Building Information Modeling for Sustainable Construction

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Abstract. The possibilities of building information modeling (BIM) for solving the problems of sustainable construction to improve the quality of construction of buildings, ensuring maximum comfort inside the premises at the expense of a minimum amount of resources are studied. The assessment of the possibility of BIM for solving the problems of sustainable construction for the conservation and Thrifty use of natural resources was carried out. The use of BIM for humanistic design is analyzed. The principle of reorganization of the last stage of the life cycle (LC) of a sustainable construction object for optimizing the LC of materials and components in construction based on BIM is studied. A scheme of the machine learning process for optimizing design based on BIM is proposed.

1. Introduction
About half of all energy in the majority of the world’s countries is consumed by residential buildings [1]. In this relation, sustainable housing construction [2] has become one of the important trends in construction. Such construction aims at minimizing the energy consumed during construction and operation while maximizing the preservation of the environment [3, 4, 5]. Methods of design, construction, operation, and disposal of construction facilities affect the energy efficiency of facilities, their optimal operation, and environmental safety. Sustainable construction results in buildings with a high quality of the living environment, being in ecological balance with nature, with eco-friendly utilities, and resolved issues of energy and transport [1]. They are surrounded by an environmentally responsible and socially harmonious culture, a beautiful and functionally attractive landscape [1].

2. Rationale
Building design with consideration for sustainable construction approaches is facilitated by the active introduction of Building Information Modeling (BIM) in the construction sector to visualize, model, and simulate design and parameters of buildings [6, 7, 8]. While modeling, exchange of information between all interested parties, design coordination, task coherence, collision detection, and monitoring of the management process are carried out [9,10]. The technology is based on the development and use of a virtual building model in the form of an information parametric model and related documents. Such a model is created in the early stages of the project, gradually being updated with information. The implementation of BIM contributes to the access of used information, controlled coordination and monitoring of the processes [11]. Parametric objects have their own data sets in an information model
[12]. Changing the size or parameters of individual parts and structural components of a future building results in the recalculation and update of the entire information model, thus making it possible to avoid errors at the construction stage. A change in any design variable can affect the environment during all relevant stages of the building life cycle. Because of competition, design and construction companies have become very interested in developing sustainable construction due to the modernization of resource potential optimization and management [13, 14]. Modeling enables us to consider the requirements of sustainable design affecting the efficiency of buildings, environmental safety, and comfortable living of people.

3. Aims
The purpose of the paper is to study BIM capabilities to solve the challenges of sustainable construction in order to improve construction quality, ensure maximum comfort indoors with a minimum of resources. A number of tasks should be performed to achieve this goal:
- assess BIM capabilities to address the challenges of sustainable construction for the preservation and sustainable use of natural resources;
- analyze the use of BIM for construction principles favoring the requirements of sustainable construction for humanistic design;
- propose the principle of rearranging the last stage of the life cycle (LC) of a sustainable construction facility to optimize the LC of materials and components based on BIM;
- develop a machine learning process diagram to optimize BIM-based design.

4. Sustainable construction requirements for the preservation and sustainable use of natural resources based on BIM
Some methods favor sustainable construction requirements for the preservation and sustainable use of natural resources (e.g. the maximum use of materials and systems with low carbon content, in particular, timber and bricks). Since everything requiring a large amount of energy is derived from petroleum products, and if large quotas are introduced for carbon emissions, such materials may become economically unprofitable. The creation of a 3D model of a future facility selecting materials and performing preliminary virtual spatial allocation enables us to find the optimal solution, avoid construction errors, and save money.

The design of standard buildings with flexible modular or block structures will make repairs, extensions, buildups and other building upgrades effective. Modularity ensures the creation of spaces that are multiple to each other, and standardization is aimed at creating universal spaces. Over time, an extensive database of standard modules will be created with their data stored in the BIM system. This will significantly reduce the time and cost of designing new facilities. The construction of a building facility consisting of several sections will decrease heat consumption by reducing the area of exterior wall envelope, material consumption for construction, length of utilities and access roads. This is achieved, for example, by designing an open courtyard of a residential building [5].

As energy becomes more expensive, the use of local materials will become cost-effective. The use of renewable energy sources — solar panels, generators using wind energy — will reduce energy consumption. Preliminary calculations based on BIM with augmented reality will allow us to determine the effectiveness of solar panels and wind-driven generators in a particular region.

