

APPLICATION OF ACOUSTIC ANALYSIS WITH BIM AND PREDICTION OF REVERBERATION TIME

Muammer YAMAN *

*PhD; Ondokuz Mayıs University, Faculty of Architecture, Department of Architecture, Samsun, Türkiye

ORCID 0000-0002-8767-4811

E-mail address: muammer.yaman@omu.edu.tr

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Abstract

Building Information Modeling (BIM) enables collaborative data transfer between architects and engineers throughout the entire building's life cycle. While BIM examines physical parameters and management processes, it presents challenges in architectural acoustic analysis. This study aims to evaluate acoustic effects and perform room acoustic analyses in BIM tools that enable significant productivity gains in the construction industry and digitally support the planning, construction, and operation of structures. The research focuses on the prediction of the reverberation time, which is a main acoustics parameter. The literature review was conducted with a comprehensive bibliometric analysis. Using Autodesk Ecotect, acoustic analyses were performed on an educational building as a case study. Reverberation times were calculated at mid-frequencies (500, 1000, 2000 Hz) in 1/3 octave bands. Suggestions to reduce high reverberation times due to reflective room conditions were developed and tested within the BIM tool. In conclusion, it was emphasized that design/renovation/improvement scenarios for acoustic analysis can be tested with BIM. It has been determined that the determination of the level of effect of other components with acoustic treatments made on BIM platforms can also provide added value to the projects designed according to outsourcing acoustic software.

Keywords: Architectural acoustics, Acoustical analysis, Autodesk Ecotect, Building Information Modeling, Reverberation time.

1. INTRODUCTION

Building Information Modeling (BIM) stands out as a product and process management for architects, engineers, and construction (AEC) professionals. This platform facilitates the integration of data analysis by adopting an information-centric networking approach. BIM provides a digital platform for storing and sharing data in a dynamic format that can be modified, updated, and queried throughout the building life cycle. The platform is designed to improve information sharing and increase collaboration among project stakeholders [1-2]. Architects, engineers, construction teams, and other related professionals use BIM to store and access all project data in one centralized model. This enables interdisciplinary solutions in various phases of the building life cycle such as

project design and coordination, construction management, maintenance and operation, sustainability analysis, and facilities management. However, BIM provides the appropriate tools for building performance analysis during the design phases. In building performance analysis, goes beyond aesthetics and engineering qualities and offers a feature where alternative solutions covering sustainability and post-occupancy characteristics (accessibility, acoustic comfort, lighting comfort, material conservation, thermal comfort, water conservation, computational fluid dynamics, etc.) can be controlled [3-4]. Although BIM tools have largely integrated various analysis methods in areas such as energy consumption and daylight, there is a need to add more inclusive tools in areas such as acoustic analysis.

The importance of acoustic performance in a building is one of the critical factors determining occupant comfort. The consequences of a poorly acoustically designed space can often lead to problems that are not easily resolved over the lifetime of the building. Therefore, conducting acoustic analyses in the early design stages is a crucial approach to find more effective solutions and minimize negative effects. As initial tools, it usually takes weeks for scale models to obtain acoustic simulation results [5]. Current computer software systems, on the other hand, require intensive acoustic model preparation and expertise to reduce simulation time to a few days while maintaining or increasing accuracy [6]. In recent years, architects, engineers, and acousticians have made efforts to integrate BIM-based tools into their projects. However, the resulting tools often take data from the BIM model and process it by manually modifying the model geometry for use in acoustic simulation software. This can increase the complexity and time-consuming nature of the process [7]. Currently, programs specifically designed for acoustic analysis are not fully interoperability with BIM software tools, and existing plug-ins are often not used extensively enough. This approach means that acousticians and designers need more powerful and specific tools that can be integrated with BIM [8]. There is a need to address the mismatch between BIM and acoustic analysis and to increase efforts to achieve more effective integration. Performing acoustic analyses in environments different from BIM-based tools limits their potential for design automation and integration and creates various challenges. Proposed solutions to these challenges include localization of acoustic simulations, integration and feedback cycles, level of development (LOD) controls, fast data transfer, bi-directional data transfer, and user training [6-9]. These solutions aim to reveal BIM potentials more effectively by increasing collaboration between architecture and acoustic engineering. It is expected that research will be conducted to increase acoustic comfort (improve positive effects) and minimize negative effects by making building design processes more efficient.

