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Orginal Article

Application of a BIM model for demolition work planning

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Abstract: The article explores the use of BIM tools in the planning of demolition works for a structure. The analysis includes the utilization of BIM to create a three-dimensional model of the object, with a level of detail that allows for accurate cost estimation of the demolition. Additionally, it enables the precise determination of the demolition sequence, identification of potential issues, and optimization of the process. BIM tools also facilitate the analysis of the environmental impact of demolition and the safety of workers. Furthermore, through virtual simulation, demolition planning can take into account ecological and social effects. The authors highlight that the application of a BIM model simplifies risk analysis and allows for the creation of scenarios for the duration of demolition work, enabling the selection of the fastest solution while simultaneously reducing costs and optimizing resources. Conclusions drawn from the case study demonstrate how advanced BIM tools can revolutionize the planning of demolition processes, introducing a new level of precision and a sustainable approach to such projects.

Keywords: demolition, BIM, CDE, advantages and disadvantages, optimization, waste management, sustainable construction

1. Introduction

Currently, there is a noticeable increase in the difficulty of finding suitable plots in convenient locations for planned investments. As a result, buildings that are still in good condition but no longer meet the modern needs of investors are often being demolished. In such cases, property owners must decide between undertaking extensive renovations, which would require many compromises, or demolishing the existing building and constructing a completely new one that meets their expectations. Increasingly, the latter option – demolition – is being chosen. Therefore, demolitions will often involve buildings that are still in satisfactory technical condition but are situated in prime locations, in dense urban areas, among other existing buildings. Such planned investments, preceded by the necessity of demolishing an existing structure, will significantly increase the implementation challenges.

According to the provisions of the Polish Construction Law (CL) [1], demolition is classified as one of the basic construction works and involves dismantling and removing an existing building or part of it from a specified space. Conducting demolition is a time-consuming process with a high degree of complexity, often consisting of multiple stages [2]. Demolition works are demanding in terms of technological, technical, and logistical aspects, and, most importantly, in ensuring safety both on the construction site and in its immediate surroundings. Their execution requires contractors to have extensive knowledge and experience, supported by construction qualifications in the relevant specialty. Due to the specific nature of the work, particularly those that pose a risk of accidents, great attention is required from all individuals involved in the project, especially those in supervisory roles, workers on the construction site, and those responsible for planning the course of the work [3].

Demolition planning can be enhanced through the use of Building Information Management (BIM). By creating a BIM model of the building to be demolished, it becomes possible to simulate various demolition scenarios. Additionally, waste management strategies can be selected with consideration for sustainable construction principles, allowing for the estimation of costs and potential profits from selling certain waste materials, planning schedules, developing scenarios for potential accident situations, and proposing solutions to maximize safety during the work. The authors of the article highlight that the application of BIM is not limited to design and construction processes but can also be valuable during later stages of the building lifecycle, including activities related to dismantling and demolition.

2. Causes of demolitions and necessary actions for their execution

2.1. Most common reasons for demolitions

The durability of a building depends on many factors. Proper maintenance and the implementation of an appropriate renovation policy are crucial to maximizing its lifespan. However, there may come a time when the durability of any building is exhausted, affecting both its technical and functional aspects. Often, it becomes apparent that repairing or modernizing a building is either not feasible or financially impractical, leading to the decision to demolish the structure [4].

Due to the increasing difficulty of finding undeveloped land in desirable locations, there is a growing trend of demolishing buildings that are still in good technical condition. This is often seen in the context of infrastructure development projects, which may involve displacing residents from an area, compensating property owners, and constructing public amenities. The demolition of a building in satisfactory technical condition may also occur when the building is situated in an attractive area, particularly those favored by developers. In large cities, especially in their centers, land prices per square meter are exceptionally high. As a result, decisions are sometimes made to demolish smaller buildings or industrial/post-industrial structures on valuable plots and replace them with more profitable real estate [5].

The decision to demolish a building may also be made when the structure is in a technical condition that poses a direct threat to the safety of its potential users or the surrounding area. Such situations typically arise due to serious design or construction errors, or prolonged neglect in maintenance.

