Krzysztof Koszewski*
orcid.org/0000-0002-7907-746X

Jakub Franczuk**
orcid.org/0000-0003-1209-4449

Karol Argasiński***
orcid.org/ 0000-0002-8250-7109

Architectural Heritage Virtual Models in Conservation Practice

Wirtualne modele dziedzictwa architektonicznego a działalność konserwatorska

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Introduction

Digital models of historical buildings have played a crucial role in studying and protecting architectural heritage for nearly forty years. Their applications and the evaluation of their potential in widely understood conservation have evolved from purely popularization models, through research purposes, to design models. This article presents and discusses applications of architectural heritage digital models in the three abovementioned main areas of use.

Architectural heritage virtual models

The initial interest in creating architectural heritage virtual models dates back to the 1980s. The work of the ABACUS team in Glasgow, under the supervision of Tom Maver, was where the creation of the 3D city model began in 1984.[1] The three-dimensional virtual model for a hypothetical reconstruction of the original Winchester Cathedral performed in 1984–1986 was among the first model activities related to historic buildings.[2] Also, earlier work related to the Roman Temple of Sulis-Minerva at Bath, from 1983–1984 was among the initial models of such type.[3] These works, particularly the Winchester Cathedral model presented as the animation, gained considerable publicity and resulted in further ambitious projects, such as the reconstruction of Cluny III Abbey under the supervision of Manfred Koob in 1989.[4]

The abovementioned examples (except Virtual Glasgow) were intended to create a visual story about no-longer existing historical buildings. These models served a particular purpose, which was a sequence of illustrations or a film. They were based on architectural, historical, and archaeological knowledge; however, the main scope was heritage popularization.

As available modeling and visualization techniques developed, the reception of the created virtual environments in relation to the simulated historical reality gained importance, both in terms of the presentation methods and the need for accessibility and interoperability of the developed models (also in the long run).[5] Moreover, the potential of these models in knowledge

* *Ph.D. D.Sc. Eng. Arch., Faculty of Architecture, Warsaw University of Technology*
** *M.Sc. Eng. Arch., Faculty of Architecture, Warsaw University of Technology*
*** *M.Sc. Eng. Arch., Ph.D. candidate, Faculty of Architecture, Warsaw University of Technology*

* dr hab. inż. arch., Wydział Architektury Politechniki Warszawskiej
** mgr inż. arch., Wydział Architektury Politechniki Warszawskiej
*** mgr inż. arch., doktorant, Wydział Architektury Politechniki Warszawskiej

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codification, space-time presentation, and semantic relations is also indicated.[6]

The creation and usage of digital heritage models pose a significant problem in terms of their reliability and research rigor observance, for instance, in the field of the uncertainty of a visualization or with regards to enriching the models semantically in the historical sources' context.[7] The adopted standards, such as the London Charter,[8] facilitate the preservation of these values, proposing the methods of conduct applied to modeling activities. Adequately prepared and documented digital models can be a valuable research tool.

The potential of digital heritage models can be considered to be the referencing of typological criteria based on the purpose for which the model is created and used. These goals include: popularizing, research, and design (alternatively related to facility management). Another criterion is the modeled object's status, namely whether it still exists or not. As stated above, digital models were initially associated with popularization purposes. They were also related to the reconstruction of no-longer existing objects. In this case, they are commonly referred to as virtual reconstructions. It is worth noting that the adopted terminology, initially based mainly on archeology,[9] may lead to some ambiguity in interpretation. Reconstruction is quite rightly associated with a faithful recreation of a monument. In the case of no-longer existing structures, modeling is based on sources and strongly depends on their quality and credibility; thus, it often refers to interpretation and hypotheses. Therefore, to maintain concept precision, such models should rather be seen as simulations of the past. According to the modeling and simulation theory, the latter is used for experimenting and testing systems that cannot be engaged at a given moment. Indeed, this understanding corresponds to cases of no-longer existing heritage objects, which belong to the past. M. Forte commented on this case: "We do not reconstruct the past anymore; we perform the digital past."[10] As the abovementioned term "reconstruction" is widespread and commonly used, it is probably not worth redefining it, but at the same time we must keep in mind the specificity of such models. To avoid misunderstandings, it is worth considering the term "hypothetical virtual reconstruction," which indicates the supposed nature of the presented solutions. A new quality in creating models of no-longer existing structures is offered by their parameterization, as it enables the dynamic encoding of the model's specific features with the account to the nature of the knowledge. In this way, such reconstructions become full-fledged simulations of the past, which clearly emphasizes their hypothetical nature.[11]