This paper aims to assess acoustic effects and perform room acoustic analyses within BIM tools, which are highly beneficial for improving efficiency in the construction industry. The research specifically focuses on the prediction of reverberation time, a key parameter in acoustics that measures how long sound persists in space after the sound source turns off. Reverberation time affects how sound is experienced in a room, influencing factors like speech clarity, music quality, and overall acoustical comfort. This

helps ensure that the buildings are not only structurally sound but also provide acoustically suitable environments for their intended use. The literature review for this study involved a comprehensive bibliometric analysis, which likely means that a wide range of academic sources were analyzed to identify key trends and insights in the field of acoustics and BIM. Acoustic analyses were conducted on an educational building as a case study using Autodesk Ecotect. In conclusion, it was highlighted that scenarios for design, renovation, or improvement related to acoustic analysis can be effectively tested within BIM tools. It is also emphasized that BIM-based acoustic analyses should be developed and supported with different acoustic parameters.

2. LITERATURE REVIEW

In this study, a comprehensive literature review was conducted for BIM and acoustic tools. Bibliometric analysis was conducted within the scope of the research. Bibliometric analysis is a scientific, computer-assisted review methodology that can identify key research or authors and their relationships by covering all publications related to a specific topic or field [10-11]. The purpose of this analysis is to identify studies on BIM and acoustics and to identify research trends. In the research, keywords were applied with restrictions based on language and research years' criteria. Within the scope of the research, the Web of Science, WOS Core Collection database was used to obtain an accurate and reliable bibliometric network. A total of 757 papers were found in the reviews ("BIM" and "Acoustics" or "Building Information Model*" and "Acoustics"). It was determined that the research was in the fields of Engineering Electrical Electronics, Acoustics, Computer Science Artificial Intelligence, and Computer Science Information Systems (Fig. 1).

It was determined that the most frequently used keywords in the research were Building Information Modeling (BIM), facility management, sound insulation, noise reduction, reverberation time, and interoperability. The fact that BIM-based facility management and Computer Aided Facility Management (CAFM) are mostly preferred, especially in recent years, reveals the importance of facility management and BIM integration. The star-shaped clusters in the keywords represent "acoustics" shown in purple clusters, "sound insulation", "reverberation time", and "dynamo" shown in orange clusters, and "facility management" shown in yellow clusters. The common point for the star-shaped cluster is shaped by the BIM



Figure 1.
WOS Categories distribution in bibliometric analysis

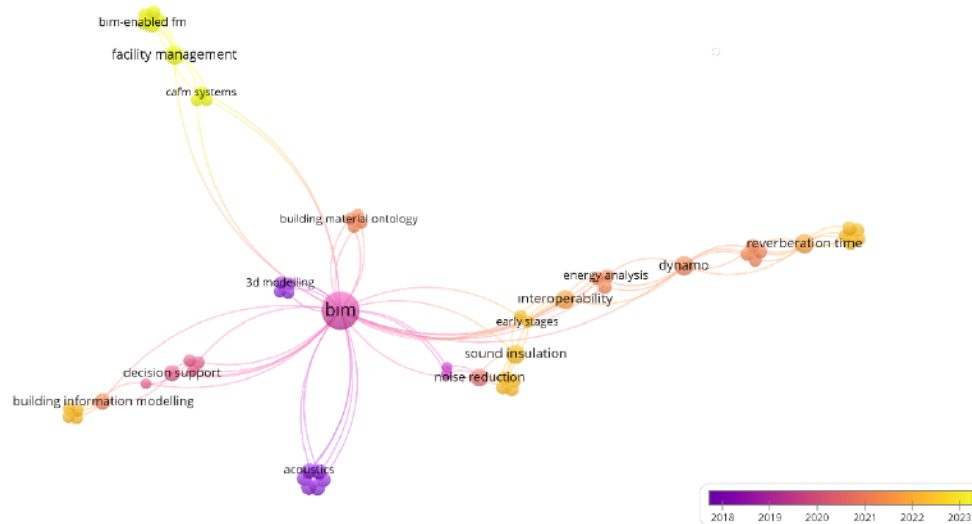


Figure 2.
Keywords and year distribution in BIM and acoustics

keyword (Fig. 2).