Enhanced thermal insulation is the most effective method since it is more profitable to save than to generate new energy. Insulation of walls and windows using energy-saving glass with sun-protection properties should be provided when choosing materials for exterior and interior finishing using BIM. The collection of rainwater and groundwater for housekeeping needs, as well as the installation of pumps for hot water supply, accumulating soil heat, will increase the efficiency of a water supply system. Green roofs can save about 25% of the energy by keeping rooms cool in hot weather and reducing the cost of heating in cold weather thanks to their good thermal insulation properties. Moreover, landscaping unloads gutters since the majority of rainfall is absorbed by soil on the roof [4].
The implementation of a building management system with sensors for automatic lighting in the entrance area, installation of automatic sliding doors, control of heat consumption, and other achievements of the smart home system improves the efficiency of BIM-based smart energy resource management. To control the environment quality and monitor the health of residents, information of smart systems inside and outside a building will be entered into the model during the entire period of facility operation and adjust the operation of various systems through the feedback.

A careful attitude to ecology, including human ecology, considering subsequent operation and disposal of design objects, necessarily makes one think about the future of the facility being designed: how it will be disposed, how safe, environmentally friendly and humanistic it is.

5. Sustainable construction requirements for humanistic design using BIM

Several principles contribute to the requirements of sustainable construction for humanistic design. For example, such a design considers the preservation of natural conditions. Here, such methods as planting greenery on all related areas by the principle of green corridor come to the forefront. This will contribute to air purification, safe migration of birds and animals, walks of residents, and increase the aesthetics of the visual environment [4]. A good example is Vertical Forest in Milan. The vertical forest plant system helps in creating a microclimate, generates moisture, absorbs particles of CO₂ and dust, and produces oxygen. Planting trees along a building will protect the walls and footpaths from overheating and create a favorable atmosphere for relaxing outdoors. Moreover, landscaping enhances sound insulation, protects buildings from noisy highways (the same way as anti-noise screens, absence of windows facing the roadway, and special architectural and space-planning solutions). At the design stage, a virtual information model makes it possible to optimize the location of the densest vegetation on a building and around it so as not to block natural light.

The provision of an accessible environment for people with various health restrictions is fully consistent with humanistic design. A virtual information model enables us to foresee, elaborate, select designs to optimize the environment for people with disabilities. Sustainable design corresponds to the multifunctional completeness of a residential building which is easiest to pre-design based on a virtual model. In large cities, many building designs include office space, retail, entertainment, and wellness facilities. Sustainable construction is facilitated by underground structures, combinations of ground and underground buildings and structures designed with BIM.

Contacts between different members of society should be promoted to create an optimal living environment. This constitutes elements of collaborative design. Sophisticated BIM planning can provoke the desired behavior: an equipped sports field gathers residents for sports; decorated recreation areas favor communication; well-thought-out office space increases efficiency, etc. [7].

6. Sustainable construction requirements for optimizing the life cycle of materials and components in construction based on BIM

The requirements of sustainable construction to optimize the life cycle of materials and components in construction are facilitated by the principle of rearranging the last stage of the construction facility life cycle. Currently, a huge amount of construction waste is generated in the world, requiring special dump-sites. Environmental damage is caused and the natural balance is violated. A sustainable approach in the life cycle of a building is to reuse and recycle materials to create new facilities [15]. It is possible to recycle such materials as plastic, glass, wood, reinforced concrete scrap, bricks and other stone materials, scrap metal in the form of reinforcing bars, partition profiles, railings. Concrete is easily recycled into crushed stone, which can be used to fill swamps or recover roads. Recycling and recovery of building components are currently in common practice, however, it is more profitable and challenging to move a building or reuse its components without recycling since it requires minimum energy compared to recycling and recovery [16].

The reuse of building components guarantees a closed material cycle when the demand for new resources and waste generation during construction and demolition are minimized. Figures 1 and 2 in four stages demonstrate how deconstruction provides a closed material cycle at the end of structural
life. A closed material loop eliminates the linear model of material movement during demolition which is a more stable construction model. The entire building is rarely reused, however, the deconstruction of building main components is feasible.

Figure 1. End-of-life scenario with demolition and disposal.

Figure 2. End-of-life scenario in a closed material cycle with recycling and reuse.

In addition to helping to recover building components and reduce landfill waste, dismantling is more beneficial than demolition. First, deconstruction eliminates environmental pollution and waste generated during demolition [17]. Other benefits include reduced emissions and energy saving.