Partial or complete demolition of a building may also be necessitated by exceptional events, such as a fire. In some cases, the decision to demolish specific structural elements may even be made during firefighting and rescue operations.

2.2. Steps for executing a demolition

According to the Building Law (BL), demolition is defined as a specific type of construction work. This term primarily refers to activities aimed at dismantling and removing an existing building or parts of it from a defined space. In the BL, demolition is classified as one of the basic types of construction work (Article 3, point 7 in [1]). Such a definition of demolition carries certain implications, particularly concerning the administrative procedures that must be completed before work can begin. Article 31 of the law [1] outlines which structures require a demolition permit, which ones require notification, and which ones do not require any of these documents (Tab. 1).

Table 1. Guidelines for demolition procedures based on the type of structure (based on the [1])

Does not require procedures	• If the construction of a given facility did not require a building permit, the law permits its demolition without obtaining permission from the authorities, as long as the structure is not subject to conservation protection.
Notification	• To initiate demolition, a notification is sufficient when the building or structure is less than 8 meters in height, the distance from the property boundary is at least half its height, and it is not listed in the register of monuments or subject to conservation protection. If the relevant authority does not object, work can commence 21 days after the documents are submitted to the office. The notification is valid for 3 years. In specific cases outlined in the law (e.g., those concerning the protection of the aquatic environment), the decision-making authority (district governor) may require the investor to obtain a demolition permit.
Building permit	• In all other cases, a demolition permit is required.
No possibility of demolition	• A building listed in the heritage register: Permission can only be obtained after it has been removed from the register.

In most cases, demolition can proceed after obtaining a demolition permit, which requires submitting documents similar to those required for a building permit.

2.3. Demolition project

Planning demolition should prioritize safety considerations. To properly plan demolition procedures, it is essential to consider the specific characteristics of the project. Over the life cycle of a building, changes may occur due to usage patterns, modifications by occupants, and the natural aging of the structure. The demolition plan should include detailed information about the building, its location, and its surroundings. Additionally, it should describe the condition of the structure, noting any damage or defects, as well as provide details about existing installations and equipment. A key element of the demolition plan is a comprehensive description of the planned work. In the initial stages of the project, the scope of work and the requirements for site preparation before demolition begins should be established. The plan should also outline the sequence of work and ensure the appropriate selection of equipment and technologies for each stage of the demolition process [2,6].

3. BIM in the building lifecycle

Building Information Management (BIM) serves as the cornerstone of digital transformation in the architectural, engineering, and construction industries. Information obtained through BIM technology enables the management of a building throughout its entire lifecycle – from planning and design to construction, operation, and even demolition. BIM technology integrates data from multiple disciplines to create a fully accessible three-dimensional digital representation of the building for all stakeholders involved in the construction process. This model, often referred to as the "digital twin," provides a digital description of the building's physical and functional properties [7]. Components are parametrically modeled, ensuring that any changes made are automatically updated in real time, not only in the model but also in drawings and reports. Designing with BIM technology goes beyond just creating a three-dimensional model; currently, there are ten dimensions of BIM, each addressing different types of information that can be obtained and managed [8,9].

Despite its many advantages, some companies still prefer the "traditional" approach to the construction process, avoiding the use of 3D software. This hesitation is often related to changes in workflow, business operations, and the reluctance of individuals to adopt additional, complex design and management tools. Familiarizing oneself with the concept of BIM technology and its associated software can be time-consuming, which may negatively impact productivity, especially during the initial implementation phase. Additionally, one of the main deterrents to adopting BIM at every stage of the building lifecycle is the often significant investment required for purchasing modern computer equipment, software licenses, and employee training.

The demolition phase is the final stage of the building lifecycle, where it is crucial to adhere to the principles of sustainable construction, particularly focusing on the environmental aspect. This aspect is largely concerned with the energy efficiency of the machinery used in demolitions, as well as the disposal and recycling of the substantial amount of waste generated during this phase [10].

