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IMPLEMENTING BUILDING INFORMATION MODELING IN RETROFITTING OF BUILDING PROJECTS AND ENERGY EFFICIENT CONSTRUCTION

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Abstract. Nowadays building projects have been encouraged to adopt green and sustainable construction strategies as the construction sector is responsible for using 42 % of the world's energy, 30 % of its raw materials, and 25 % of its fresh water. The priority purpose is not only to upgrade and enhance projects of existing buildings, the target is also to reevaluate the approach of the whole construction sector [1]. The issue requires complex and modern methods which should include retrofitting as well as reconstruction of existing infrastructure. The housing fund of Ukraine as well as other European countries calls for alterations which will lead to gaining and raising its energy efficiency. To create the optimum alternatives there should be conducted an investigation of the possibilities of changing the real estate's usage. A framework for value engineering and building information modeling, especially appropriate for existing buildings, is required to aid decision-makers in selecting the best options for current building utilization.

Keywords: *BIM-technologies; information modeling; information technologies; retrofitting*

УПРОВАДЖЕННЯ ІНФОРМАЦІЙНОГО МОДЕЛЮВАННЯ БУДІВЕЛЬ У МОДЕРНІЗАЦІЮ БУДІВЕЛЬНИХ ПРОЕКТІВ ТА ЕНЕРГОЕФЕКТИВНЕ БУДІВНИЦТВО

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Анотація. Сьогодні будівельні проекти заохочують до прийняття стратегій екологічного та сталого будівництва, оскільки будівельний сектор відповідає за використання 42 % світової енергії, 30 % сировини та 25 % прісної води. Пріоритетною метою стала не лише модернізація та поліпшення проектів існуючих будівель, на меті також перегляд підходу до усього будівельного сектора [1]. Це питання вимагає комплексних і сучасних методів, які повинні включати як модернізацію, так і реконструкцію існуючої інфраструктури. Житловий фонд України, як і інших європейських країн, потребує змін, які спричинять набуття та підвищення його енергоефективності. Для створення оптимальних альтернатив необхідно провести дослідження можливостей зміни цільового призначення нерухомості. Для поліпшення прийняття рішень у виборі варіантів поточного використання будівлі потрібна основа для розроблення функціонально-вартісного аналізу та інформаційного моделювання будівель.

Ключові слова: *BIM-технології; інформаційне моделювання; інформаційні технології; модернізація*

1. State of art

Retrofitting is the process of modifying something after it has been manufactured. Retrofitting a building involves changing its systems or structure after its initial construction. As a result there are improvements in amenities and significant reduction in energy and water usage. Moreover, upgrading an entire building and its systems decreases negative effects on the environment and therefore benefits the comfort of residents. Thus such targets as reducing operational costs, improving residents` health and productivity can be achieved. Energy efficient retrofit of the building stock is an important and contemporary issue in the built environment [2]. Building Information Modeling (BIM) can offer a comprehensive and integrating platform for construction projects, as has been demonstrated for many large-scale schemes, mostly in new buildings but sometimes also in retrofit projects.

BIM is widely used for prototyping, visualization, collaboration, energy simulation, comparing different design options, facility management and energy demand prediction. The capability of BIM to provide comprehensive visualization can assist designers to communicate to residents in a more precise way by providing a walkthrough of the retrofitted dwelling. BIM could be offered as a solution for these types of social challenges to achieve a sustainable approach by providing digital prototypes of premises and making the process comprehensive for stakeholders and assure them about the quality of retrofit measures. By adding cost information to the model, designers and stakeholders are able to obtain more accurate quantity schedules and cost estimations. At the initial stage of a project stakeholders can be reassured over the matter of payback period.

This research focuses on the potential of adopting BIM through a smaller scale activity of residential retrofit to achieve energy efficient housing. Although many strategies and technologies have been developed during the last decades, retrofit processes are still confronted by technical, economic and social challenges. This paper investigates how BIM may be integrated all the way through the residential retrofit process and how new digital technology can be engaged.

Construction projects may now be examined using BIM to identify their benefits and drawbacks, as well as possibilities, while taking into consideration other elements such as financial, technical, and environmental concerns. These elements are consistent with the notion of sustainable construction with its three pillars (social, environmental, and economic).