When the literature review on architecture and construction disciplines is examined, research on BIM-integrated acoustic analysis and prediction of various acoustic parameters remains limited. Although there are acoustic evaluations in universal green building certification systems in design processes, there are no models suitable for performing acoustic analyses integrated into design processes [12]. To guide tool selection, Azhar and Brown compared three simulation tools (Autodesk Ecotect, Green Building Studio-GBS, and Virtual Environment-IES) based on their ability to conduct acoustic analyses through interviews with BIM and LEED experts. Autodesk

Ecotect is superior to other programs in acoustic analysis [13]. In their research, de la Hoz-Torres et al. obtained high levels of satisfaction among participants and results showing the potential of the use of 3D models based on BIM methodology in building acoustics. The potential of BIM models to provide information for understanding the procedure followed during data collection in experimental analyses and to facilitate the understanding of system behavior has been emphasized [14]. Nik-Bakht et al. performed a model-based acoustic analysis of interior spaces in an educational building in Autodesk Revit, using the algorithm developed in Dynamo. In the research, they calculated the reverberation time of a

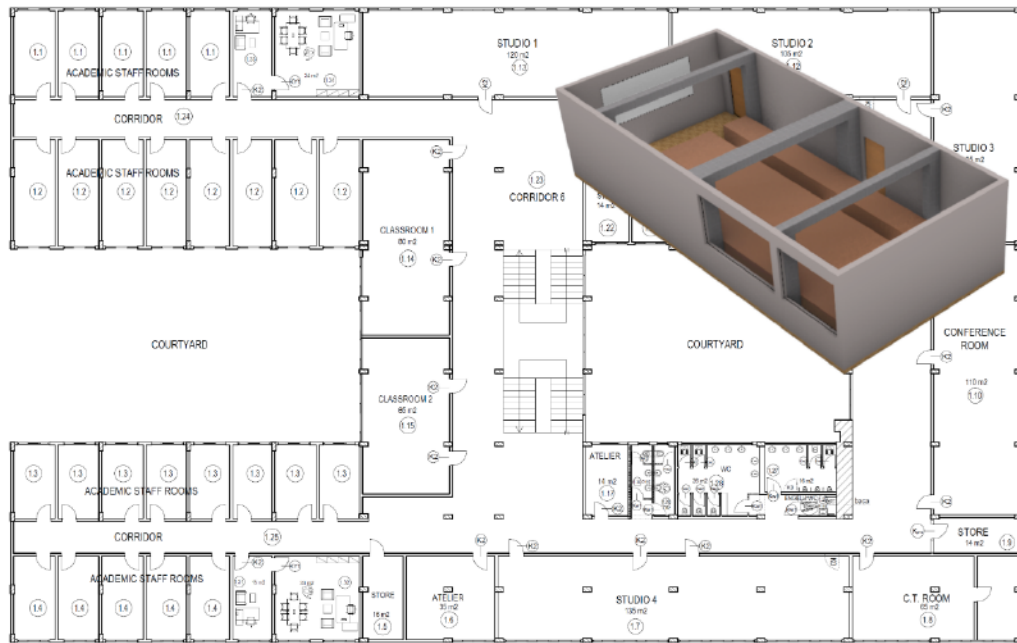


Figure 3.
Classroom on the first floor and 3D model

space by emphasizing the application advantages of BIM-based tools [9]. Sušnik et al. investigated two different methods to address the BIM model interoperability issue. While the first method focuses on the transfer from the BIM authoring tool to the analysis tool, the second method is based on the fact that the export can be avoided completely [15]. Using an external acoustic material database, a Revit 3D model, and the analysis process they developed, Erfani et al. calculated the reverberation time of the room without requiring an additional third-party software program. This both solves interoperability problems in the BIM model (by keeping the entire process in the same software platform) and re-storing simulation outputs about room elements enrich the BIM software model. As a result of the research, the researchers emphasize the need to test existing BIM-based scenarios in different tools/case studies, thus indicating that the research can be improved [16]. Butorina et al. carried out noise reduction operations in workplaces with the connections between BIM and external software. Implementation of noise control measures and efficiency evaluations have been made with the use of BIM [17]. Literature review shows that BIM-based acoustic analyses are limited and that there are new research needs, testing with different BIM tools, and knowledge gaps regarding the integration of acoustic analyses into performance-based design [18].

