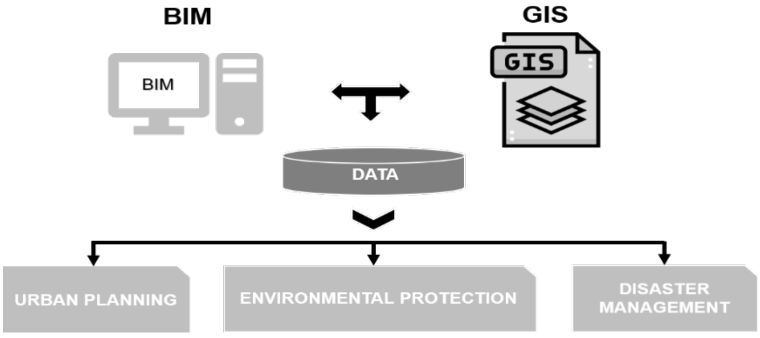

Figure 3. Integrating BIM & GIS

any potential problems with the building's condition or operation. Several sensors are embedded in the structures namely Vibrating wire (VW) gauges, Electrical resistance (ER) strain gauges, and thermistor sensors). Also, building management systems, indoor sensors, such as the Hobo U12 data logger, surface temperature, airspeed, and Thermal images, as well as weather monitoring and laboratory tests, can be used to monitor the buildings' environmental and structural performance (HAJDUKIEWICZ et al., 2015).

INTEGRATION OF INNOVATIVE CONSTRUCTION MATERIALS IN BIM

There has been a growing interest in the application of innovative materials in construction. BIM has an important contribution to make to such adaptation, where sustainable design plans provide us with the ability to move forward by using any material for construction perfectly well. The integration of BIM is essential in the assessment of innovative construction materials. This will become an important tool for designers, manufacturers, builders, owners, engineers, and regulators as new materials are introduced into the building industry. It helps in the understanding and experimentation of new materials with respect to performance, cost, maintainability, and durability. It offers a way to predict and mitigate problems early on in a project's design stages of construction projects. An interdisciplinary approach called the Life Cycle Sustainability Assessment (LCSA) evaluates the outcomes of products and activities from an economic, social, and economic perspective (ONAT et al., 2017). Therefore, BIM represents a digital information database that allows the organization of all data in a project, which can enhance the implementation of LCSA for selecting construction materials(FIGUEIREDO et al., 2021). Hence, LCSA aims to integrate the three dimensions and combines the three methods (Environmental) Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) (LLATAS; SOUST-VERDAGUER; PASSER, 2020). The First method, LCA, is a process that evaluates the environmental impacts of a product or service. It is an important tool for sustainable design and construction. The particular input of data for the different materials necessary for environmental impact assessment is supported by BIM for the entire process of building materials production, construction, and demolition(LEE et al., 2015). Life Cycle Costing (LCC) is a process that evaluates the total cost of a building over its lifetime. It includes all the costs associated with raw material extraction, material processing, manufacturing, transportation to the site, installation on site, maintenance and repair over time, and removal from the site at end of service life. Lastly, Social Life Cycle Assessment (S-LCA), different social impacts of adopting this approach in the construction sector can be examined, such as impacts on worker safety, fair pay, and access to material resources (DONG; NG, 2015).

ENVIRONMENTAL CERTIFICATIONS IN BIM ENVIRONMENT AND NEW STANDARDS

The use of BIM methodology in the AEC sector can provide valid support in the direction of assessments on the sustainability of the intervention, verifying the impacts of the choices adopted to limit any technological-environmental criticalities of an intervention ((JALAEI; ZOGHI; KHOSHAND, 2019)). Among the dimensions widely shared by the scientific literature, that relate to sustainability, is in recent years orienting working methods and new approaches to the project. In fact, if for parametric model other dimensions, the evolution of the working approach in the construction of a digital twin has led to the definition of operational standards, at least shared at the local level, as part of the assessment of the sustainability of the intervention there are still no defined operational guidelines. Digital objects in BIM describe building components and are parametric elements because they are not only modeled for their geometry but a set of data is associated with additional information. The parametric BIM model, therefore, follows the real building in all the phases of the life cycle from conception to demolition, with varying and increasing levels of detail and deepening (A. Pavan 2017). To support these progress times, it should be noted that for these types of evaluations there are numerous sources from which reliable and digitized data can be found (PALUMBO et al., 2020). It is precisely with a view to conscious choices in the project in the field of AEC that evaluations on the choices of materials with specific attention to innovative materials with a natural matrix and their applications to technological components can be the starting point for overall evaluations on the work. If until recently the focus was mainly on recycled materials or prefabricated and reversible construction solutions, today thanks to environmental certifications for new materials it is possible to have useful information for environmental assessments. The Environmental Product Declaration (EPD) is the main source by collecting according to specific standards the information provided by manufacturers concerning the production cycle of the material itself. The EPD "quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function." (ISO14025 2006) providing useful data for overall assessments of the building or infrastructure. The need to integrate environmental data into a project developed through a parametric BIM approach has recently led to the standardization by ISO of a new standard "Sustainability in buildings and civil engineering works — Data templates for the use of environmental product declarations (EPDs) for construction products in building information modeling (BIM)" (ISO22057 2022) that allows the use and availability of environmental data in BIM, obtained from EPDs. Environmental information will now also be available in a digital format developed specifically for use in BIM by incorporating EPD data into a common parametric data model. The data model provides all actors in the building process with a common technical language that allows them to acquire and share accurate and reliable information, through the possibility of teamwork that such digital platforms offer. This possibility allows the different specialist skills to work on a single model, each sharing its contribution to the project, verifying in real time any clash or evaluating advantages and disadvantages between different solutions, also evaluating the environmental impact of the building.

CONCLUSION

Construction materials have a significant effect on the sustainability of buildings. They are used to form the building envelope, control indoor environmental quality and provide thermal insulation. The benefits of using innovative construction materials are now widely recognized, and as a result, their use is increasing rapidly. It can help reduce the carbon footprint of buildings with their integration into BIM. This is because they are durable and sustainable, and can be easily integrated into Building Information Models (BIMs). A variety of software and certifications have been used to assess sustainable techniques and materials.

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