As a result, BIM technology is seen to have the capacity to assist the contemporary construction industry, and its broad use has the potential to have a considerable influence on sustainability (in this sense, sustainable construction). However, among all the benefits it may give, one of the obstacles facing its implementation is determining the best strategic approach to encourage the use of BIM in sustainable construction [4].

2. Key targets of the research

The issue requires a complex and modern approach which should include retrofitting as well as reconstruction of destroyed infrastructure. The housing fund of Ukraine calls for alterations which will lead to gaining and raising its energy efficiency.

To create the optimum alternatives there should be conducted an investigation of the possibilities of changing the real estate's usage. A framework for value engineering and building information modeling, especially appropriate for existing buildings, is required to aid decision-makers in selecting the best options for current building utilization.

One of the purposes of the research is to improve the energy efficiency of the building through a review of alternatives for architectural and technical solutions. This may be achieved by making an attempt to merge them during the retrofitting process. Thus, the strategies are established and the energy consumption of the building can be simulated using various BIM programs. As a result, we acquire a reduction of energy consumption and increase of the lifespan of the building by choosing one of the retrofitting methods. The effectiveness of BIM technologies allows implementing modern requirements to reduce the time and cost of design, optimize design solutions based on experience in designing new buildings and structures, and provide the necessary information to support the investment project throughout its life cycle [2].

BIM implementation in retrofitting has its potential strengths and weaknesses. This paper studies creating retrofitting schemes, and engaging BIM into the retrofit process to support automation at retrofitting stages. Further research will give an analysis of such aspects as:

1) Presenting optimal solutions to the project's functions at a lower cost.

2) Visual and detailed analysis of the work performance technology.

4) Controlling the fidelity and validity of the construction schedule.

6) Development of construction site areas.

7) Implementing alternative methods for operating the building process.

8) Detection and elimination of space-time collisions.

9) Optimization of logistics [4].

3. Methodology

To exploit BIM in the retrofit process the condition of the building related to type of house structure, age and ownership should be considered due to the influence of these differing frameworks, required level of details and its functionalities based upon the need of users. The benefits of BIM application in new buildings are confirmed by involved parties in projects such as high rendering visualization, improved collaboration, clash detection, and implementation of lean construction. However, the application of BIM in existing buildings confronted other challenges and potentials. BIM's potentials in existing buildings embrace quality control of retrofit measures and services, retrofitting planning, operation and maintenance, energy analysis, cost calculation and life cycle assessment. BIM applications in new buildings create lifecycle stages from outset to demolition. BIM implementation in existing buildings is almost reverse engineering processes and recaptures building data. The application of BIM in existing buildings has faced different challenges. Incomplete information of residential buildings mainly brings about inefficient management in the retrofit process. Integrated BIM or IBIM provides pertinent information that supports the project's management and operation throughout its life cycle ranging from insurance, handbook information, operation and maintenance cycle and future monitoring [3].

Under BIM themes, Project Scope Management and Project Integration Management gained the most attention. A possible overlap between the two concepts resides in the usage of BIM for energy modeling and subsequently defining the scope of retrofit of existing buildings. Facilitating energy-driven refurbishments of existing buildings through BIM technologies will help achieve sustainability ratings and certifications in a shorter period of time. Besides using BIM as a strategy to facilitate the analysis of energy performance of existing buildings, the literature provides other methods for achieving energy driven renovations. For instance, energy audits can be utilized for refurbishment of existing buildings to identify the energy usage and the associated costs with retrofitting. The advancement of energy audit technologies offers more reliable information. For example, Building Automation Systems (BAS) and Building Energy Management and Control System (EMCS) offer data that can be deployed for calibration of the parameters in an energy simulation model. The accuracy of the collected data directly affects the reliability of the energy analysis for retrofit purposes.