3. MATERIALS AND METHOD

In this study, acoustic analyses and predictions in BIM were comprehensively reviewed and analyzed through bibliometric analysis. In the research, the analysis of reverberation time, a basic of the acoustic performance components of the classroom of a current educational building, was investigated. In the investigations, the predicted reverberation time of the current situation was made through the BIM application (Autodesk Ecotect). The frequency spectrum on reverberation times obtained through the software has been determined to be suitable for the current situation. Autodesk Ecotect, one of the programs used for BIM applications, was used in this research.

3.1. Case study

The classroom of a current educational building was considered for building information modeling acoustic analysis. The classroom of the educational building under consideration creates a defective learning environment in terms of room acoustics with its high sound reflective properties. The classroom (Classroom 1) is designed with two doors on the first floor. The floor is finished with ceramic coating, and the walls and ceiling are constructed with paint and plaster. In the classroom, there are two student desk layout arrangements on the sides and one student desk layout arrangement with four students. The classroom has one lecturer's desk, one blackboard, and two large windows (Fig. 3).

The acoustic environment, which is a physical component of learning environments, has a great impact on students' motivation and learning process [19-20]. It is necessary to improve the acoustic performance in the indoor environment and create a homogeneous sound distribution. One of the most critical parameters in the acoustic performance of the learning environment is reverberation time [21]. There is no unique universal and perfect reverberation time for learning performance. According to flexible teaching methods, reverberation times in classrooms with no more than 40 students should not exceed 0,6 s under full occupancy conditions or 0,7 s in classrooms with empty situations [22]. The Acoustical Society of America has determined the maximum recommended reverberation time level for classrooms as 0,5 s. However, the standard of learning environment acoustics is not strict and can be determined by reference to regional laws, regulations, or local codes [23]. This value may vary depending on the regulations of the countries.

3.2. BIM Tool – Autodesk Ecotect

Autodesk Ecotect is a simulation and analysis tool that enables designers to create highly energy-efficient and sustainable building designs. Autodesk Ecotect, developed by architects, is a software focused on environmental analysis and can perform various analyses for sustainable buildings at every phase, from concept design to detailed project design [24]. The tool was initially developed by Square One Research and later acquired by Autodesk.

The tool can examine various environmental factors such as shadow, daylight, lighting, thermal, ventilation, and air conditioning [25-27]. Autodesk Ecotect can simulate the effects of environmental factors on building performance and provide an interactive 3D view of these effects. It can address elements such as solar radiation, shadow and reflections, shading designs, and visual impact studies [28]. Although Autodesk Ecotect software is mostly used in analyses involving environmental factors such as shadow, lighting, and thermal issues, it can also be used for acoustic analyses [29-30]. In acoustic analyses, the tool can perform statistical reverberation, linked acoustic rays, acoustic rays and particles, and acoustic response analyses. In the program, analysis of buildings of all sizes and geometries is possible. However, as the model geometry becomes more complex, the number of vertices may increase and the precision of the calculations may decrease. Therefore, when evaluating the analysis results, it is important to take into

account the assumptions used by the program when making calculations [31]. To obtain more precise and accurate results, the program can work with simulation programs such as EnergyPlus, ESP-r, AIOLOS, and Radiance when necessary. These simulation programs can provide more detailed and comprehensive analyses in special areas such as energy performance, heat transfer, and lighting analysis [32]. This way, designers can optimize their designs more effectively by accessing more specific and reliable data.

Modeling complex building forms in the software can be more difficult because the software is not intended for drawing purposes. In this case, detailed acoustic geometries are usually created in a different environment such as Autodesk Revit, Autodesk AutoCAD, ArchiCAD, SketchUp and then imported into Autodesk Ecotect with appropriate file extensions such as .3ds or .dxf. This file transfer enables data integration between the software, allowing analyses to be performed more easily and effectively. In this way, designers or engineers can use the data obtained from detailed drawings within Autodesk Ecotect and perform various analyses.