The popularizing and research applications of architectural monuments models (including their hypothetical reconstructions) increasingly refer to the conservation practice following the change of its doctrine. An increasing amount of attention is being paid to public education aspects and information concerning heritage. In this way, such models may even constitute a requirement for effective action in the field of monument protection. In the light of successive declarations adopted by the ICOMOS and UNESCO, social awareness may be indicated as the essential criterion for the valuation of monuments,[12] whereas the dynamic changes in the surrounding reality require innovative thinking and unconventional actions. Gustavo F. Aroz,[13] the President of ICOMOS, called for such actions in his speech at the Second Congress of Polish Conservators in 2015. This approach applies, for instance, to the reconstruction of monuments damaged as a result of military hostilities. The admissibility of such a reconstruction was indicated in the Dresden Declaration[14] as strongly related to a sustainable sense of identity. Although nearly forty years have passed since the announcement of the abovementioned Declaration, discussions concerning the reconstruction of buildings destroyed during the Second World War are still intense in Poland. However, should these aspirations be interpreted in the light of the social reception of lost heritage, the hypothetical virtual reconstructions may at least partially assume this function, especially in the context of re-evaluations resulting from the pandemic crisis. The ubiquitous mediation of reality through virtual contacts (whatever its assessment as a substitute for direct relations, undoubtedly the technologies related to such communication have become popular and familiar) prompts an outlook on the role of virtual heritage models, particularly hypothetical reconstructions, also in this respect.

The usefulness of virtual (thus, intangible) heritage models in conservation practice is often juxtaposed with the characteristics of traditional conservation, which focus on preserving and protecting historical, physically existing substance. However, it seems that in addition to the abovementioned arguments regarding the public perception of monuments and research potential, other aspects of the evolving conservation doctrine are worth attention as well. Alongside the primary protection of the factual matter, the preservation of a monument's form and spirit should also be considered. Andrzej Tomaszewski discussed the protection issues related to these values and their characteristics.[15] In the case of virtual models, it is challenging to discuss the matter authenticity aspect. However, showing specific intangible values related to a monument may provide a discussion subject, especially regarding disseminating knowledge on heritage. Virtual models are often perceived as determined by characteristics of the digital tools used to create them, which force unambiguous precision and favorize explicit and specific knowledge at the expense of tacit knowledge. This aspect is, in fact, characteristic of the entirety of digital humanities. However, it would be wrong to assume that this "excessive" accuracy and sterility are characteristic exclusively for digital tools. As stated by, for example, Adam Miłobędzki's in 1973 (well before the era of virtual models), "however, it is worth warning against too realistic reconstructions that isolate the object from its cultural context and its dynamics, thereby presenting architecture 'statically,' in shapes as clean and orderly as if they used to exist in the conditions of utopia."[16] Therefore, this may be a feature of all activities aimed at recreating a no-longer existing condition, whereas appropriate methodology of activities remedies this problem regardless of the tools used.

Digital models are also becoming an increasingly important element of the practice related to the transformation of historical matter and design in the historical context and the active protection of this resource. It happens, among other reasons, thanks to the application of BIM (Building Information Modeling) technology in modeling architectural heritage.

