METU JFA 2022/1
(39:1) *1-22*
DOI: 10.4305/METU.JFA.2022.1.1

HERITAGE BUILDING INFORMATION MODELLING FOR CONSERVATION OF 20TH CENTURY MODERNIST ARCHITECTURE

Şahin AKIN*, İpek GÜRSEL DİNO, Ayşen SAVAŞ SARGIN****

Received: 02.04.2021; **Final Text:** 17.01.2022

Keywords: Conservation planning; modernist architecture; heritage building; heritage building information modelling; architectural visualization.

INTRODUCTION: CONSERVING 20TH CENTURY BUILT HERITAGE

The need to conserve the Modernist heritage buildings has been one of the central concerns of the 21st-century architecture. Modern Architecture has been characterized by its innovative approach towards social, technical, and aesthetic intentions, as well as its experimental –and sometimes untested- use of materials, structural principles and infrastructure (Henket, 1998). Moreover, the original function and infrastructure of Modernist buildings have been subject to change, failing to meet the contemporary needs of its occupants. Today these buildings are under the risk of irreversible alteration, demolition, or destruction. As a result, there is an increased need for architectural conservation initiatives targeting Modernist heritage.

This paper focuses on the conservation management planning activities carried out for The Middle East Technical University's (METU) Faculty of Architecture Building with Getty Conservation Institute's support, and specifically, the Heritage Building Information Model (HBIM) developed during this process (Savaş, 2019a). The building was originally designed as a school of architecture and still accommodates the same function. Particularly for this reason, it has been well preserved over the last 60 years; yet there are challenges. Some of the problems this building face are very unique and some apply to almost all the early 20th century structures. The developed HBIM facilitated the systematic collection, structured representation, sharing and visualization of the vast amounts of building data gathered during the research activities, which are highly interdisciplinary, heterogeneous, and fragmented. The architectural and material qualities of the building, in a way, facilitated the construction of the HBIM, as standardization in architectural elements, the elimination of cladding and the rejection of all means of decorative elements, the known aphorisms of Modern Architecture, made it relatively easier for

* *Corresponding Author;* Department of Architecture, Middle East Technical University, Ankara, TURKEY. Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, NORWAY

**Department of Architecture, Middle East Technical University, Ankara, TURKEY.

the researchers to develop the said model. Moreover, HBIM acted as a core representational environment on which the other digital technologies and computational tools converge, such as LiDAR (Light Detection and Ranging) imagery, image-based 3D reconstruction, auxiliary analytical tools, and virtual reality visualizations.

This article intends to disseminate the tools and actions aimed at the use of HBIM for heritage buildings and the coordination of digital technologies supporting heritage building conservation planning into an integrated approach. Moreover, the HBIM and its development process presented in this article, aim to act as an exemplary model that can help facilitate the effective use of building information models for heritage buildings in the future.

The Significance of the Building

METU Faculty of Architecture Building is located in a university campus in Ankara, and functions as a school, housing three departments: Architecture, Industrial Design, and City and Regional Planning. The building was designed by the architect couple, Altuğ - Behruz Çinici between the years 1958-1961 as a competition entry, followed by its construction in the following two years (**Figure 1**).

This iconic building's spatial, aesthetic, and material qualities, as well as its stylistic maturity is considered as a genuine interpretation of Modern Architecture. Not only this building, but also the entire campus was an outcome of the creative intellect of post-war architectural engineering and became the laboratory of new materials, mechanical equipment, and construction techniques in Turkey. Its architectural qualities were motivated by the Bauhaus program reflected in the functional and volumetric layout of the building, including its material workshops, open-plan space distribution, transparent courtyards, exposed concrete curtain walls, large glazed surfaces, brise-soleil façades and the flat roof (**Figure 2**) (**Figure 3**).

Due to the high quality of materials used in the construction, meticulous detailing and application techniques, the building has been in good physical condition (**Figure 4**); yet it is still under the threat of various material, environmental and political pressures. The daily population of the building has reached 2000 people, tripling in quantity since its construction. The ideological shifts and the city's rapid growth with its new roads, underground transportation systems, and additional urban functions are threatening the integrity of both the campus and the building. Moreover, new building codes, comfort demands, and infrastructural requirements

Figure 1. The entrance arcade and interior view of the METU Architecture Faculty building (METU photography archives).

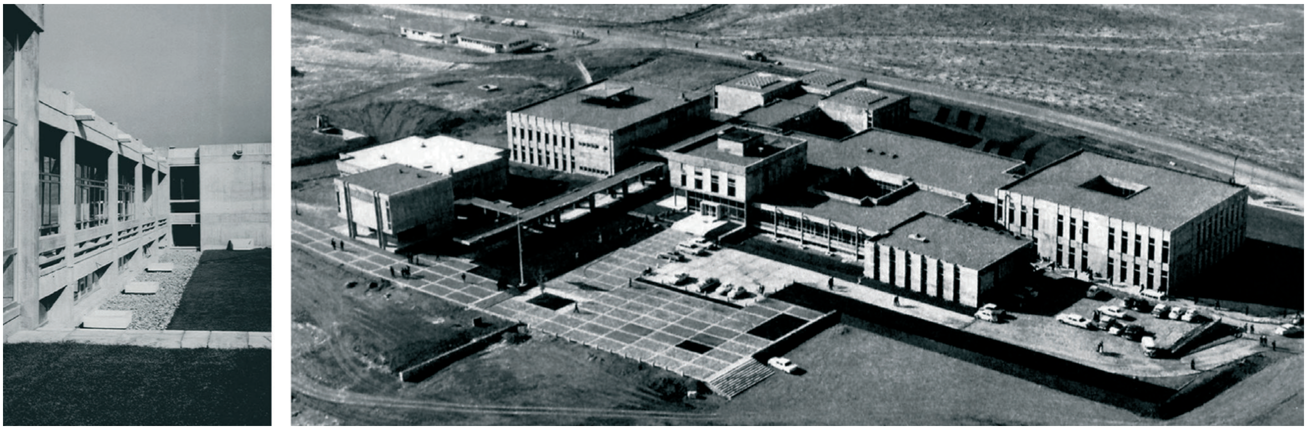


Figure 2. The façade detail and the aerial view of the METU Architecture Faculty building (METU photography archives).

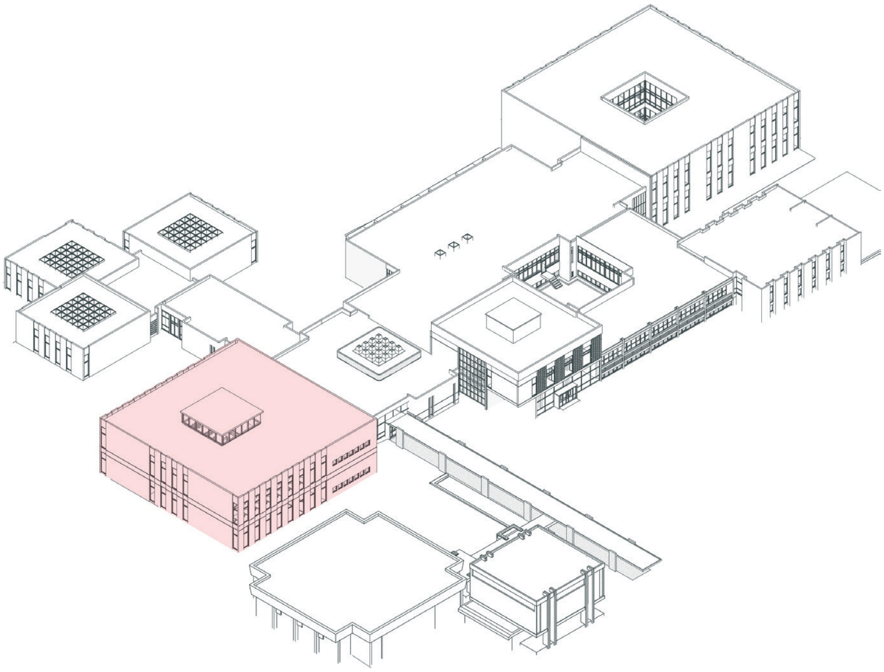


Figure 3. The METU Faculty of Architecture Building. The focused area is indicated in red (Model made by Şahin Akın).

of information/communication technologies introduce additional technical challenges to the building. As a result of a series of physical interventions that it has been subject to during the last three decades, the building's authentic architectural and material qualities are being threatened (Savaş and Dino, 2019).