In traditional construction project design, a vast amount of analytical, descriptive, and drawing documentation is produced. This often leads to challenges in standardizing the project in line with the architect's vision, as well as conflicts or inconsistencies in the drawings, which can ultimately result in disputes and errors. Additionally, the absence of a three-dimensional model of the proposed building can hinder the effective realization of the project due to difficulties in visualizing spatially complex solutions. Conversely, a three-dimensional representation of a specific structural solution helps to eliminate disputes between designers from different disciplines and those involved in the construction process. The use of spatial models ensures better and more straightforward communication.

The adoption of BIM tools in construction is gradually becoming standard practice in the design and construction phases, as evidenced by the requirements often specified in tender documentation. Investors frequently require the use of BIM tools for the creation or management of documentation during construction projects [11,12]. However, BIM tools are less commonly used in demolition and dismantling work [13,14]. This is often due to a lack of awareness about the benefits that building a digital twin can offer, as well as a lack of skills in using specialized tools. The main benefits of using BIM in the demolition phase are outlined in Fig. 1.

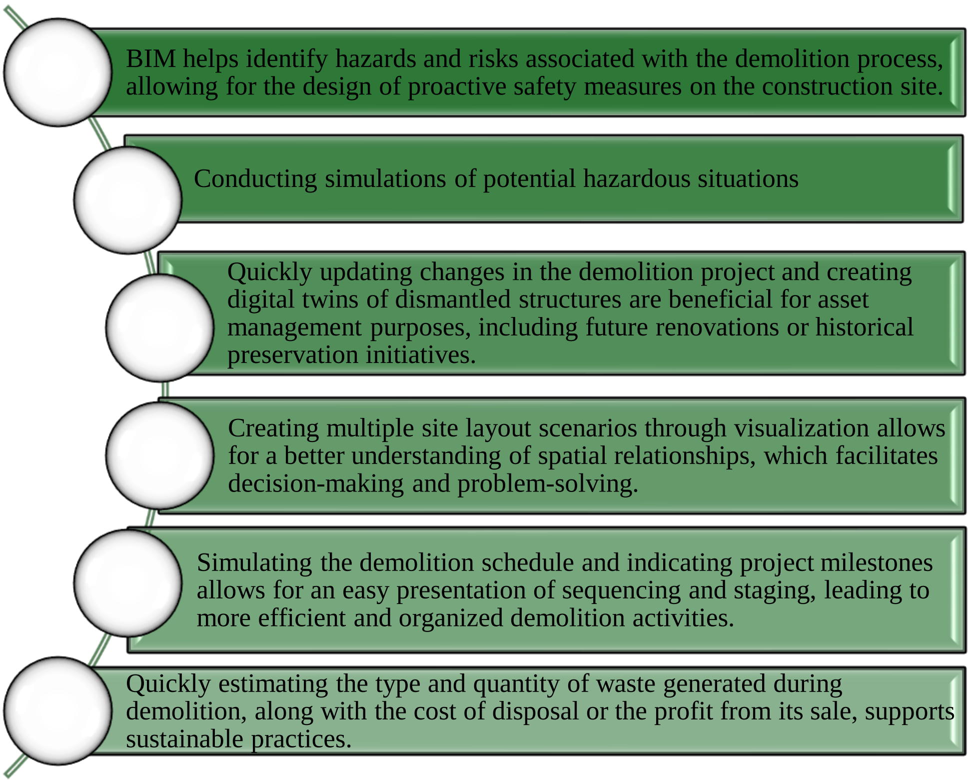

Fig. 1. Comparison of the main benefits of using BIM in the demolition phase, own elaboration

BIM technology can be applied not only to model the building undergoing demolition but also to plan the surrounding area with elements necessary for safely conducting work (Fig. 3). An additional advantage is the ability to present visualizations close to reality using programs such as Enscape (Fig. 2).