Semantically-enriched object modeling

The application of BIM enables the creation of virtual building models. It also allows for the structuring and integrating of information sources, related data management, and interdisciplinary cooperation.[17] Since a significant part of the current building processes concerns the conservation, repair, and maintenance (CRM) of existing facilities, there is a growing demand for BIM technology development towards the surveying and recording of semantic information. The basis of the HBIM (Historic Building Information Modeling) approach is to determine the value, significance, and currently researched data about the structure under study.[18]

The model and its information are processed at different stages of the project, which allows for the integration of analyses, documentation, verification of existing conditions, technical details concerning the physical building's components, and facility management. At the same time, the BIM model maintains its structure and connections, enabling the elimination of information redundancy. It can also provide the basis for architectural and conservation works, as it may be used to make the right design decisions. Through an integrated system approach, appropriate filtering, and information use, the entire life cycle of a building[19] may be viewed and managed, which is essential for historic buildings.

The use of HBIM in architectural and conservation practice is still under research and experiments related to information techniques development. Among the issues under discussion, the insufficient functionality of BIM processes should be mentioned concerning the demand and the data used in cultural heritage.[20] The majority of the current commercial BIM platforms are based on object-oriented modeling. They use predetermined procedures to combine individual model elements and can be read by other information systems. Parametric information and data beyond the definition of geometry are used to create an object, which is then part of a library on BIM platforms. Libraries of objects, created according to global standards and classification methods, may solve the complexity of recording the historical objects.[21] Thus, such data forms the basis for the interdisciplinary use of the model.[22] The universal approach to cooperation in BIM is also raised within the open BIM methodology.[23]

Procedural modeling allows creating complex geometric relationships and can be used as a recording and hypotheses testing means. Unlike traditional 3D modeling (MESH – mapping a given object's surface with a polygon mesh and NURBS – curves and surfaces created using control points), object libraries use variable parameters to define the volumetric properties of components, thereby simulating various assumptions in real-time. Parametric objects can be interpreted and transformed at a given detail level based on specific architectural analyses and studies.[24] Issues related to modeling with standards of detailedness were covered by R. Bruman.[25]

The complete mapping of the detailedness, heterogeneity, and variability of historical buildings over time is often impossible, despite the potential of predefined objects. Therefore, the models are significantly simplified in terms of visualizing reality and challenges appear regarding the reliability, quality, and understanding of data.[26] Research conducted under the DURAARK project[27] indicates that by enriching a BIM model with semantic information, the need for detailed geometry modeling may be reduced. Classification and assigning additional properties in HBIM enables evaluation at the level of individual elements by defining functions, determining the structure, assigning meaning, or linking external sources. Moreover, semantic enrichment allows for combining various heterogeneous sources, including historical data and conservation valorization.[28] J. Plume described the model created in this way as an Integrated Digitally-Enabled Environment (IDEE),[29] which can be used to understand the studied place fully, popularize knowledge and make the right design decisions.

An example of the HBIM model based on laser scanning of the Sztorch Tenement in Jarosław

The study of the Sztorch Tenement in Jarosław provides an example of the potential of semantically-enriched object modeling. The building is subject to conservation protection based on an entry in the register of monuments No. A-850 of April 9, 1997. The building was erected at the beginning of the twentieth century (around 1910), and its technical condition was described as good. In the post-war period, the tenement was renovated several times. Currently, only a small percentage of the plaster in the lower parts of the facade is damaged. According to the monument's record sheet,[30] the most critical conservation postulates include the preservation of the facade décor and maintaining the body of the tenement house. Hence, the described model puts the most significant emphasis on the exact reproduction of these aspects.

The laser scanning method and photogrammetry were used to prepare the digital building survey of the

Fig. 1. Comparison of archive photo with the scanning data and HBIM model, from left to right: archival photo, laser scan, linear model view, visualization, photo source: Registration card of architectural and construction monuments no. A-850; by the authors.
Ryc. 1. Porównanie fotografii archiwalnej z danymi ze skanu i z modelu HBIM, od lewej do prawej: fotografia archiwalna, skan laserowy, model linearny, widok, wizualizacja, źródło: karta rejestracyjna zabytku architektury i budownictwa nr A-850; oprac. autorzy.