Aside from project management there are modeling aspects which allow visualization of the project on its earliest stages. There are practice-specific (top-third of the model) and education-specific (lower-third) dimensions. For example, the representation theme has three common BIM processes: 3D/virtual modeling, documentation, and presentation, design analysis, and creative, intuitive visualization. In addition, practitioners raised the importance of use of level of development (simplicity of the model, BIM setup, and live rendering) [4]. BIM dimensions (D) help in comprehending construction projects and the practice of connecting more information and dimensions to the building model. It entails the addition of information about the phases of design, construction, and maintenance. These include 2D, 3D, 4D, 5D, 6D, and even 7D. The 2D model is the simplest kind of construction model, made up of a plain X- and Y-axis. The 3D model adds the Z dimension that describes the geometry, location and orientation of elements and components needed for conceptual designs, design development stage, construction documentations and details. The 4D displays time dimension required for scheduling resources, quantities, and project phasing, while the 5D includes cost estimate and time associations which supports predicting or forecasting the flow of cash and funds and the final cost of a project.

As far as the retrofitting process is concerned, and with the objective of coordinating all existing information, another five dimensions are usually adopted, coinciding in name with those referred to for BIM models, 3D–7D, but with somewhat different concepts. Thus, the 3D HBIM model, in addition to being related to the three-dimensional model, considers the data collection performed on the building. 4D is related to historical evolution. 5D cannot be directly related to the actual construction costs as in BIM, since, obviously, the building is already constructed; 6D includes the cultural context, and, finally, 7D addresses preventive programs and conservation of the building [5].

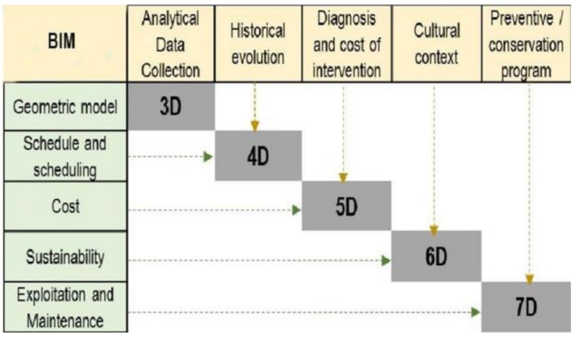

Fig.1. Application of BIM dimensions according to retrofitting and reconstruction requirements

Building information modeling (BIM) creates a virtual building to physically construct it. The integration allows designers and builders to collaborate on a single aim, allowing design and construction operations to develop in the most efficient way possible. BIM is more than simply a piece of software; it is a mix of software and methodology. Destroyed structures require reinforcing their efficiency and functionalities, and necessitating adaptive reuse when it comes to their primal designs. The ideal reuse option to choose is not straightforward, and it necessitates a variety of considerations owing to the many parties and criteria involved. Determining the best appropriate selection strategy in the adaptive reuse project is critical. The goal of the BIM is to leverage the BIM model to facilitate visualization so that users may see multiple project design options. The constructability and coordination, 4D scheduling, and 5D cost planning will all be affected by the evaluation and selection of a suitable alternative design through the 3D-BIM model, which helps to develop the maximum number of alternatives to deliver the functions cost effectively through the following:

1. Create a list of innovative ideas for alternative methods to conduct each specified function.

2. Provide optimal solutions among the available solutions to the project's essential functions at a lower cost.

3. Create a variety of viable options for performing the function to increase the project's value.

Many construction planning functions and stages of the construction planning process are considered to be more effective using 4D BIM than current construction planning practices. 4D BIM is deemed to be more effective than traditional construction planning for gathering information, planning construction sequence and planning logical dependencies [6].