Fig. 2. Visualization of scaffolding for dismantling the front facade of the Tawo building, own elaboration

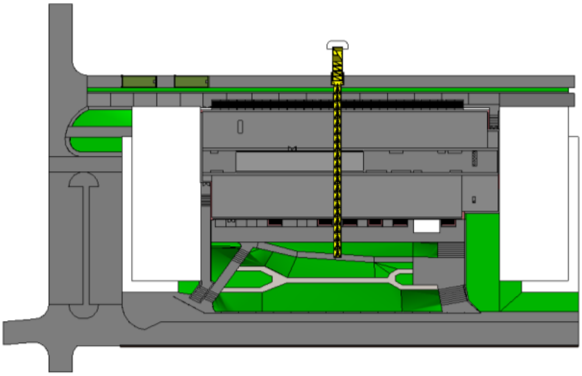

Fig. 3. Site plan around the Tawo building undergoing demolition - shaded version, own elaboration

4. Example of utilizing BIM potential in demolition planning.

4.1. Analysed object

The object for which the decision to demolish was made is the former AGH Tawo academic canteen building. This building has two above-ground floors and one partially submerged below ground level. Originally built in 1984, the building stood independently until 2018 when the construction of the eastern wing began directly adjacent to it. Three years later, a twin structure started to emerge on the western side of the canteen building. Both new wings are independently detached structures (Fig. 4).

The main load-bearing structure of the building consists of a transverse arrangement of steel frames spaced approximately 510 cm apart. The frame columns at the front elevation (at axis A) of the building are made of I-section beams 300 x 300, while columns in the other axes are made of C240 channels connected by plates (Fig. 5). The building features two types of floor slabs. The first type consists of 24 cm thick channel concrete slabs (20 cm slab and 4 cm topping), supported on lower shelves fixed to the joists by shaped steel supporting elements attached to the main load-bearing structure. Channel slabs are present in the main part of the building. The second type of slab is the Ackermann slab, 24 cm thick (20 cm block and 4 cm topping), found in the eastern and western parts of the building. A ventilated space was created between the slab above the 1st floor and the roof, which is made of prefabricated trough panels. The staircases are constructed from reinforced concrete slabs. For a more detailed description of the solutions used in the building, refer to the archival documentation of the AGH [15].

Fig. 4. The front elevation of the Tawo building, sourced from the authors' archives, 18 April 2023

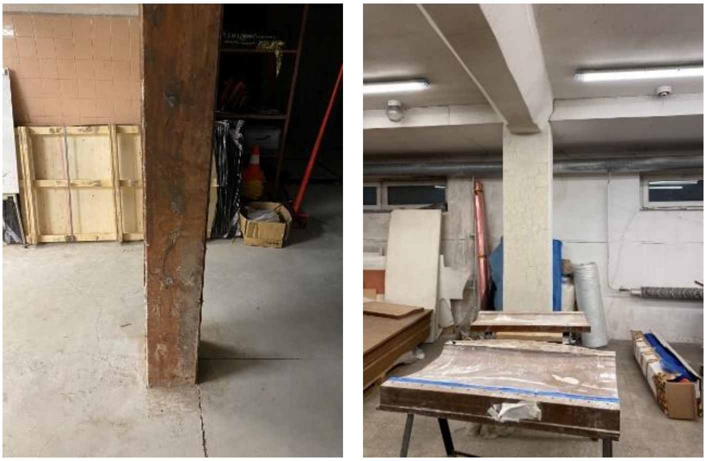

Fig. 5. Structural column in the basement – condition without and with casing, sourced from the authors' archives, 18 April 2023

4.2. The assessment of the technical condition and the decision to demolish

In order to assess the current technical condition, the authors conducted a site visit on 18 April 2023 and referred to the technical assessment records conducted a few years earlier by the Technical Sector (ST) of the university. The building is currently almost entirely out of use. Previously, it served a gastronomic function, but now the western part of the building is used as the headquarters of the University Student Government Council (URSS). The assessment of the building was based on the technical condition assessment scale according to Zabielski [16].

Fig. 6. Damaged elements of the southern façade, authors' archives, 18 April 2023

Fig. 7. Southern and western façades - 2009. Source: archival documentation of AGH

The assessment of the technical condition began with determining the state of deterioration of the façade. In the building, only the condition of the northern and southern façades could be assessed. Due to the directly adjacent new building D-2 and the building D-3 under construction, it was not possible to assess the condition of the eastern and western façades. The assessment could only be conducted based on archival photos from several years ago and documents from previous inspections.