Sztorch Tenement. The obtained data was then used to create a highly detailed HBIM model (Fig. 1). It is crucial to plan measurement data acquisition and prioritization[31] when measuring monuments, as it helps determine the number of parameters necessary for registration. The constant development of laser scanners accounts for a reasonable compromise between the high accuracy of the record required in the case of works on the monument and the time spent making a model. Laser scanning extended by photogrammetry allows mapping reality at a very high level of detail (Fig. 2). This data provides the basis for creating 3D models filled with information. Thanks to the orthophotos recorded in color, it is possible to precisely visualize the object already at the stage of its survey. Such visualization can provide the desired amount of information to both an expert and a layman.

The point cloud database consists of combining the total data obtained from the laser scanner stations. Purging the object of undesirable elements (measurement errors, e.g., a reflection of the beam from glossy surfaces) constitutes an element of the process. Then, successive iterations of the point cloud are optimized for data size. The processing of point clouds is culminated by linking them to the BIM environment. Creating BIM models using point clouds helps to minimize the number of steps taken while inventorying an object and avoid losing accuracy, data quality, and mapping detail. Another advantage of this modeling method lies in the possibility of integration with other information systems, such as the GIS (Geographic Information System) environment or external databases.

For models of high visual quality (as in the case described), properly collected data is used to create com-

Fig. 2. Elevation view with sgraffito mapped using photogrammetry, against the background of a snapshot view of a model with a point cloud as a base; by the authors.
Ryc. 2. Widok elewacji ze sgraffito zmapowanym przy użyciu fotogrametrii, na tle widoku modelu wykonanego na podstawie chmury punktów; oprac. autorzy.

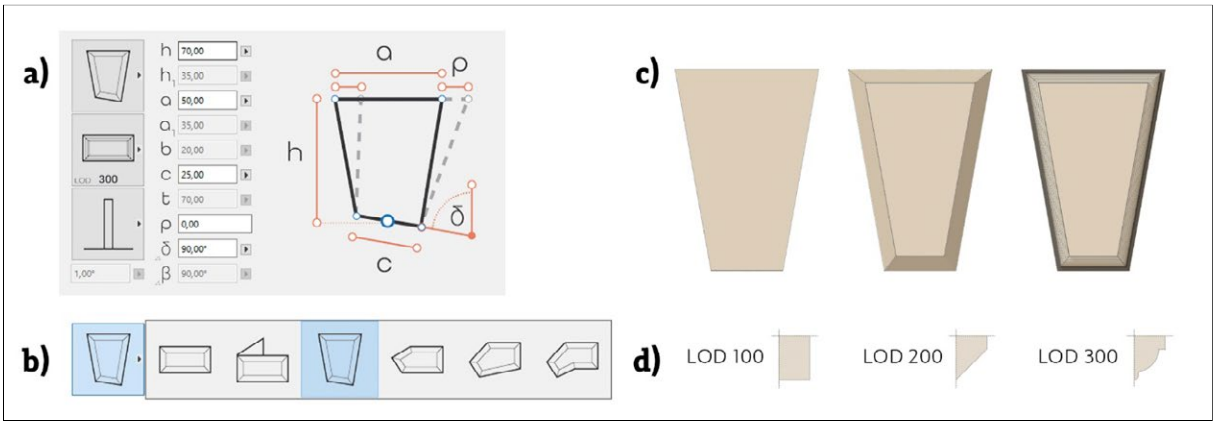

Fig. 3. A parametric object used to create rustication, developed for the project's purpose: a— interface for entering detailed dimensions of the element in the form of parameters, b—possibility of creating various shapes using a single object, c—possibility of changing the element's detailedness level depending on the needs, d—edge profile automatically adjusted to the detailedness level; by the authors.
Ryc. 3. Obiekt parametryczny użyty do wykonania boniowania, stworzony na potrzeby projektu: a – interfejs do wprowadzania wymiarów szczegółowych w postaci parametrów, b – możliwość tworzenia różnych kształtów przy pomocy pojedynczego obiektu, c – możliwość zmiany poziomu szczegółowości w zależności od potrzeb, d – profil krawędzi automatycznie dostosowany do poziomu szczegółowości; oprac. autorzy.

plex library objects. The process of the HBIM model creation, in this case also a possibly complete data repository, has been automated by using object-oriented modeling. Thanks to the possibility of projecting the point cloud in each generated view (floor plans, elevations, sections, and 3D views) and modeling with BIM building objects (such as walls, columns, or windows) could be practical and precise. In the Sztorch modeling process, both the objects existing in the software library and the proprietary ones (Fig. 3) were used in the case of atypical elements or items requiring a higher level of detail. They were created using GDL (Geometric Description Language – ArchiCAD programming language) and Grasshopper visual programming to create variable library elements that constitute a parameterized object-oriented representation of scanning measurements.