The Planning Activities

The planning activities took place between June 2017- December 2018 with the valuable support of the Keeping It Modern Grant of the Getty Conservation Institute, USA. The grant helped the initiation of the conservation management plan to guide long-term maintenance and conservation policies developed for the building. That required the thorough investigation and documentation of the current performance of its physical building systems, as well as its social and cultural significance. Specifically, three assessment phases were simultaneously executed: (a) the elicitation of cultural and spatial values, (b) structural and material assessment, and (c) environmental performance assessment. These activities involved the collection, documentation and analysis of large

Figure 4. Meticulous detailing and application techniques (Photographs by Serra İnan).

amounts of interdisciplinary building information. Inaccessibility of such building information is an obstacle against the seamless communication between the team members, hindering effective decision-making. The introduction of Heritage Building Information Modelling (HBIM) as an effective and practical visualization medium helped the team to make the complex data more accessible, comprehensible and usable. All the related steps of the conservation management plan have been conducted in parallel to the ongoing daily maintenance activities. As such, building codes, users' demands, architect's dreams, personal histories, historical narrations, memoirs, legal documents, and many similar and seemingly unrelated data had been overlapped with more quantitative information. Moreover, HBIM helped the research team to overcome the specific aspects of Modern Architecture that were challenging the conventional heritage documentation techniques. The idea of open plan in architectural design, for instance, forced the photographic and textual documentation of each space as an autonomous entity in the building.

Photographic documentation, which is a widely applied, systematic visual data collection method, has been conducted with the assumption that each space is autonomous and defined by surfaces that can be identified as elevations/façades, floors and/or ceilings. However, in Modernist buildings, the definition of the physical borders of rooms, halls, and circulation areas are usually open to interpretation. The spaces flow into each other due to a desired volumetric fluidity and spatial flexibility. Various kinds of transparencies, mezzanine floors, bridging over passes, glazed surfaces and courtyards enhance this complexity (**Figure 5**). To address these and similar challenges, the HBIM was developed in parallel with the aforementioned three assessment activities. Throughout the project, HBIM acted as a comprehensive digital twin of the building, capturing vital information and continuously supporting various planning activities in the long term.

Figure 5. Open plan, volumetric continuities, courtyards and large glazed surfaces (Left photo by Duygu Tüntaş, right photo by Serra İnan).

HERITAGE BUILDING INFORMATION MODELLING: A GENERAL PERSPECTIVE

Heritage building conservation planning is an information-intense process that requires the management of vast amounts of data about the building. According to the RECORDIM guiding principles, the scope of heritage documentation includes metric, quantitative and qualitative information about the building assets, their values, significance, management, condition, maintenance and repairs, as well as the threats and risks to their safekeeping (Letellier et al., 2007). Digital technologies, especially computer-aided architectural design (CAAD) tools, are widely used for 3D modelling, but they cannot extensively support the information-rich workflows of heritage planning processes. Building Information Modelling (BIM) is a technology that can support Architecture, Engineering and Construction (AEC), building management, and maintenance activities. The main premise of BIM is one single model encoded in a standard, interoperable file format that maintains the entire building data. This data can be related to a wide range of sources, including 3D object geometry, building components, object properties, activities throughout the time dimension, or building actors.

In this research, following the need for information management for heritage buildings, the scope of BIM has been expanded to support heritage information, namely Heritage Building Information Modelling (HBIM). HBIM managed to leverage the existing capabilities of BIM and further harnessed it by the domain-specific heritage information gathered through a wide variety of sources. The object-oriented structure of BIM allows the modelling of heritage building objects with domain-specific properties associated with them. In contrast with BIM, HBIM additionally aims to capture the as-is condition of heritage buildings, while making room for imprecision and incompleteness due to missing information or degradation. The data types include but are not limited to geometry, data tables, audio, still or moving images, web pages, and other data types embedded in various software tools.

It is generally argued that to realize the value and significance of cultural heritage assets and to support long-term conservation activities, a wide range of technologies (including information capturing and structuring, performance analysis, visualization) need to converge on HBIM (Arayici et al., 2017). Central to such technologies is the capture of building geometry, which is currently handled with LiDAR, due to its increased accuracy, dataset quality and data visualization capabilities. The resulting point cloud has great significance, especially for the documentation of buildings under the threat of being demolished, for the remote/virtual access of heritage buildings that are otherwise inaccessible, and for buildings that require the application of visual analytical methods on buildings in three dimensions (Counsell and Taylor, 2017). The conversion of 3D point clouds into BIM, known as Scan-to-BIM, is a labour-intensive workflow involving the "fitting" of parametric BIM objects (i.e., windows, columns) onto the point cloud, supported by information from design drawings and site surveys (Hajian and Becerik-Gerber, 2010).

Semantic data is also a critical complement to geometric data in BIM, which accounts for the non-geometric information about the building, its site, components and processes. In heritage buildings, semantic data includes not only technical performance data but also information regarding heritage values, including the architectural, cultural, social and historical significance.

Other advantages of BIM are the auxiliary functionalities such as energy performance analysis or environmental performance analysis. Tools that operationalize simulation-based analyses can be made accessible through semantics-based interoperability standards (i.e., the Industry Foundation Classes, gbXML) that allows access to a BIM model through (semi)automated methods and procedures (Pauwels et al., 2009). As such, concurrent performance evaluation in distributed environments can be facilitated through both synchronous and asynchronous communication modes (Lam et al., 2004). Other potential benefits of BIM for existing buildings include planned or ad-hoc maintenance information (Rodríguez-Moreno et al. 2018), assessment and monitoring (Gigliarelli et al., 2017), energy and space management (Bonduel 2021), emergency management (Feng et al., 2021), virtual/augmented reality (Akin et al., 2020), Web-based GIS applications (Brumana et al., 2019), life cycle assessment (Naneva et al., 2020), and retrofit planning (Volk et al., 2014).

HBIM In Heritage Building Planning And The Need For Customization

Currently, comprehensive, well-documented implementations of HBIM are still scarce. This is partly because reaching a consensus on a shared, standard schema for heritage buildings is difficult due to the fragmentation of the heritage-related information sources, the technical and cultural differences between stakeholders and difficulties in integrating interdisciplinary, heterogeneous information into one single BIM schema (Lam et al., 2004). Specifically for existing buildings, missing, outdated, or incorrect building information that results from the lack of continuous as-is building documentation is common (Volk et al., 2014). In new or unconventional application areas, there are other difficulties against a common- standard data schema. These include the volatility of the domain knowledge that continuously changes and expands and the unpredictability of transactions between process actors (Fischinger et al., 1998).

Heritage building conservation is such a new domain of expertise that has no a priori agreement of shared standards on the domain ontology. Therefore, there is a need to seamlessly manage the fluid conventions of different disciplines, cultures and periods in the development of building information models (Niemeijer et al., 2008). The a priori, top-down BIM approaches, which “offer a complete and uniform description of the project data, mainly independent of any project specifics,” (Stouffs and ter Haar, 2006) run the risk of failing to capture the specificity of heritage building information. In the top-down approaches, there are generally strict municipal/national/international standards or guidelines to be met, and there is no room for customization. On the other hand, the bottom-up approaches are suitable for capturing and representing individual building characteristics, which is crucial for the HBIM model development. The bottom-up approach does not confine itself based on prescribed standards from authorities. Instead, the approach allows a model to morph into a medium that could address some additional concerns in a more flexible, fluid, and customizable way. Both of the approaches are required for stakeholder communication, but their suitability depends based on the contextual framework.

This research supports that the diversity of heritage buildings needs to be maintained rather than absorbed in standard domain models. Therefore, it stresses the need to integrate bottom-up a posteriori approaches that allow evolving custom representations while adhering to universal, top-down representational standards. As such, standardized building representations can be augmented with a local, strategic, and pragmatist character (Lam et al., 2004).