4. RESULTS AND DISCUSSION

The reverberation time was determined with Autodesk Ecotect to determine the current acoustic conditions of the classroom of the educational building used for Building Information Modeling, BIM. First of all, the model of the classroom was created in the Autodesk Ecotect environment. The model geometry was obtained by following the room boundaries. Each building element and reinforcement inside the space are determined by the frequency spectrum on sound absorption coefficients (Material Library). The floor, walls, and ceiling are defined by their current materials with high sound absorption coefficients (Table 1).

The frequency spectrum of reverberation times in the classroom was determined. The lecturer's position in the classroom was used as the sound source position. In 1/3 octave bands, reverberation times at mid-frequencies were determined as 1 s for 500 Hz, 1,02 s for 1000 Hz, and 1,06 s for 2000 Hz. Room conditions with high sound reflectivity surfaces increase the reverberation time. Early lateral reflections with reflective surfaces located close to the source position contribute to the increase in sound pressure level (Fig. 4). In room acoustics can be explained by the fact that the early decay time is higher than the reverberation time. As a result of this situation, it states

Table 1.
Sound absorption coefficients of current materials in the BIM tool

Building Materials* (Current Materials)	63 Hz	125 Hz	250 Hz	500 Hz	1.000 Hz	2.000 Hz	4.000 Hz	8.000 Hz	16.000 Hz
Floor (Ceramic)	0,00	0,00	0,01	0,01	0,02	0,03	0,07	0,07	0,04
Walls (Brick + Plaster + Paint)	0,10	0,07	0,03	0,02	0,02	0,02	0,03	0,02	0,03
Ceiling (Concrete + Plaster + Paint)	0,01	0,02	0,02	0,02	0,03	0,04	0,05	0,06	0,06
Windows (Double Glass)	0,12	0,10	0,06	0,04	0,03	0,03	0,03	0,04	0,04
Doors (Wooden)	0,44	0,41	0,35	0,25	0,20	0,15	0,14	0,13	0,12
Blackboard (Laminate Surface)	0,19	0,18	0,14	0,12	0,10	0,07	0,09	0,11	0,11
Lecturer and Students	Classroom density was entered as 80%.								

* Materials are used from Autodesk Ecotect material library.