From the front (north façade), partially discoloured areas due to weathering and dirty surfaces of the panels were observed. Minor damages were visible on the windows, and one of the windows was broken. On the southern façade, significant corrosion of the steel elements of the light fixtures was observed (Fig. 6), caused by long-term use and lack of maintenance. Numerous cracks exceeding allowable values were also observed, running across the entire width of the windows to the pillars.

Analysis of archival photos of the eastern and western façades also showed damage and efflorescence on the brick elements (Fig. 7). Ultimately, the condition of the façades was assessed by the authors and presented in Table 2, where the cumulative wear of each façade was compiled, the average percentage wear was calculated, and the technical condition was determined.

Table 2. Classification of the technical condition of the façade of the analysed building, own elaboration

Facade	Percentage of wear and tear	Technical state classification	Average percentage of wear and tear	General technical condition classification
North	25%	Good	30%	Satisfactory
South	40%	Satisfactory		
East	20%	Good		
West	35%	Satisfactory		

In the interior of the building, the on-site inspection revealed numerous damages to finishing elements. Cracks and dampness were observed on the suspended cassette ceiling, as well as cracks and detachment of plaster, scratches, and dampness on the walls (Figs. 8 and 9). Additionally, many structural elements do not meet current requirements outlined in the WT [17], as evidenced by the narrow staircase, which does not comply with fire safety regulations (Fig. 10). Furthermore, to assess the technical condition of the building's roof, which was inaccessible during the inventory, a drone survey was conducted. The information obtained from the photographs and recorded footage helped to supplement the knowledge about the technical condition of the building (Fig. 12).

Fig. 8. Damaged cassette panels, authors' archive, 18 April 2023

Fig. 9. Detached plaster on the wall connecting wing D-3, authors' archive, 18 April 2023

Fig. 10. Staircase run with a width of 95 cm, authors' archive, 18 April 2023

Ultimately, it was determined that the building is on the borderline between satisfactory and poor condition, with damage assessed at 40%. Considering the 30% wear and tear on the façade, the overall assessment of the building is 35%, placing it in the satisfactory category. Given the building's low technical condition, it can be inferred that restoring it to its original state would require significant financial investment. Additionally, adapting it for new functions would necessitate extensive modifications while accommodating various constraints stemming from its existing structure. The low technical rating, coupled with the need for costly adaptations, ultimately led to the decision to demolish the building and replace it with a modern academic facility.

4.3. Preparing a BIM model for demolition purposes

Preparing a BIM model for demolition purposes involves several steps aimed at accurately representing the structure and facilitating the demolition process.

In the first scenario, if an existing BIM model of the building is available, it should be reviewed and updated to reflect any changes or deterioration that may have occurred since its creation. This may involve incorporating new survey data or additional information gathered during site inspections. Next, specific elements of the building that are targeted for demolition should be identified within the BIM model. This includes walls, floors, columns, and other structural components, as well as non-structural elements such as fixtures, fittings, and finishes.

In the second scenario, if the building does not already have a previously created BIM model – as was the case with the Tawo building – the demolition plan using BIM should begin with the creation of a three-dimensional model of the object based on technical documentation in the software; in this case, Autodesk Revit was used. When modeling a building prepared for demolition, it is not necessary to model it to the same level of detail as required for a newly constructed object, significantly reducing the time required for its creation. The created model will help approximate the sequence of demolition works, taking into account the planning of machinery on the construction site and designating areas for the removal of demolition waste. The use of BIM technology positively impacts the logistical aspect of construction, reducing problems associated with managing work on the construction site. Fig. 11 illustrates the model of the Tawo building.