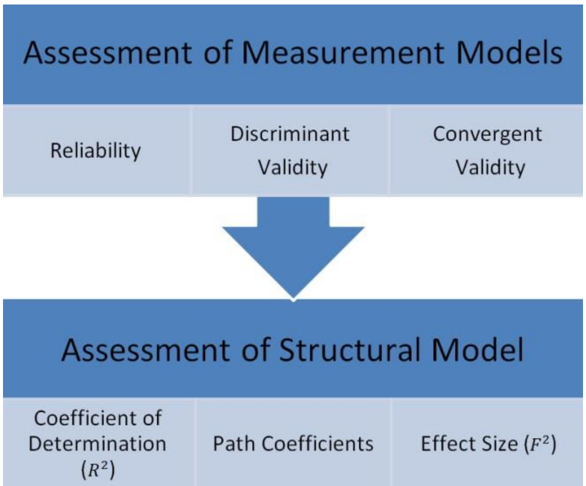

Fig.2. Testing and data analysis for SEM

Data analysis consists of identifying and evaluating the indicators utilized in the creation of the sustainable BIM model. The various metrics that reflect BIM and sustainability factors were analyzed using current literature. The analysis may be conducted using Structural Equation Modeling (SEM). SEM is divided into two kinds, namely covariance-based SEM (CB-SEM) and partial least square SEM (SEM PLS). Covariance-based SEM generally tests causality or theory while SEM PLS is more directed towards predictive models. However, there is a difference between covariance-based SEM and component-based SEM PLS. Namely, they differ in their respective utilizations of structural equation models to test theories or theory developments that aim to make predictions [9]. In this study, the SEM approach used was SEM PLS, considering that this research is more predictive and helpful for building a new theory, rather than for testing an existing theory. There are several software programs that can be used in analyzing SEM, but in this study, we used the SMARTPLS 4 application. Before processing could be done using the SEM method, first, the data obtained from the respondent survey needed to be tested. Data testing consisted of two stages, namely testing for the measurement model and for the structural model as we can see from Figure 2.

Measurement models were evaluated using algorithms in statistical applications to determine reliability and construct validity as well as discriminant validity and loading of all construct indicators. A model was considered reliable when the composite reliability and Cronbach's alpha of each construct was equal to or greater than 0.70. The next step was structural model testing, which was developed after the measurement model had been validated. The structural model was assessed using algorithms in the SEM data processing application. The basic concepts for assessing the structural model included:

• Coefficient of determination (R^2). The coefficient of determination (R^2) describes the degree of explained variance of the dependent latent variable. It is used to determine the explanatory power of the structural model [8]. R2 must be met, where values between 0.02 and 0.12 are considered weak, values between 0.13 and 0.25 are considered moderate, and values of 0.26 and greater are considered substantial;

• Path coefficient. The second criterion for SEM evaluation involves assessing the path coefficient; it measures the strength of the relationship between the latent variables of the research model, where the significant value should be at least 0.05;

• Effect size (F^2).The F^2 effect size is a measure of the impact of a particular predictor construct on an endogenous construct. In addition to assessing the size of the R^2 values of all endogenous constructs, the $F^2$2 effect size can also be calculated for each construct. An F^2 effect size of 0.02 is considered small; 0.15, moderate; and 0.35, strong [8].

After all stages of testing, with both measurement model and structural model testing having been completed, the data that were collected and validated were processed into SEM form with the help of SEM data processing software.

Another strategy used to analyze refurbishment options is the environmental assessment tools. These tools provide frameworks to check and enhance the energy performance of existing buildings. Performance assessment tools have gained popularity with the development of rating systems which benchmark energy performance of existing buildings against quantitative and qualitative performance indicators. Other literature work describes the prerequisites, credits, and measurement methods required to achieve a certification for a refurbished building; while others quantified the financial benefits of improving the environmental performance of existing buildings. In addition to the strategies provided by advanced energy auditing technologies and environmental assessment frameworks for refurbishment of existing buildings, computer simulation software can be used to model and simulate the energy performance of retrofit measures. Today, the three-dimensional modeling of cities is becoming increasingly feasible and popular. Thus, through building information modeling (BIM), the aim is to generate more controllable, collaborative, fluid, and realistic systems with the purpose of creating a graphic platform to provide data on the landscape, the city, public services, buildings, etc. Likewise, in line with the smart cities philosophy, this platform can constitute the technical support for future urban operations centers and the creation of digital twins, facilitating the management of information in a single system.

Despite the functions and benefits of the adoption of BIM technology, its implementation has been limited thus far due to several barriers. A study discovered that BIM awareness, knowledge, and interest vary across construction industry disciplines, but perceptions of the main factors affecting its implementation are consistent among engineers, architects, project managers, and other key stakeholders. As a result there are socio-organizational barriers such as resistance to change; financial barriers which include cost of BIM training, software, and hardware; technical barriers; contractual barriers (lack of BIM-related aspects in current contracts); and legal barriers (ownership of BIM models, intellectual property, and copyright issues) as the five main classifications of barriers to BIM adoption [7].