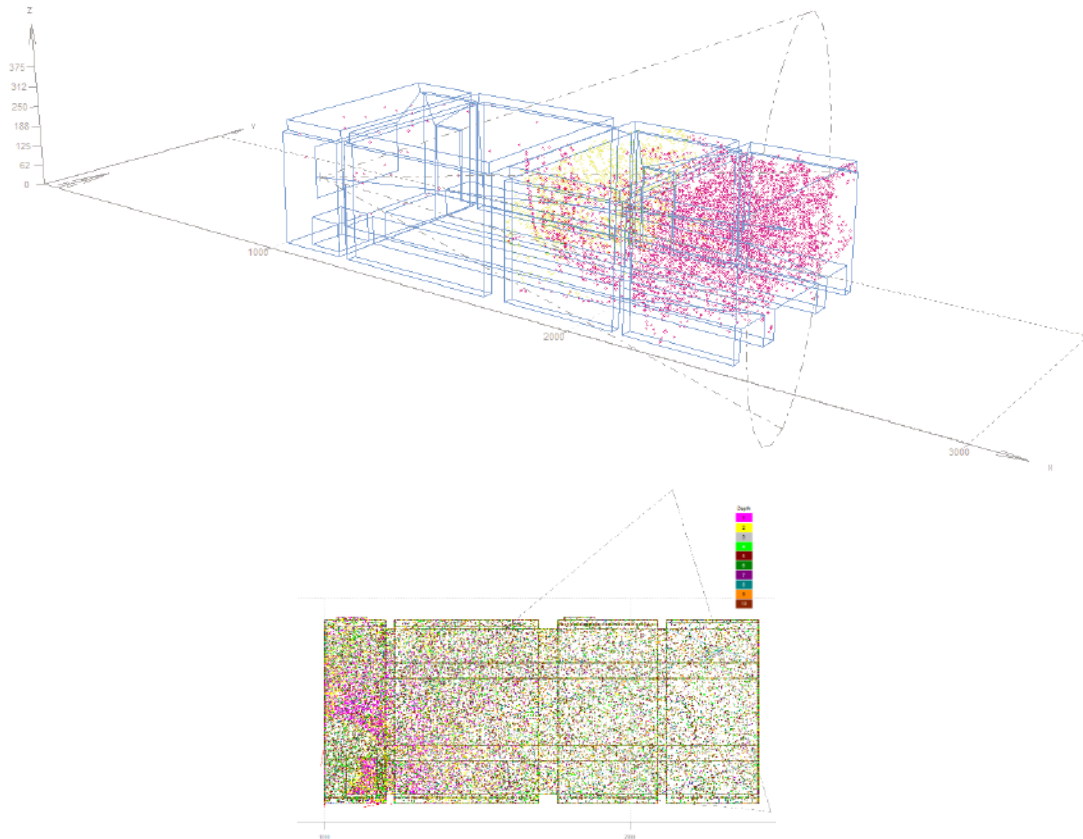


Figure 4.
Propagation of sound rays as particles, 3D model, and plan

that an incomprehensible learning environment may occur even for students in the front rows of the classroom's space organization.

The reverberation time should be reduced for the classroom examined within the scope of educational buildings [22-23]. For this reason, sound absorption materials were added to the walls and ceiling of the classroom (Table 2). With the recommended sound absorption materials, the average sound absorption coefficient of the classroom was increased. The fre-

quency spectrum of reverberation times occurring in the classroom was determined. The lecturer's position in the classroom was used as the sound source position. All other components that are not changed in the BIM tool are considered common with the current state simulation. Reverberation times at mid-frequencies in 1/3 octave bands were determined as 0,68 s for 500 Hz, 0,7 s for 1000 Hz, and 0,72 s for 2000 Hz.

Table 2.
Sound absorption coefficients of new materials in the BIM tool

Building Materials*	63 Hz	125 Hz	250 Hz	500 Hz	1.000 Hz	2.000 Hz	4.000 Hz	8.000 Hz	16.000 Hz
Walls (Sound Absorption Panel)	0,06	0,06	0,13	0,47	0,91	0,94	0,78	0,74	0,70
Ceiling (Sound Absorption Panel)	0,45	0,45	0,80	0,65	0,72	0,78	0,74	0,74	0,68

* Materials are used from Autodesk Ecotect material library.