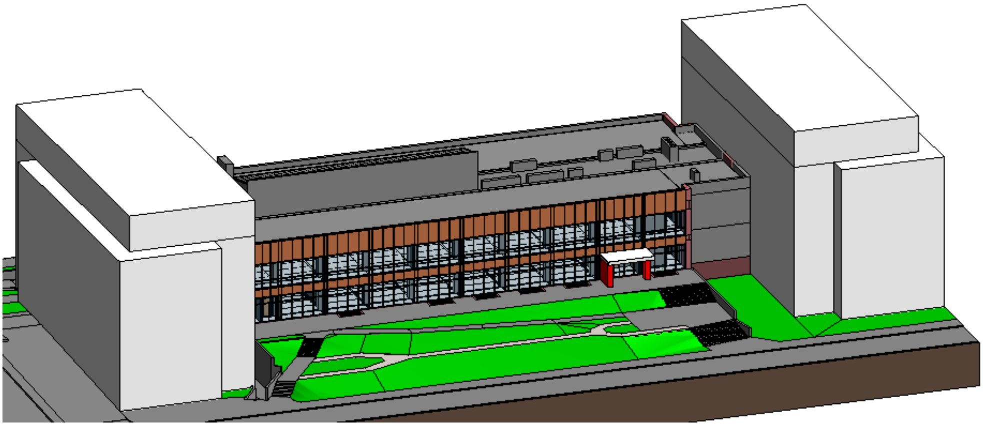

Fig. 11. A 3D model of the building created in Revit software, own elaboration

4.4. Using a CDE platform during demolition planning

Building Information Models created using BIM technology are complex, multidimensional models typically developed by multidisciplinary teams. Fully leveraging the potential of the digital twin is possible through enabling real-time exchange of project information among stakeholders and the necessity of drawing information from a single, up-to-date database. Common Data Environment (CDE) platforms, when integrated with BIM models, significantly facilitate construction processes [18–20]. The CDE platform, as a cloud-based IT solution, is based on containers of information and their associated metadata. The organised data storage structure of the model enables streamlined, efficient access to specific information for all project participants, which is a key element of effective project organisation.

The built Tawo building model was uploaded to the Dalux CDE platform [21]. Using the application, reports can be easily prepared for coordination purposes, such as scheduling work and cost estimation during planned demolition. With the ability to access the platform on both desktop and mobile devices, such as tablets or smartphones, data collection regarding the technical assessment of the object (Fig. 14) can be effortlessly conducted, as well as subsequent coordination of demolition work.

Fig. 12. Drone aerial survey – northern side, Source: private archive of the AGH Technical Department inspector, 26 August 2023