HERITAGE BUILDING INFORMATION MODELLING FOR THE METU FACULTY OF ARCHITECTURE BUILDING

The systematic investigation of the physical condition and performance of the Faculty of Architecture building, as well as the documentation of its social and cultural significance, was carried out by an interdisciplinary team that included architects, engineers, social scientists, conservation specialists, IT experts, chemists and archivists. The team pursued three main pillars of research. The first, titled the elicitation of cultural and spatial values, aimed to present a comprehensive understanding of the building as a modern heritage, together with its history, development and present state. This phase was essential for achieving the appropriate assessments and, consequently relevant proposals for the principles, policies and related actions for its conservation. The second pillar, namely structural and material assessment, involved the visual assessment of the structural members, the evaluation of the structural damage and deteriorations, the identification of the material conditions and various visual decay forms through visual inspections. The third pillar, environmental performance assessment, carried out a quantitative methodology using energy simulations to understand and improve the energy performance, occupant comfort and environmental footprint of the building.

As a result of these research activities, archival information (such as photographs, drawings, models, and written documents) and technical information (related to the structure, mechanical system, electrical systems, materials, environmental performance and occupant comfort analyses) have been collected in different media. The nature of information gathered during the assessment activities was found to be rather heterogeneous and diverse, and many similar and unrelated data were in need to be overlapped and integrated.

As a digital environment for storing and retrieving the collected data, the HBIM was developed in parallel with the other planning activities. The purposes of the model are:

- The documentation of the building, including information on the geometry, architectural significance, and the results of the assessment activities,
- Data sharing between the team, and data interoperability with other digital tools (i.e., structural analysis or energy simulation),
- The visualization of the geometric and semantic data (**Figure 6**).

Modelling Building Geometry

The HBIM was developed using Autodesk Revit 2017 (Autodesk 2020a), a 3D building modelling software tool used for building information modelling in architectural design practices. Revit maintains 3D objects to define architectural elements and their parametric attributes, both geometrical and non-geometrical in the model. HBIM requires precise geometric information of a building. To this end, different data capturing methods were used, including LiDAR, surveying, image-based 3D reconstruction.

LiDAR

LiDAR technologies are widely used to support the high-accuracy surveying of the physical environment. In our research, the Faculty of Architecture building was laser-scanned twice using different levels of resolution. In the first step, the whole building was scanned in four

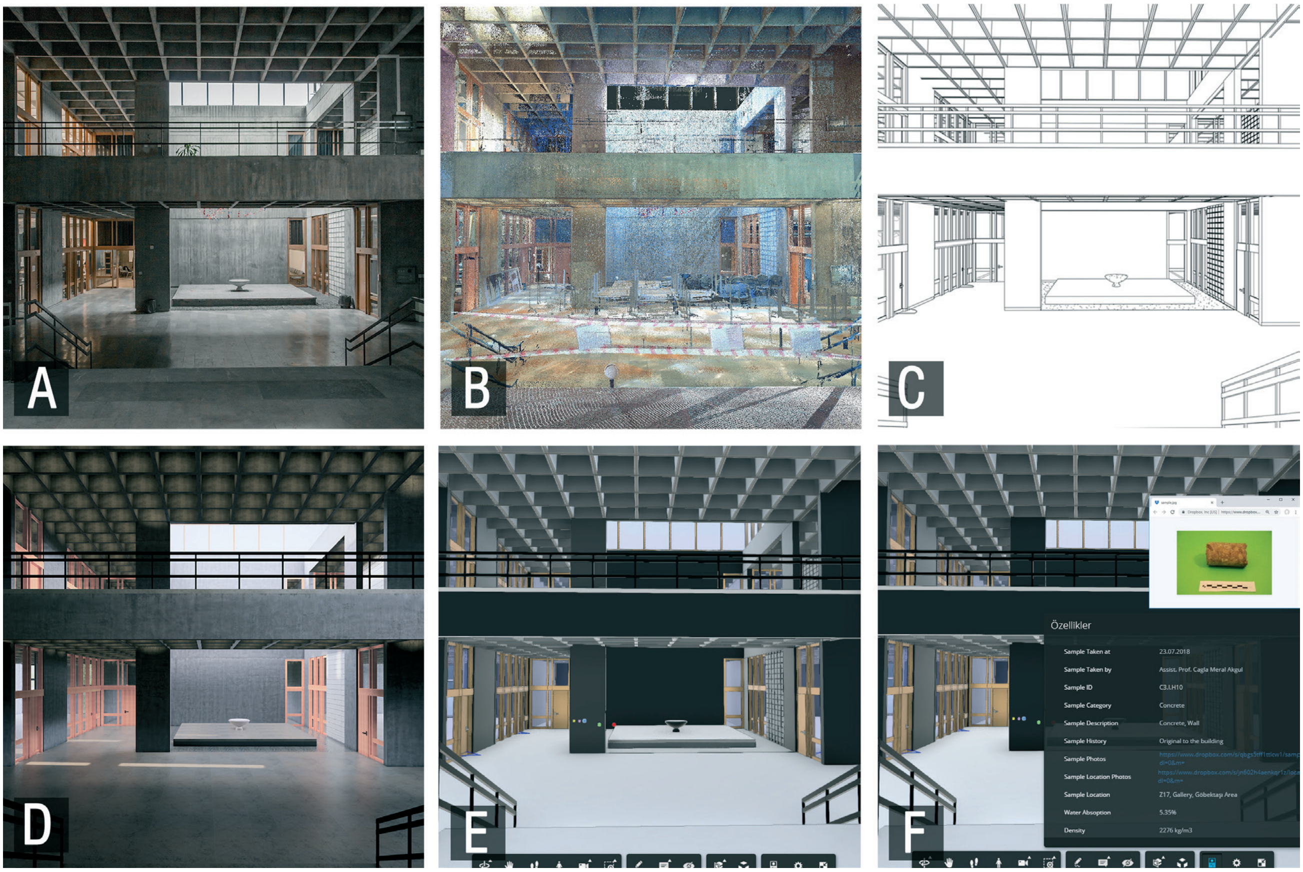


Figure 6. A) Photograph of the selected area, (B) Point cloud of the selected area, (C) BIM model of the selected area (D) Realistic rendering of the selected area (E) Interactive web-based visualization of the selected area with Autodesk A360 (F) HBIM data stored in model elements (Model made by Şahin Akın).

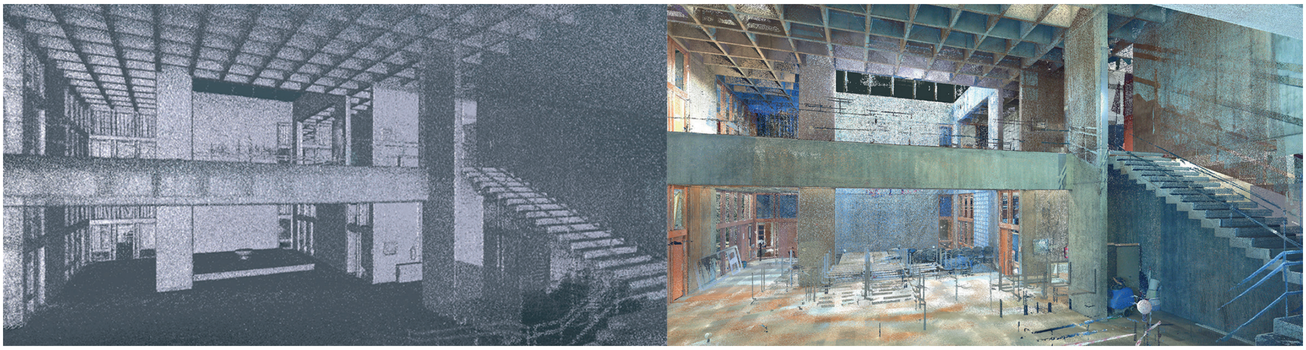


Figure 7. Point cloud model scanned with a low precision scanner (left), and with a high precision scanner (right) (Model made by Şahin Akın).

hours using a handheld, low-precision 3D laser scanner, called ZEB-REVO (GeoSlam, 2020). The scanner has -/+ 0.1% accuracy with an indoor range of 30m and it has a 43.200 points/sec data acquisition rate with 905 nanometres –nm laser wavelength. ZEB-REVO scanner is advantageous to steady cameras due to its ease of use, flexibility, and scan speed. The second scanning process focused on a selected area of the building (indicated in red in **Figure 3**), in which detailed technical analyses were carried out. A stationary, high-precision laser scanning device, Faro Focus Laser Scanner 120 (Faro 2020), with a 905nm wavelength and a scan speed of 122 kpt/sec was used. The 3D point cloud models were generated as a result of a total number of 75 sessions and two days. **Figure 7** shows a comparison between the low- and high-resolution point cloud models of the building. While the initial low-precision scan allowed the definition of the building's overall geometry and main features, the high-resolution scan facilitated the detailed modelling of all architectural elements. As such, this latter point cloud also was used as the basis to define a library of parametric objects (in other words, families) for HBIM (see Section 3.2).