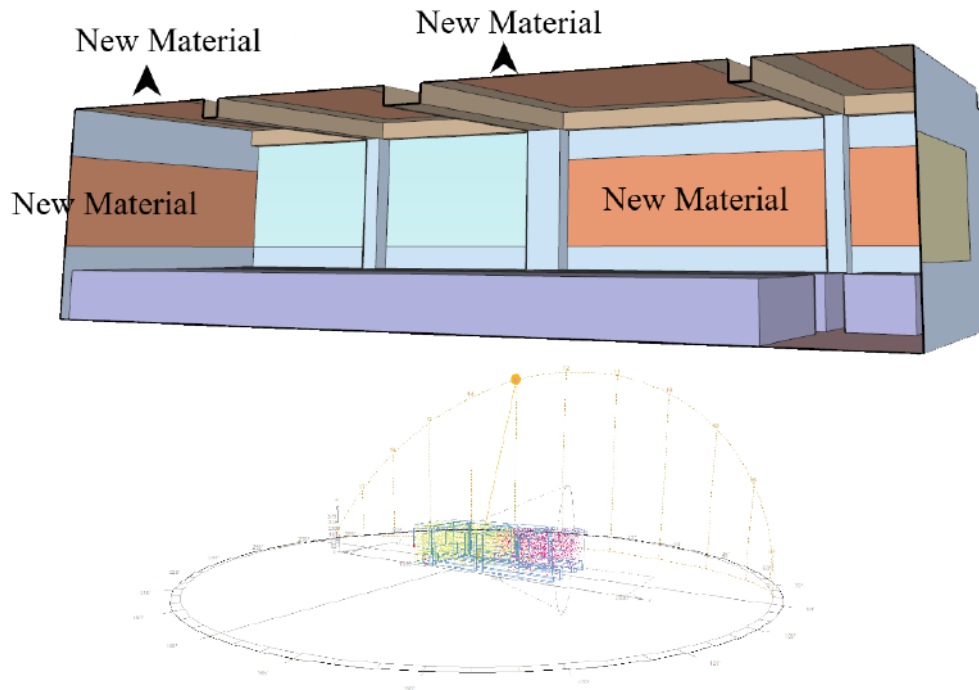


Figure 5.
Recommendations for acoustic improvements and the position of the 3D model

The reverberation time of the classroom in the education building has been improved. Sound absorption materials were added in the middle part of the walls (h: 120 cm) and in the inner parts of the area bounded by the beams of the ceiling to improve the reverberation time (Fig. 5).

In Autodesk Ecotect, a BIM-based tool, an acoustic analysis of a classroom in an educational building was performed. For the acoustic analysis, the current situation was transferred to the BIM with its components, elements, and furniture. Sound absorption materials were added to the walls and ceiling of the room to reduce the reverberation time at the high levels calculated. With the improvement suggestions made, the current classroom was transformed into an acoustically appropriate learning environment.

Inevitably, the materials to be used for improvement in acoustic analysis in BIM software will affect other physical requirements of the space. In the revisions made, the lighting level of the classroom (natural

lighting), the thermal requirements of the room, finishing materials, and system layers are affected. Additionally, properties of building materials such as thickness, weight, u-value, lifetime, cost, and maintenance cost can also be defined. While performing acoustic analysis, it is of great importance to perform other physical and cost analyses and analyze their interaction. This shows that Autodesk Ecotect is a BIM software that can also be used for acoustic purposes. However, Autodesk Ecotect software is limited to statistical reverberation, linked acoustic rays, acoustic rays and particles, and acoustic response properties for room acoustics analysis. For room acoustic parameters such as speech transmission index (STI), definition (D50), and signal-to-noise ratio (SNR) need to be determined along with reverberation time in classrooms. For this reason, it is necessary to improve the Autodesk Ecotect program, which is examined as a BIM tool, or to make new additions and updates. It is recommended that more BIM tools should be developed for architects,

designers, BIM experts, and acousticians and acoustic designs should be considered within the scope of building life cycle assessments.

5. CONCLUSION

This study provides a comprehensive literature review on the use of BIM-based applications in acoustic analysis to evaluate the reverberation time of spaces and improve acoustic performance with BIM integrated method. As a result of the bibliometric analysis conducted within the scope of the literature review, it was determined that BIM and acoustic integrated studies are increasing and are primarily used in issues such as sound insulation, prediction of reverberation time, and building facility management. For this purpose, Autodesk Ecotect software, one of the BIM tools, was used to predict and improve the reverberation time of a current educational building and to create an appropriate learning environment.

The data obtained from the BIM tool includes architectural and non-architectural elements, their type, location, surface area and material properties, and possible intersections with other elements. Automatic coordination with design, construction, and other physical parameters (updating the model and re-analyzing it with new properties added to the model) provides the most important tool in the use of BIM tool for the improvement of reverberation time in acoustic performance analysis. This property provides architects, engineers, and construction (AEC) professionals with the ability to test different design/renovation/improvement scenarios and determine the level of impact on other components. With Autodesk Ecotect as a BIM tool, these processes can be carried out and the steps to improve the reverberation time can be carried out practically through the 3D model. Analyzing the acoustic performance of the environment according to the changing acoustic properties of the building materials can be done by improving the reverberation time. It also provides a useful simulation and analysis tool for educational purposes to understand the acoustic properties of different surfaces in spaces and their effects on reverberation times.

The limits of this study were created by calculating and improving the prediction of reverberation time in an educational building classroom. With the differentiation and future versions of BIM tools, it can be extended to include the determination of sound pressure levels and the simulation and calculation of fac-

tors such as structure-borne noise (impact noise). The system also needs to be tested with models with more complex levels of detail. Future studies should prioritize the use of different BIM tools and algorithm-assisted acoustic analysis.

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