Fig. 13. Designed waste storage area, own elaboration

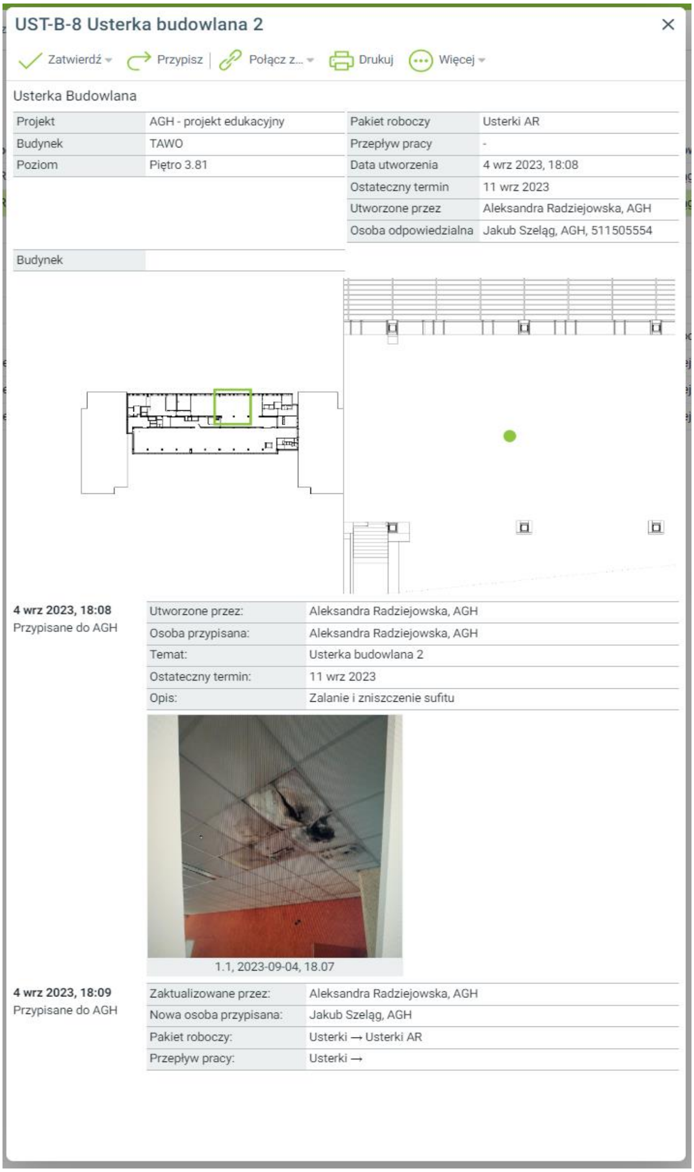

Fig. 14. Sample report of visible defect in the Tawo building, own elaboration

4.5. Schedule and costs during demolition planning

BIM tools allow for integrating project data contained in the model with project execution schedules. Reflecting real parameters of the object in the form of a model with information regarding the timing of individual construction processes is referred to as the fourth dimension of BIM (4D). Creating a schedule using BIM also enables project participants to visualise the sequence of construction processes and project progress over time (Fig. 14). Connecting the BIM model with the schedule allows for creating simulations of construction execution, which can be helpful in conducting preliminary analyses of potential issues and clashes. Additionally, by utilising BIM tools, several scenarios of demolition work execution can be considered quickly and presented through various simulations. Presenting the execution of the construction process in the form of a simulation with a project timeline positively impacts communication and interdisciplinary cooperation among project participants. The three-dimensional presentation of work execution supports making optimal decisions and reduces the number of possible errors during construction site work. Furthermore, introducing material prices into the programme (assigning them to individual components) allows for quickly estimating the costs to be incurred at various stages of demolition.

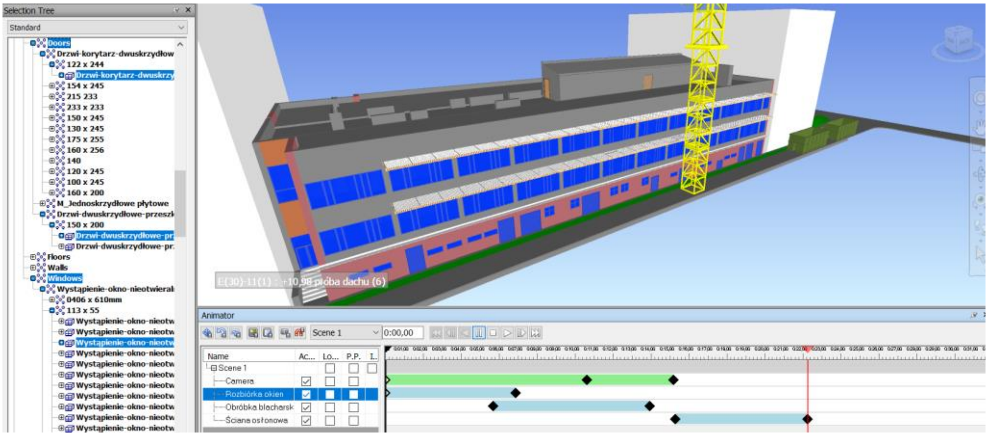

Fig. 15. Panel for creating animations in the Revit programme, own elaboration

4.6. Waste management on the demolition site

Efficient management of demolition waste involves developing a waste management plan that includes steps such as:

- Analysis of construction processes to determine waste generation,
- Classification of demolition materials according to the waste catalogue,
- Presentation of waste segregation and local storage methods.

With the built BIM model, these steps can be executed quickly and efficiently. For example, it allows for easy filtering of materials based on various characteristics, such as recyclable building materials, enabling the extraction of quantities of specific types of waste and quick estimation of the costs of disposal or profit from their sale. With the model of the building and the surrounding terrain, efficient site management can be achieved, including determining the optimal location for waste containers. In the case of the demolished AGH canteen building, it was decided to store construction waste behind the building (on the southern elevation side – Fig. 13). Designating a landfill in such a location will allow delivery vehicles direct access from the main gate to the rear of the building.