Surveying

The building features that were not captured by LiDAR were documented by on-site surveys such as physical details or building materials. This task was carried out in parallel with the data collection and condition assessment activities and registered the gathered information in the model as required. The information that was already contained in the BIM model was instantiated directly. However, as will be described in the following section, many new information types were identified and captured during the project, which were added to the HBIM by extending the schema with new families and/or family parameters.

Image-based 3D reconstruction

Image-based 3D reconstruction aims to deduce the 3D geometry of a scene captured by a set of images taken from different angles. The technique is applied with high-resolution photographs to model building elements with high significance value. For precision modelling, some key factors that affect the quality of the output geometry include:

- To reduce any possible distortion, every angle of the object must be captured and photographed accordingly.
- Evenly distributed light conditions are needed to be provided for the prevention of cavities on the model surface.
- A high number of images are needed for a high-precision model.

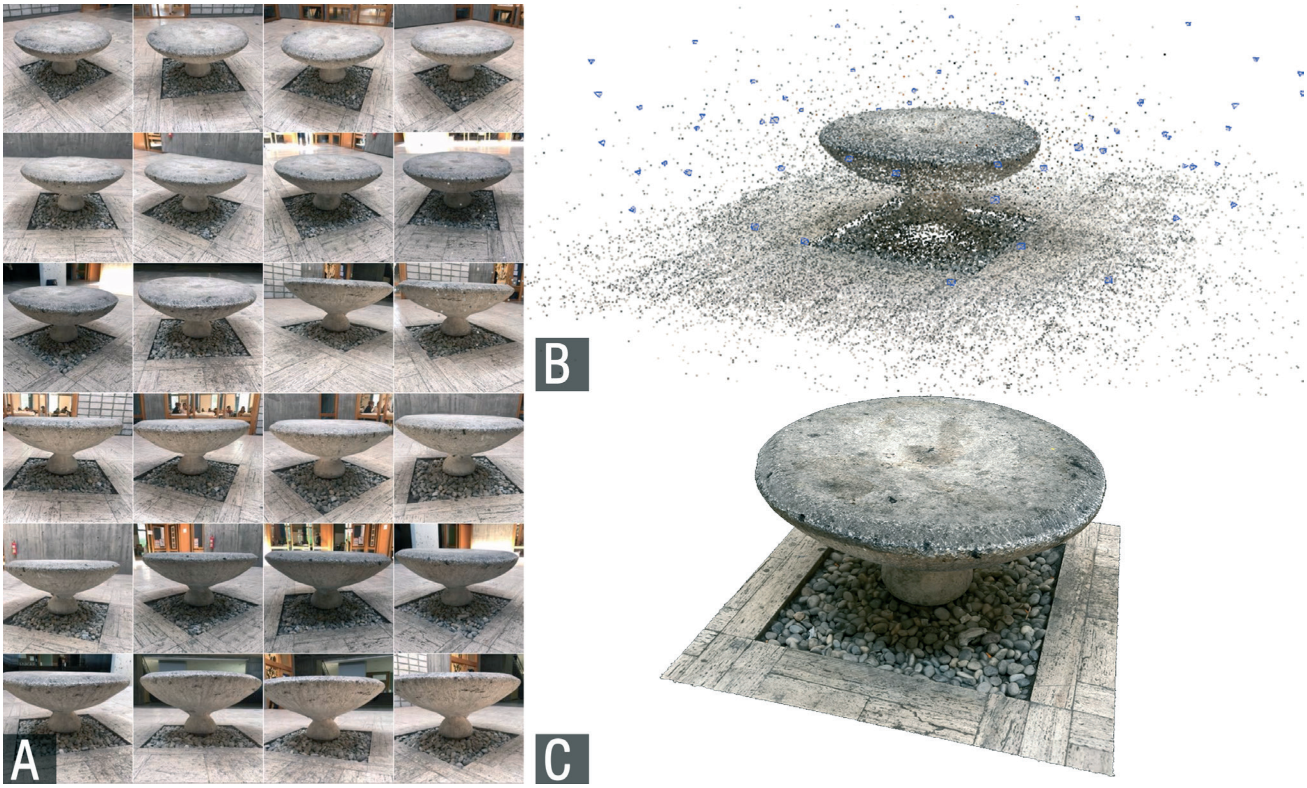


Figure 8. A) The photos of the selected geometry, B) Sparse point cloud model, C) Coloured mesh model of the Göbektasi (Model made by Şahin Akın).

An artwork in the building, *Gobektasi*, which has high historical significance for the building, is selected for 3D reconstruction (**Figure 8**). A commercial photogrammetry and 3D modelling software, 3DF ZEPHYR (3DFlow 2020), was used for the automated construction of the geometry. Using 95 photographs, a point cloud with 36.824.754 points and a mesh model were generated. Finally, the mesh model was introduced to HBIM according to its relevant building element category.

Modelling the Parametric Building Elements

A critical phase in HBIM development is the development of custom families. A family is defined as "a group of elements with a common set of properties, called parameters, and a related graphical representation"(Autodesk, 2020a). The main premise of a family is that its elements encapsulate a number of attributes that assume specific values, as they are instantiated in the model. An element of a family, therefore, is of the same type with other family elements, but can take different forms in the model. Therefore, the repetition of an element is key to the use of families. In the faculty building, the standardization in architectural elements and their repetition further justified using the custom-made standard families for the building.

Family creation is a manual process that requires translation of a point cloud into objects, such that an element is identified, isolated from its broader context, parameterized, and modelled. An example of a family in our research is the windows. During HBIM development, various window types are identified, parametrically modelled as families, and instantiated in the building model (**Figure 9**). All windows within each family share the same basic attributes such as level, sill height or opening aperture, while specific ones can be extended with additional attributes such as division

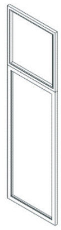
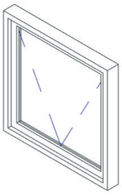
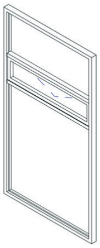
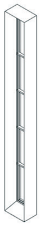
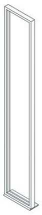
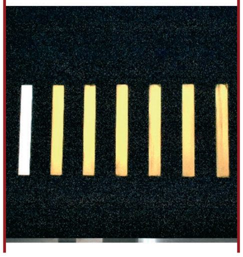
FAMILY	TYPE	DESCRIPTION	PROPERTIES	IMAGE	PHOTO
getty_studios_window	getty_gobektasi window	Vertical window with single opening, bottom-hung (design studios)	Level: -0.95 Sill Height: 0.00 Opening Aperture: Bottom Frame Material: getty_aluminum Glass Material: getty_glass Height: 390 cm Width: 112 cm Split Line Height: 270 cm Frame Thickness: 5 cm Glass thickness: 1.36 cm Function: Exterior Arch. Significance: Moderate		
getty_square window	getty_gobektasi office	Square shaped window, operable opening, bottom-hung (offices)	Level: -0.95 Sill Height: 80.00 Opening Aperture: Bottom Frame Material: getty_aluminum Glass Material: getty_glass Height: 95 cm Width: 95 cm Frame Thickness: 5 cm Glass thickness: 1.36 cm Function: Exterior Arch. Significance: Moderate		
getty_triple window	getty_dean	Triple window with single opening, bottom-hung (Dean's Office)	Level: +4.71 Sill Height: 0.00 Opening Aperture: Bottom Frame Material: getty_aluminum Glass Material: getty_glass Height: 350 cm Width: 190 cm 1st Split Line Height: 210 cm 2nd Split Line Height: 260 cm Frame Thickness: 8 cm Glass thickness: 1.36 cm Function: Exterior Arch. Significance: Moderate		
getty_sloped window with 4division	getty_4 division	Non-operable slim window, with stained glass , four black iron dividers and exterior angled opening cut	Level: +0.25 Sill Height: 10.00 Opening Aperture: None Frame Material: getty_iron Glass Material: getty_glassstained Height: 347 cm Width: 39 cm Division Line: 31.50 cm Frame Thickness: 4 cm Glass thickness: 1.36 cm Function: Exterior Arch. Significance: High		
getty_clerestory	getty_clerestory gobektasi	Non-operable slim clerestory window with colored glass, black iron frame and exterior angled opening cut	Level: +5.00 Sill Height: 68.40 Opening Aperture: None Frame Material: getty_iron Glass Material: getty_glassyellow Height: 200 cm Width: 40 cm Frame Thickness: 4 cm Glass thickness: 1.36 cm Function: Exterior Arch. Significance: High		