An effective closed-loop strategy for the extraction and reuse of building materials provides a number of requirements: a building shall be dismountable; building materials shall be recyclable; the production and use of materials shall be harmless; materials obtained during recycling shall be harmless as well [18]. However, the selection of materials for reuse or recycling should not begin at the end of the building life cycle; it should begin at the design stage. At different stages of the construction facility life cycle, gas emissions, transport emissions, generation of solid waste and toxins, water discharges are inevitable. Architects and engineers should monitor the entire building life cycle and choose building materials based on their ability to be reused or recycled after the building is liquidated. The current trend of sustainable architecture implies that deconstruction can be planned during building design. Buildings that were originally designed with deconstruction in mind are easier to maintain and adapt to new uses [19]. Planned deconstruction suggests different options for the end of service life: reuse of the building or relocation to a new place; reuse or relocation of a component in a new building; reuse of material in the manufacture of a new component; recycling of materials into new ones. As a rule, reuse is more environmentally friendly than recycling or disposal. Buildings should be designed in such a way as to stimulate more environmentally friendly end-of-life options.

BIM is widely used since it enables us to analyze and model the effectiveness of buildings, evaluate costs and energy consumption, perform lighting analysis before construction [20]. This allows us to compare alternative project options when choosing the most cost-effective and sustainable solution, and identify potential design errors and operational problems at a stage when changes to the design are much cheaper. Since waste is generated at all stages of the life cycle, the use of BIM for waste management will make it possible to effectively collect data related to waste from design to the end of the life of buildings.

7. BIM and machine learning
The introduction of BIM facilitates the use of machine learning [21, 22] to optimize projects. Machine learning can be divided into three stages: preliminary, creation of projects, and final. At the preliminary stage, various data are collected, e.g. requirements for insolation, material savings, energy costs, and maximization of the useful area. Next, user-defined variables are selected, and the main restrictions are set — requirements of regulatory documents or customer requirements, selection criteria for options (e.g. noise exposure level, the proximity of adjacent buildings), and target functions. At the stage of creating projects, a multitude of options for solving multi-parameter issues
are compiled and evaluated by computer according to the given criteria. Changing the parameters improves the new version in relation to the previous one, this is how machine learning is implemented. As a result, the user receives several ready options. At the final stage, a designer chooses the best options or makes adjustments to the algorithm. Then the process is repeated. Figure 3 shows a workflow diagram.

![Figure 3. Machine learning workflow diagram.](image)

This technology enables us to optimize the consumption of resources at the initial stages of design when alternative solutions are chosen. It will be possible to create floor plans according to regulatory documents and consider customer requirements by developing a plugin for Revit. This will significantly speed up the process of finding the optimal solution for the given criteria, e.g. when optimizing the consumption of building materials. Machine learning related to searching through options based on BIM provides new possibilities for sustainable construction.

To build a model based on data, it is advisable to use regression, classification and clustering methods. All data are divided into two parts. We train the model using a training set, and then we determine accuracy of its predictions using a validation set. Visualization is one of the best data analysis tools. However, the task to be solved can vary over time. For instance, building operation depends not only on the labor input, duration of construction, period of inventory turnover, construction-in-progress level and material consumption, but also on the state of economy. If there are significant changes in the economy, prior trends are not applicable, since the characteristics of the random process underlying the data have changed. The models trained earlier are not applicable — new data should be collected and a new model should be trained. As an alternative, a feedback mechanism can be used. It feeds information on the model efficiency back to the model and then the model can be adjusted throughout its use.

8. Results
In the course of the studies performed:

1. The capabilities of BIM were assessed to address the challenges of sustainable construction for the preservation and sustainable use of natural resources.
2. The use of BIM for construction principles favoring the requirements of sustainable construction for humanistic design was proposed and analyzed.
3. The rearrangement of the last stage of the sustainable construction facility’s life cycle was proposed and investigated to optimize the life cycle of materials and components in construction.
4. The possibilities of using BIM for designing the deconstruction of a building were analyzed.
5. The diagram of machine learning when optimizing BIM-based design was proposed.

9. Conclusion
Sustainable construction is based on many factors. This includes the creation of a healthy external and internal living environment; the creation of a single architectural and landscape complex, decoration and landscaping, orientation of a building for better insolation and shading; preservation and support of nature, reduction of the built-up area due to the multi-functionality of buildings and structures. Sustainable construction features the resource and economic efficiency of operation, the use of renewable energy, independence from external networks, the efficiency of water consumption and water use, collection, storage and use of greywater. In addition to that, building materials’ selection is environmentally and economically balanced — local and renewable materials are preferred as well as
materials that do not pollute air, water and soil throughout life, materials and structures suitable for disassembly and reuse, materials requiring minimum energy for their production. Moreover, infrastructure is designed for recycling after destruction. This will reduce the impact on the environment and human health; ensure energy saving of buildings; reduce operating costs; create new components and products from environmentally friendly materials.