5. Discussion

The planning of any project relies on a thorough analysis of technical drawings and material lists. Searching for information regarding construction solutions on paper-based drawings is time-consuming and challenging. The lack of standardisation in defining information on drawings can lead to execution errors and misunderstandings among participants, resulting in delays or even work stoppages. Monitoring progress and cost analysis is done manually, which takes more time and causes less precise management of the building lifecycle.

In the context of construction project planning, BIM technology allows for better coordination and communication during its implementation [8]. By creating a three-dimensional model, detailed information about materials, the geometry of individual elements, as well as information about installations and structural solutions is obtained. All documentation is stored in one place, and each participant in the project has access to it. Any changes made to the model are automatically updated in the documentation and are visible to every participant. This form of information transfer positively affects communication and increases work efficiency.

BIM modelling enables the efficient conduct of various analyses, such as the flow of workers at the construction site during work, allowing for resource optimisation. BIM technology allows for cost forecasting, the development of various schedule versions, waste management planning, as well as conducting analysis for creating the occupational health and safety plan, which will increase safety levels and simultaneously reduce risk. Managing construction through a CDE platform allows for the smooth flow of information between project participants, standardisation of generated reports, which are created very simply using the application version of the software, and maintaining one common place with up-to-date documentation [20].

The application of a BIM model in the demolition phase of a building brings numerous benefits [13]. Through the model, it is possible to simulate the subsequent stages of planned work and find the scenario that is optimal for carrying out the work safely, which is particularly important for the most dangerous demolition tasks. Based on the constructed model, a work schedule can be quickly and accurately created, and the demolition costs can be estimated in multiple variants. The large amount of waste generated during demolitions can be very accurately estimated at the planning stage using the BIM model, allowing for the budget needed for disposal to be planned and potential profits from the sale of recyclable building materials to be estimated. Another advantage of the created BIM model is the ability to quickly design the site layout, with the possibility of creating various options. Fast data updates and exchanges among participants are possible thanks to the common CDE environment. The platform allows access for all participants, enabling them to communicate quickly and work on a single database, minimising the risk of incorrect or outdated information. In summary, the application of a BIM model in the demolition phase of a building brings numerous benefits, including better planning and coordination, time and cost savings, improved safety, and efficient waste management.

6. Conclusions

Conducting demolition works requires careful attention during their execution. In the traditional approach to demolition, especially at the beginning of the works or during the preparatory stage, many significant factors that may arise in subsequent stages of work can be overlooked. The lack of visual representation of the site and the building significantly limits preparation for demolition work, particularly in terms of safety. Utilising Building Information Modelling (BIM) technology for demolition works yields several benefits in executing the tasks. Creating a model and reflecting the terrain around the project area allows for understanding the object and its location before commencing work. The use of BIM technology significantly outweighs the traditional approach, especially in scheduling, waste management, project management, and ongoing information updates.

The presented example of modelling a Tawo building that will be demolished in the near future allowed the investor to gather data on its geometry and materials in one cohesive dataset. The constructed model enables the creation of demolition scenarios that consider factors crucial for decision-makers, such as optimising the time and cost of demolition works, minimising the risk of potentially hazardous situations, and efficiently planning the management of waste generated from dismantling individual components, with particular emphasis on the environmental aspects of sustainable construction.

Despite many benefits, the use of BIM technology in demolitions is not common, partly due to the need to create a building model that will soon cease to exist. This situation arises when the owner does not already have a model of the existing building and needs to create one solely for the purpose of planned demolition. However, it is worth noting that a 3D model for demolitions may be less accurate and contain many simplifications compared to a model of a new building. Another aspect of the reluctance to use BIM in demolitions is the cost of the software itself and the cost of training employees. Employee resistance to changing work methods also contributes to the reluctance to utilise BIM technology in demolitions.

However, observing trends in the construction market, it is only a matter of time before BIM becomes a standard not only in the design and implementation phase of new buildings but also in other phases of their lifecycle. Moreover, an increasing number of buildings already have a built digital twin, which will allow for more efficient planning of demolition work in the future when the decision to demolish is made.

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