Figure 9. Parametrically modelled window family examples (Model made by Şahin Akın).

line or split line-height. While repetition is critical for family elements, there are several objects –either artwork or furniture- that are unique in the building (i.e., chandeliers, fountains). Although these elements were fully modelled as parametric families, they were used only once.

Customization of HBIM

The custom data collected during heritage building assessment processes was registered to the model elements in HBIM. As mentioned above, a bottom-up, a posteriori modelling approach that can result in custom, one-of-a-kind representations while adhering to universal, top-down representational standards is adopted in this research. The object-oriented structure of object-oriented models, or product families as parametric building elements, can represent objects with properties that both exist as part of the model and that can be added as needed. The HBIM can be extended either by adding new attributes to the existing family elements or new families that encapsulate the data gathered during assessment. The data sources for new information types originate from the three research pillars, including documentary evidence of architectural and social values, structural and material assessment and environmental performance assessment.

Documentary Evidence of Architectural and Social Values

Architectural and Social Values of the building are extracted from the archival documents, which are composed of different groups of materials: Visual documents (photographs, blueprint drawings, moving images), written documents (construction diaries indicating the details of the application and implementation processes, institutional documents, correspondence and interviews) and physical objects (the building materials, finishing details and the furniture).

The building has been subject to a series of physical and functional changes over time. As there were no official records of these changes, the best medium to follow the traces of the major alterations in the architects' design ideas was the four sets of architectural drawings that were prepared for different purposes during the execution of the project. Subsequently, these drawings can be listed as the Competition Drawings (1961), Conceptual Drawings (1961-62), Application Drawings (1962), and the Publication Drawings (1964-69). In addition to these four sets, Survey Drawings (2018) are prepared during this project in order to be able to show the alterations after the construction until today. Motivated by the desire to uncover the initial design principles, material qualities and social/environmental integrity of the METU Faculty of Architecture, the research team brought together architectural drawings, photographs, publications, films, student projects, course syllabi, studio assignments, etc., the sources of original impetus behind design, construction and use. The diversity of the archival material required the development of a spatial archival method. Archival processes necessitate appropriate ontologies and applicable software tools.

Structural and Material Assessment

Structural assessment data collection for the faculty building was carried out during several different phases. Visual evaluation of the building involved expert inspection during building surveys. Different structural parts of the building are investigated by putting special emphasis on each element. To evaluate compressive strength of the concrete and its variations, non-destructive Schmidt hammer testing was carried out on the selected elements of the building. Moreover, the reinforcement layout of concrete columns and slabs was identified using a Ferro meter and was registered on 2D drawings. Finally, eight problematic areas with bending and shear cracks in the concrete waffle slabs were identified, and eight linear variable differential transformers (potentiometric LVDTs) and two temperature sensors were installed to monitor the crack width for a year. Moreover, laboratory studies on the concrete samples for characterization were carried out, including x-ray fluorescence (XRF), X-ray powder diffraction (XRD), and ultrasonic testing. The data obtained from these sources were integrated into the HBIM model in different data formats and data types.

The material assessment procedures started with the determination of material conditions through visual inspections. A framework to map the visual decay forms, such as material loss, detachment, discoloration, deposits, cracks and deformation, was developed and the assessed materials were classified under these categories. The location and distribution of these decay forms in the building are needed for diagnostics and the long-term monitoring of the decay form. Here, HBIM claims the responsibility of managing asset information for long-term condition assessment, planning, and maintenance scheduling. As the measurement data collected during the building lifecycle is also born-digital, it can precisely be associated with the corresponding model elements when required. The data collected on material condition and measurements can establish the basis of decision-making for preventative or corrective maintenance activities.

Environmental Performance Assessment

Environmental performance assessment procedures are motivated by reducing the environmental footprint and improving the occupant comfort of the building. The current building condition was assessed through visual inspections, where information regarding the building geometry, materials, set points and schedules (mainly of building use and internal loads) was gathered by observation or from other project sources. The HBIM model was also used for energy modelling and simulation to quantify the energy use (heating + electricity) and occupant comfort (air temperature + adaptive comfort + overheating) using EnergyPlus (US Department of Energy 2010). A number of performance-improvement scenarios that include various measures were developed, modelled, and simulated to assess the most effective measures. As such, the potential of BIM as a tool of interoperability that can support data integration between disparate tools was realized. Field measurements were also carried out to monitor the indoor dry bulb temperature and relative humidity of two critical rooms in the faculty building. Similar to the potentiometric LVDTs, these sensors continuously measured and registered data into time-stamped tables, which provides long-term insight into occupant comfort in building spaces.

Based on the relevant data types captured during the three research pillars, the HBIM is extended with the following custom families. The Architectural Documentation family addresses the need for archival documentation of the building collected since its construction, such as architectural drawings from different building phases (i.e., plan, section, or elevation drawings), technical drawings (i.e., mechanical, structural, or electrical drawings) or photographs. These documents are categorized to represent the significant phases in the building’s life, such as Competition Drawings, Conceptual Drawings, Application Drawings, or Published Drawings.

The Material Assessment family represents the tests performed on the collected material samples. Therefore, the family includes information on the sample collection process, sample description and the test results. The Material Assessment family can be associated with all physical model elements but is most typically used for construction materials such as concrete and brick walls. The Structural Assessment family represents the procedures followed during the structural assessment and the data collected or generated during this process. This family can be associated with structural elements in the model. The Environmental Assessment family is associated with building spaces and contains simulation-based information regarding the building energy use, occupant comfort, space daylight illuminance and room occupancies. Probe Measurements family represents data sets that are results of continuous on-site data collection through sensors. As described above, measurements that were considered in this research include but are not limited to indoor air temperature, air relative humidity, and crack width measurements. This family can be associated both with the physical elements and spaces.

It must be stressed that the research team followed a bottom-up approach during HBIM development. This means that the Revit model's proposed extension was carried out based on the collected and generated data types. While the new families proposed herein have the capacity to cover a wide range of heritage conservation planning activities, it still can be developed further to include information if and when required by other practices.

Visualization of HBIM

The HBIM environment acts as an interactive medium in which users can view, visualize, edit and share the model and its elements for various purposes. Several visualization modes are implemented for the HBIM (**Figure 10**).

Photo-realistic Renderings, Stereo Panoramic Renderings, Web-based Standalone and Executable Walkthrough Experience

The photo-realistic renderings were created at the designated viewpoints inside the HBIM model by using real-time rendering software programs named Lumion (Act-3D, 2020) and Enscape (Enscape, 2020). To achieve photorealism in still renders, material textures are critical. Textural pieces of information of selected building elements were captured by taking high-resolution photographs. These photographs were then accurately converted to seamless textures that can create homogeneously distributed surfaces that can reflect the real visual conditions.