Considering the above, it is necessary to use BIM for the management of building construction more actively. Proper design solutions based on BIM can have a significant impact on waste minimization and performance characteristics of buildings at the end of their useful life. The study focuses on revealing the capabilities of BIM that will ensure efficient decision-making mechanisms with regard to deconstruction at the design stage. It will also be possible to optimize management resources at the final stage of the life cycle using BIM tools.

10. References
[1] Tetior A N 2003 Architectural and construction ecology Sustainable construction Legal issues of environmental protection Express information (Moscow: VINITI) 11 pp 39-40
[2] Robert J Howlett, Lahkmi C Jain, Shaun H Lee 2009 Sustainability in Energy and Buildings: Proceedings of the International Conference in Sustainability in Energy and Buildings (SEB'09) (Brighton and Hove in the United Kingdom) pp 179-188
[3] Hamraie A 2017 Building Access: Universal Design and the Politics of Disability Journal of Design History (University of Minnesota Press) 3(31) pp 296-298
[4] Koshkina S, Korchagina O and Voronkova E 2013 "Green" construction as the main factor in improving the quality of the environment and human health Questions of modern science and practice (Moscow: Vernadsky University) 3(47) pp 150-158
[5] Duving S 2012 "Green" buildings in Russia and abroad UNIDO in Russia 8 pp 72-79
[6] Eastman C, Teicholz P and Liston K 2011 BIM Handbook Second edition (NJ: Wiley) p 626
[7] Azhar S et al. 2011 Building Information Modeling for Sustainable Design and Leed (R) Rating Analysis Automation in Construction 20(2) pp 217-224
[8] Succar B 2009 Building Information Modelling Framework: A Research and Delivery Foundation for Industry Automation in Construction 18(3) pp 357-375
[9] Tardif M and Smith K D 2009 Building Information Modeling: A Strategic Implementation Guide (John Wiley & Sons. Hoboken) p 216
[10] Azhar S et al. 2012 Building information modeling (BIM): now and beyond Australasian Journal of Construction Economics and Building 12(4) pp 15-28
[11] Bukunov A 2019 Functional Modeling of an Integration Information System for Building Design Cyber-Physical Systems and Control (CPS&C 2019): Lecture Notes in Networks and Systems vol 95 Springer Cham pp 525-535
[12] Repin V V, Eliferov V G 2005 The process approach to management Business Process Modeling (Moscow: RIA "Standards and Quality") p 408
[13] Bukunov A S May 22-24 2018 Lifecycle management of a construction object based on information technology System analysis in design and management (SAEC): Collection of scientific papers XXII Intern. scientific -practical conf Part 1(Spb.: Polytechnic Publishing House University) pp 324-330
[14] Bukunov A S and Bukunova O V 2019 Information exchange in the common system when creating BIM BIM in construction and architecture: Proceedings of the II International conference BIM (Spb.: SPSUACE) pp 59-64
[15] Akinade O O et al 2015 Waste minimisation through deconstruction: a BIM based Deconstructability Assessment Score (BIM-DAS) Resources, Conservation and Recycling p 105
[16] Giglio F 2002 Controlling environmental impacts in the dismantling phase Design for deconstruction and materials reuse Proc. of the CIB task group 39 Deconstruction Meeting (Karlsruhe) p 272
[17] Bukunov A, Nurulin Y 2020 Environmental assessment of the building life cycle based on BIM *Electronic scientific journal. Engineering Bulletin of the Don* 5 pp 1-10

[18] Kibert C J 2002 Deconstruction’s role in an ecology of construction Design for deconstruction and materials reuse *Proc. of the CIB task group 39 Deconstruction Meeting* (Karlsruhe) p 272

[19] Ulanova O V, Starostina V U 2012 A brief overview of the method of assessing the product life cycle and waste management systems *Modern problems of science and education* 4

[20] Bukunov A S and Bukunova O V 2018 Integration of blockchain technology and information modeling of real estate objects *BIM – modeling in construction and architecture problems: materials of the All-Russian Scientific and Practical Conference (SPb: SPSUACE)* pp 45-51

[21] Alpaydin E 2017 *Machine learning: new artificial intelligence* (Massachusetts Institute of Technology: Alpina Publicher) p 208

[22] Liu T-Y 2011 *Learning to Rank for Information Retrieval* (Heidelberg: Springer) p 323