The challenge of integrating BIM into sustainable construction lies in considering the proper strategic directions to promote the application of BIM in sustainable developments. BIM is well-suited for sustainable building projects and applications requiring data on sustainability and energy efficiency [9]; however, it can be utilized in a range of industries. It is essential to conduct additional studies to attain a deeper understanding of BIM adoption strategies for sustainable construction projects.

Furthermore, for the part of the challenges faced by companies to implement BIM, it was found that among the challenges at the initial exposure, stage involving no party introducing BIM and also no BIM exposure at the university level. According to Kleiner & Schaefer (2022), the interdependence between universities and industry is increasing as it relies on the intellectuals of students from the university. In addition, most of the participants agreed that they have challenges in the financial aspect which involves the cost expensive of BIM and also financial constraints in the company (Shin et al., 2018). According to Noor Akmal Adillah Ismail et al (2021), the use of BIM will cause a company organization to make a large investment financially because only large organizations can afford the high cost of technology [10]. Next, study participants also provided information on other challenges they faced namely time, not yet getting a BIM project, and clients. Finally, the participants provided insights on the initiatives that have been taken by the company to overcome the challenges, namely attending continuous seminars and also slowly accepting new cultural changes.

4. Conclusions

As construction projects are becoming more demanding and sophisticated, BIM applications have risen to automate, and modernize the industry's traditional work procedures. It has acquired considerable prominence in recent years to present digital representation of the physical and functional characteristics of a building over its life cycle. When compared to the conventional way, BIM projects can save project time by 7 %, save 10 % on contract value owing to early clash detection, and generate cost estimates up to 80 % faster [3]. This increases productivity, efficiency, quality, and sustainability while also minimizing errors and improving interdisciplinary project team coordination. The use of BIM applications can easily transfer distinct data into a real-time information platform and decision-support system. Thus, it can synchronize data about building materials and their environmental impact, enabling environmental analyses and fostering a perspective of selecting building materials and products.

Achieving low energy consumption through retrofits of existing buildings is a feasible objective. Lately, the Architecture, Engineering and Construction (AEC) industry has witnessed an increasing interest in using the concept of building information modeling in conjunction with sustainability principles during the design and construction of green building projects. BIM tools could help designers explore different design alternatives at the early stage and to transfer the design information to energy and simulation tools for validation and analysis efficiently and fast. On the other hand, by using BIM tools, owners can better visualize the development of their building projects all over the different stages of their construction. The building team uses BIM models to coordinate activities, takeoff material quantities and detect possible clashes between equipment [3].

A successful retrofitting project`s outcome includes improvement in a vast number of aspects. The obtained developments cover

- Lower operating costs.
- Diminishing the building’s energy expenses
- Increasing the lifespan of the building.
- Preserving the investment value of the project.
- Updating the building drawings which can be used for maintenance later.
- Improving the quality of the building’s internal environment.
- Reducing the amount of carbon emissions emerging from demolition and manufacturing operations.
- Saving resources.
- Achieving thermal and visual comfort for residents of the building.
- Advancing the health of the residents.
- Creating opportunities for simple social relations and activities by exploiting the roof of the building or any unexploited spaces [2].

The expected outputs listed above may be achieved by means of Building information modeling (BIM). BIM is a mix of software and methodology. It creates a virtual building to construct it physically. The integration allows designers and builders to collaborate on a single aim in the most efficient way possible. The core of BIM is the concept of sharing and exchanging information among project's stakeholders throughout the entire building’s life cycle. It provides platform-neutral file format which can be read and edited by any BIM software for better coordination and interoperability, hence, remaining linked to a generalized central approach that houses all building-associated data. It also supports the decision-making process using its multifaceted data processing and problem-solving techniques through modeling, simulation, visualization and optimization of alternatives [2]. This determines the precision and validity of the environmental analysis which is required for performing uncertainty and sensitivity analysis.

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