Figure 10. Various visualization methods for the HBIM model A) Autodesk Revit Live, B-C) Autodesk A360, D) Photo-realistic still render, E) Web-based Walkthrough (Enscape), F) Standalone Walkthrough Experience, G) Stereo Panoramic Render (Model made by Şahin Akın).

360° view images, namely stereo panoramic renderings, allow the observers to experience HBIM models in an immersive way. A designated location can be defined in the HBIM model and the location can be reviewed in 360 degrees. The panorama views were generated in rendering software programs named Enscape and Autodesk Rendering (Autodesk, 2020b). These 360° images can be accessed via QR codes or URLs. The visual access can be provided on various platforms such as personal computers or mobile devices. Augmented immersive experience can be achieved with the head-mounted displays that adjust the orientation of the image and viewers' point of view simultaneously, thereby help to surround the user with the virtual environment.

Virtual walkthroughs increase the comprehension of the finer architectural details of the building (Yan et al., 2011). The users can navigate inside the models, similar to first-person shooter computer games. For the faculty building's game-like visualization, two types of walkthrough methods were adopted: Web-based Standalone (WBS) and Executable Walkthrough (EW). Even though the outputs of these two methods are similar, they serve different needs. WBS offers low rendering quality, access via a web browser from a tablet or PC, and requires no high-end graphic card. On the other hand, EW has more features such as time of the day adjustments, virtual reality support, various visualization filters; however, it requires powerful graphic cards and a PC. Both of the visualization methods were generated via Enscape for this project.

Hybrid Visualizations: A Data-centric approach

During assessment processes, heritage professionals are in need of not only geometric but also semantic information related to buildings. In this study, an unprecedented strategy was adopted to incorporate the visualization of non-geometric information in the HBIM model. Distinctive visual markers (spherical shapes) that indicate the five custom families explained above are inserted into the HBIM by associating these family elements with the existing model objects (i.e., columns, walls, waffle slabs). Upon clicking, these markers in the HBIM display their stored data in a pop-up dialogue. For instance, during the structural assessment processes, the data on an existing crack was monitored, and various data, including the close-up images of the crack, crack depth information, hazard conditions, were collected and assigned to a particular visual marker that is placed in a wall element in the HBIM. These data on HBIM can be reviewed by selecting the visual marker interactively. Clicking on a staff office door helps the retrieval of historical data related to the previous users of that particular space, restorations that the door had been subject to, material properties, manufacturing techniques of that door and the industrial resources of its doorknobs, hinges, and locks. To achieve interactive and accessible HBIM data and HBIM geometry, A360 platform (Autodesk, 2020c) and Revit Live (Autodesk, 2020d) were utilized. Both platforms support combined visualization of semantic and geometrical data in an integrated way; while the A360 platform presents a web-based interactive visualization environment, Revit Live offers a standalone walkthrough experience. The interactive visualization capacity of the model, is also useful for the assessment activities and for sharing the architectural heritage values with a broader audience. All the details of the above-mentioned visualization methods are shared on the project website (Akın, 2022) and the published report (Savaş et al., 2018).

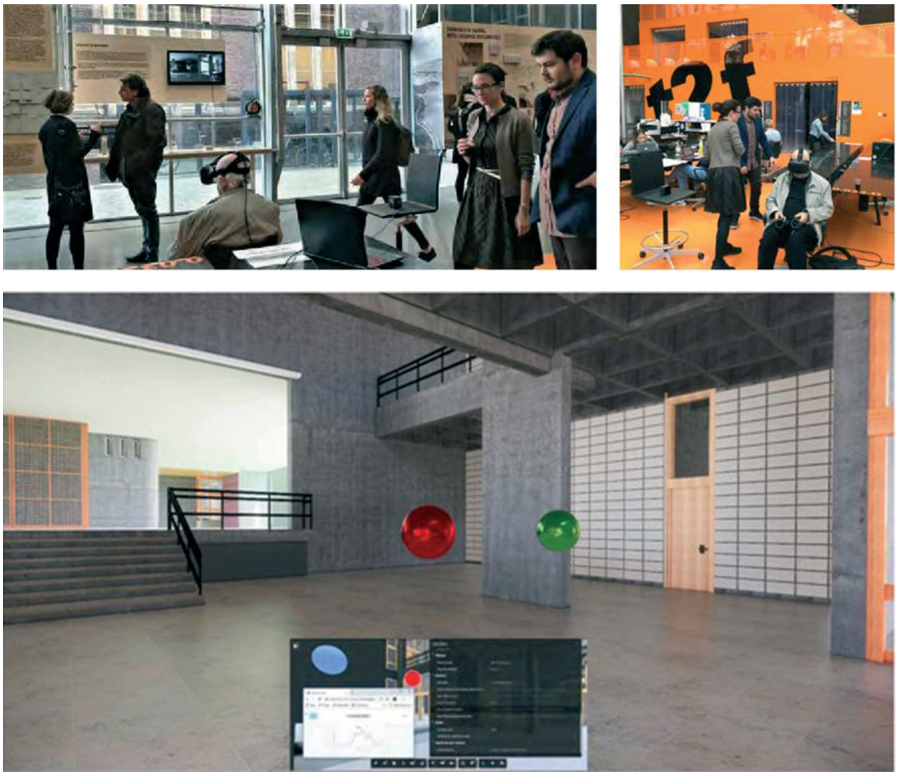


Figure 11. Getty Foundation Keeping It Modern METU Campus Exhibition TU Delft, 2019 (Photographs by Serra İnan).

In the final step, the HBIM was made available in the virtual reality (VR) environment. In this fully immersive VR environment, users can walk in the rendered HBIM model by means of a head-mounted display and interact with the building components (**Figure 11**). VR-based visualization was made available to a broader audience during public meetings with the building's faculty members and national/international exhibitions (Savaş, 2019b).

Integration With Energy Performance Analysis Tools

A conservation planning process that focuses on environmental performance mandates that conservation interventions take into account sustainability issues and meet environmental targets for the current and future climate. In this direction, building energy-efficiency, environmental impact and occupant comfort (especially for those buildings that are still being actively used) need to be considered through quantitative analysis. Building energy simulation is used in this study to quantify performance metrics, the development of alternative scenarios that can improve the current conditions, and the comparative analysis between the current state and these scenarios. Finally, a critical evaluation on the ways in which interventions can be realized while preserving the cultural and spatial qualities needs to be made.

To provide deeper insight into the thermal behaviour of the faculty building, simulation-based analyses were conducted. The first step in energy model development is to export the HBIM to DesignBuilder, a software tool used for energy modelling and hourly energy simulation using gbXML (Green Building Extended Mark-up Language) data exchange format. Although seamless data transfer between digital tools is not fully achieved yet, missing information required for simulations, such as internal loads (occupants, lighting, and equipment), heating setpoints, or materials' thermal properties, are manually added in DesignBuilder. Simulation-based analyses are used to quantify performance metrics such as annual energy use, CO2 emissions, and occupant comfort. Other detailed results include heat loss through the building envelope, natural ventilation cooling capacity, solar gain from windows, or internal loads. The possibility of data integration between other tools and HBIM, as exemplified by the simulation-based environmental assessment activities, further justifies the development of a detailed HBIM. Similar data transfer processes can be realized using other tools in the future, such as building structural analysis.

Following, several scenarios that aim to improve building performance that consider different building interventions were developed, including improving window type and frames, roof insulation, window aperture angle, cross-ventilation possibilities, the application of components such as phase-change materials or infrared reflective coating. The existing energy model was edited for each scenario and simulations were run to be able to benchmark each scenario against the original building. The simulation results indicate that improving the airtightness of the building, improving the roof isolation by increasing the insulation thickness and using high-performance glazing have the maximum impact on energy efficiency. Combined scenarios that consider multiple interventions can reduce the energy use by 45% and indoor overheating hours from 21969 to 1724-degree hours.

Future Uses of The HBIM

The HBIM development constitutes an inseparable part of the conservation planning processes in this research. The model is considered not as a static end-product that is merely used within the limits of this project, but as a reliable medium that has the capacity to support a wide range of functionalities for data collection, classification, information modelling, representation and visualization. Potential benefits of HBIM for heritage buildings should be considered in the future as part of the long-term policy.

The conventional workflows in the heritage building conservation are based on paper-based activities focusing on many fragmented specialties, which transfer the design documentation from one to another in a sequential manner. The lack of a shared medium for communication between different disciplines, such as architects, heritage conservation specialists, engineers, policy-makers, results in ineffective collaboration, a lack of a shared understanding into the heritage building's architectural and heritage values. As a result, misunderstandings and mistakes can surface during conservation planning and implementation processes. HBIM can function as the common medium through interdisciplinary collaboration and coordination. The presented research initiated the use of the model as a digital environment for information sharing, communication, and decision-making across the project team members. In the future, it can maintain this function with the involvement of other stakeholders, disciplines, conservation activities, and contexts unforeseen at the moment.

Clash detection occurs when physical building elements are in spatial conflict. BIM allows the automated detection of physical clashes, especially for those elements that require the involvement of different disciplines such as structural engineers, mechanical and electrical engineers, or environmental engineers. For heritage buildings, clashes also occur conceptually, when an intended intervention to a building element conflicts with the building's heritage values. As an instance, assume that an administrative stakeholder wants to replace the historical stained glazing without knowing its history with a better performing double-pane glazing on the grounds that they are causing air leakages. In this case, the HBIM model can warn and inform the stakeholder regarding the historical value of the building element in the case of an intervention. When heritage information is embedded into the HBIM model, both physical and conceptual clashes can be detected in the future.

Each discipline; MEP (mechanical, electrical, plumbing) engineering, structural engineering form a model independently from all others, based on the architectural model that sets up a layout for other professions. In the future, the structural and MEP models can be developed in detail to support conservation activities, such as clash detection and analytics.

A BIM model can quantify the modelled materials and provide cost information in an automated way. Therefore, work processes based on BIM can be performed more effectively and accurately. For heritage buildings, the generation of quantities can assist decision-making when building interventions are considered and inform the decision-makers in the exploration of different design alternatives and concepts. For the same feature of the BIM models, an existing building's life cycle assessment (LCA) can be conducted to identify its embodied and operational carbon emissions related to initial material consumption and operation throughout the lifecycle. Identification of the environmental impacts can help various stakeholders to detect the carbon footprint of existing buildings, which is crucial for understanding their environmental performance. HBIM models can be used to conduct LCA with various software tools (i.e., OneClick LCA (Bionova, 2020)) established on a seamless workflow between BIM environments. The planned retrofit actions for buildings can be assessed with these LCA tools by using the same information-rich HBIM models.

CONCLUSION

In this paper, the development of an HBIM model for a Modernist heritage building was presented. The physical and architectural qualities of the Faculty of Architecture building facilitated the generation of this unique environment. Consistency in the design principles of the existing building, standardization in detailing, the abstract formation of its masses and the elimination of all the cladding and ornamentation, helped the construction and development of the HBIM model.

The model is visualized in different platforms such as virtual reality and web-based applications using state-of-the-art software programs. The tested platforms revealed different visualization possibilities of HBIM, towards enabling the users' interacting with the model, including its elements and data in multiple scales. Thus, this new HBIM platform enables interoperability and communication between different professions and prevents conflicts and clashes that are very common in most modelling processes. The existing building data in the standard BIM schema, as well as the extended schema that contains the new data types, can provide critical support to the heritage professionals during assessment processes. Moreover, the users can instrumentalize the HBIM model as a guiding tool for managing and maintaining the faculty building throughout its lifecycle.

The created HBIM model is anticipated to be used actively in case of need and to be kept up-to-date according to emerging developments by the stakeholders.

The HBIM also has the potential to be used as a long-term digital medium that supports future activities regarding operations and maintenance, major renovation, or analysis. The project benefits from the potential of BIM to allow collaboration on a single object-based model that is shared across the whole team throughout the building lifecycle. The methodology developed for the Faculty of Architecture Building will form a sustainable model for similar undertakings in the other campus buildings or other campuses in the country.

ACKNOWLEDGEMENTS
This research is supported by the Getty Foundation's Keeping It Modern Grant [Grant number R-ORG-201735141]. We would like to extend our sincere thanks and gratitude to all members of the METU Faculty of Architecture. No potential competing interest was reported by the authors.

BIBLIOGRAPHY

3DFLOW (2020) 3DF Zephyr Photogrammetry Software. [https://www.3dflow.net/3df-zephyr-photogrammetry-software/] Access Date (19.12.2020).

ACT-3D (2020) Lumion 3D Rendering Architectural Visualization Software. [https://lumion.com/index.html] Access Date (19.12.2020).

AKIN, S. (2022) Interact Keeping It Modern METU Project. [http://kimproject.arch.metu.edu.tr/en/gallery/interact-0] Access Date (20.05.2022).

AKIN, S., ERGUN O., SURER, E. DINO, I., G. (2020) An Immersive Performative Architectural Design Tool with Daylighting Simulations: a Building Information Modeling-based Approach. *Engineering, Construction and Architectural Management* (28) 4 1319-44.

ARAYICI, Y., COUNSELL, J., MAHDJOUBI, L., NAGY, G., HAWAS, S. DEWIDAR. K. (2017). *Heritage Building Information Modelling*. Routledge, London.

AUTODESK (2020a) Revit BIM Software. [https://www.autodesk.com/products/revit/overview?plc=RVT&term=1-YEAR&support=ADVANCED&quantity=1] Access Date (19.12.2020).

AUTODESK (2020b) Autodesk Rendering. [https://gallery.autodesk.com/a360rendering] Access Date (19.12.2020).

AUTODESK (2020c) A360. [https://a360.autodesk.com/] Access Date (19.12.2020).

AUTODESK (2020d) Revit Live. [https://www.autodesk.com/products/revit-live/overview] Access Date (19.12.2020).

BIONOVA (2020) One Click LCA. [https://www.oneclicklca.com/] Access Date (20.12.2020).

BONDUEL, M. (2021) *A Framework for a Linked Data-Based Heritage BIM,* unpublished Ph.D. Dissertation, KU Leuven, Leuven.

BRUMANA, R., CONDOLEO, P., GRIMOLDI, A., PREVITALI, M. (2019) Towards a Semantic based Hub Platform of Vaulted Systems: HBIM

Meets a GeoDB, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, Vol. XLII-2/W11; 301–8.

COUNSELL, J., TAYLOR, T. (2017) What Are the Goals of HBIM?, *Heritage Building Information Modelling*, eds. Y. Arayici, J. Counsell, L. Mahdjoubi, G. Nagy, S. Hawas, K. Dewidar, Routledge, London.

ENSCAPE (2020) Enscape Real-Time Rendering and Virtual Reality. [https://enscape3d.com/] Access Date (20.12.2020).

FARO (2020) User Manual for the Focus3D 20/120 and S 20/120. [https://knowledge.faro.com/Hardware/3D_Scanners/Focus/User_Manual_for_the_Focus3D_20-120_and_S_20-120] Access Date (20.12.2020).

FENG, Y., WANG, J., FAN, H., HU, Y. (2021) A BIM-Based Coordination Support System for Emergency Response, *IEEE Access*, (9) 68814-25.

FISCHINGER, M., CEROVSEK, T., TURK, Z. (1998) EASY: A Hypermedia Learning Tool, *Journal of Information Technology in Construction* (3) 1–10.

GEOSLAM (2020) ZEB Revo RT. [https://geoslam.com/solutions/zeb-revo-rt/] Access Date (20.12.2020).

GIGLIARELLI, E., CALCERANO, F., CESSARI, L. (2021) Heritage BIM, Numerical Simulation and Decision Support Systems: An Integrated Approach for Historical Buildings Retrofit, *Energy Procedia* (133) 135-44.

HAJIAN, H., BECERIK-GERBER, B. (2010) Scan to BIM: Factors Affecting Operational and Computational Errors and Productivity Loss, *2010 - 27th International Symposium on Automation and Robotics in Construction, ISARC 2010*.

HENKET, H., J. (1998) The Icon and the Ordinary, *Modern Movement Heritage*, ed. A Cunningham, E & FN Spon; 13–7.

LAM, K.P., WONG, N. H., MAHDAVI, A., CHAN, K. K., KANG, Z., GUPTA, S. (2004) SEMPER-II: An Internet-Based Multi-Domain Building Performance Simulation Environment for Early Design Support, *Automation in Construction* 13 (5) 651-63.

LETELLIER, R., WERNER S., FRANÇOIS L. (2007) *Recording and Information Management for the Conservation of Heritage Places: Guiding Principles*, The Getty Conservation Institute, Los Angeles.

NANEVA A, BONANOMI M, HOLLBERG A, HABERT G, HALL D. (2020) Integrated BIM-Based LCA for the Entire Building Process Using an Existing Structure for Cost Estimation in the Swiss Context, *Sustainability* 12 (9) 3748.

NIEMEIJER, R. A., DE VRIES B., BEETZ, J. (2008) Identifying Technical Obstacles for a Constraint-Based Mass Customization System, *9th International Conference on Design & Decision Support Systems in Architecture and Urban Planning*, Eindhoven .

PAUWELS, P., VERSTRAETEN, R., DE MEYER, R., VAN CAMPENHOUT, J. (2009) Architectural Information Modelling in Construction History, *Proceedings of the Third International Congress on Construction History* 3 (May); 1139–46.

RODRÍGUEZ-MORENO, C., REINOSO-GORDO, J., F., RIVAS-LÓPEZ, E., GÓMEZ-BLANCO, A., ARIZA-LÓPEZ, F., J. ARIZA-LÓPEZ, I. (2018) From Point Cloud to BIM: an Integrated Workflow for Documentation, Research and Modelling of Architectural Heritage, *Survey Review* 50(360) 212–31.

SAVAŞ, A. (2019a) *Research and Conservation Planning for the Metu Faculty of Architecture Building By Altuğ-Behruz Çinici*, Ankara.

SAVAŞ, A. (2019b) The Metu Campus Documented V: Representing Itself May 2019, Tu Delft, *Metu Journal Of The Faculty Of Architecture* 36 (1) 285–95.

SAVAŞ, A., DINO, I.G. (2019) Constituting an Archive: Documentation as a Tool for the Preservation of the METU Faculty of Architecture, *100 Years Bauhaus, What Interest Do We Take In Modern Movement Today?*, eds. M. Melenhorst, U. Pottgiesser, T. Kellner, and F. Jaschke, Berlin: Lemgo; 319–31.

SAVAŞ, A., DEREBAŞI, B., DINO, I.G., SARICA, S., İNAN, S., AKIN, Ş. (2018) *Research and Conservation Planning for the METU Faculty of Architecture Building Complex by Altuğ-Behruz Çinici, Ankara, Turkey*, Keeping It Modern Project Report, Getty Foundation, Los Angeles.

STOUFFS, R., TER HAAR, A. (2006) Constructing Design Representations BT - Intelligent Computing in Engineering and Architecture, ed. Ian F C Smith, Berlin, Heidelberg, Springer; 653–62.

US DEPARTMENT OF ENERGY. (2010) *EnergyPlus Engineering Reference: The Reference to EnergyPlus Calculations*, US Department of Energy, Berkeley.

VOLK, R., STENGEL, J., SCHULTMANN, F. (2014) Building Information Modeling (BIM) for Existing Buildings - Literature Review and Future Needs, *Automation in Construction* (38) 109-27.

YAN, W., CULP, C., GRAF, R. (2011) Integrating BIM and Gaming for Real-Time Interactive Architectural Visualization, *Automation in Construction* 20(4) 446-58.

Alındı: 02.04.2021; **Son Metin:** 17.01.2022

Anahtar Sözcükler: koruma planlaması; modernist mimari; tarihi değeri olan binalar; tarihi bina bilgi modellemesi; mimari görselleştirme

20. YÜZYIL MODERNİST MİMARİSİNİN KORUNMASI İÇİN TARİHİ DEĞERİ OLAN YAPILARIN BİNA BİLGİ MODELLEMESİ

Tarihi yapıların koruma planlaması, ilgili bina bilgilerini yakalamak, temsil etmek ve görselleştirmek için etkili araçlar gerektiren, değere dayalı, disiplinler arası bir süreçtir. Bu sürecin bilgi yoğun doğası, oldukça heterojen, parçalanmış ve yapılandırılmamış tarihi bina bilgilerini sürdürebilen bir modelleme ortamı gerektirmektedir. Bu makale, 20. yüzyıl Modernist bir yapı olan Orta Doğu Teknik Üniversitesi Mimarlık Fakültesi binasının bir Tarihi Yapı Bina Bilgi Modelinin (HBIM) geliştirilme sürecini takdim etmektedir. Modelleme çabaları, bu eşsiz bina için bir koruma planı geliştirmeyi amaçlayan ve Getty Foundation, Keeping It Modern hibesi tarafından desteklenen bir araştırma projesinin parçasıdır. Modelleme sırasında veri toplama, temsil, görselleştirme ve entegrasyon ile ilgili çok çeşitli teknolojiler kullanılmıştır. Model oluşturma sürecinde, mevcut model şeması, toplanan verilerin temsili için yukarıdan aşağıya (*top-down*) bir yaklaşım kullanılarak genişletilmiştir. İlgili teknolojilerin kullanımı, HBIM'in çeşitli değerlendirme sonuçlarını temsil etme kapasitesi, HBIM'in kolaylaştırdığı farklı görselleştirme modları ve HBIM ile bina performans değerlendirmesi için yardımcı araçlar arasındaki veri entegrasyonu olanakları tartışılmıştır. Sonuç olarak, HBIM'in tarihi binalar için mevcut bina bilgilerini güncellemek, görselleştirmek ve bu bilgilere erişmek için sürekli olarak kullanılma potansiyeli konusu değerlendirilmiştir.

HERITAGE BUILDING INFORMATION MODELLING FOR CONSERVATION OF 20TH CENTURY MODERNIST ARCHITECTURE

Heritage building conservation planning is values-based, interdisciplinary process that requires effective means to capture, represent, and visualize relevant building information. The information-intense nature of this process requires a modelling environment that can maintain heritage building information that is highly heterogeneous, fragmented and unstructured. This paper presents the development of a custom-made Heritage Building Information Model (HBIM) of the Middle East Technical University Faculty of Architecture building, a 20th-century Modernist structure. The modelling efforts were part of a research project supported by the Getty Foundation, Keeping It Modern Grant, which aimed at the development of a conservation plan for this unique building. A wide variety of technologies regarding data acquisition, representation, visualization and integration were used during modelling. In the process of model construction, the existing model schema is extended using a top-down approach for the representation of gathered data. We discuss the use of the relevant technologies, HBIM's capacity in representing assessment information, different modes of visualization that HBIM facilitates, and possibilities of data integration between HBIM and auxiliary tools for building performance evaluation. In the end what is assessed, is the HBIM's potential to be continuously used to update, access, and visualize as-is building information for heritage buildings.

ŞAHİN AKIN; B.Arch, M.Arch.
Received his bachelor's degree in architecture from Izmir University of Economics, and master's degree in architecture from Middle East Technical University. Currently a Ph.D. candidate in Engineering at the Norwegian University of Science and Technology's Industrial Ecology Programme. Major research interests include building performance assessment, energy efficiency, building informatireon modeling (BIM), virtual reality for design. sahin.akin@ntnu.no

AYŞEN SAVAŞ; B.Arch, M.Arch., PhD.
After being trained as an architect in the METU Department of Architecture and Bartlett School of Architecture, she received her PhD from the History, Theory, and Criticism Program at MIT. Currently, she is teaching courses on representation and architectural design at METU. aysens@metu.edu.tr

İPEK GÜRSEL DİNO; B.Arch, M.Arch., PhD.
Completed her bachelor's degree in architecture in Gazi University and received her master's degree in architecture at Middle East Technical University. She pursued her studies further in computational design at Carnegie Mellon University in USA (M.Arch) and Technische Universiteit Delft in the Netherlands (PhD in Architecture). ipekg@metu.edu.tr