The model elements were enriched with semantics, color-related information, and historical data combined with archival drawings and photos. Based on such entered data, it is possible to manage the facility and plan future activities for the monument. A virtual building may enable a wide range of analyzes regarding the geometry of a tenement house itself. It also contains data from archival documentation and publications, such as descriptive or photographic information. With the use of this data, the geometry of the elements may be enriched or recreated (Fig. 4). It becomes possible to valorize it properly, mark its authenticity, modifications, defects, or missing and damaged elements (Fig. 5). The semantic data used in this case can also be applied to aid the initial determination of construction parameters (e.g., wall bearing

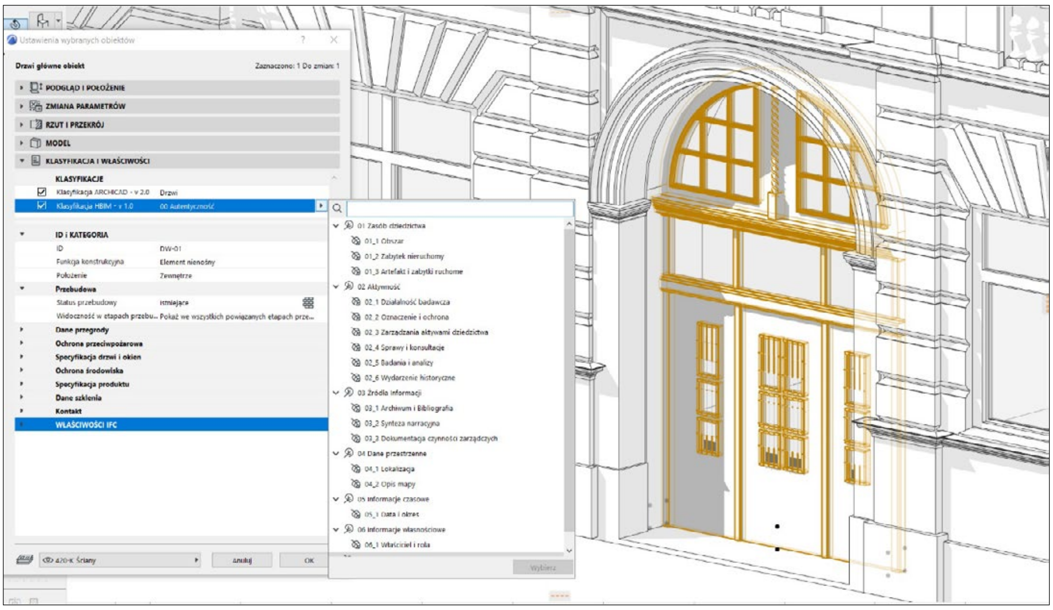

Fig. 4. Overview of the classification and historical properties of the modeled library element; by the authors.
Ryc. 4. Przegląd klasyfikacji i cech historycznych zamodelowanego elementu bibliotecznego; oprac. autorzy.

Fig. 5. Example of the possibility of filtering and visualizing information in the context of conservation valorization; by the authors.
Ryc. 5. Przykład możliwości filtrowania i wizualizowania informacji w kontekście waloryzacji konserwatorskiej; oprac. autorzy.

capacity) if this is impossible based on geometric representation alone.

This contextual set of information can be linked to a specific element, such as using a CDE (Common Data Environment) platform and used for the subsequent management of the monument. Thus, the HBIM model is a comprehensive interdisciplinary data environment of particular use in conservation design. However, it can also be applied during the building's occupancy, including ongoing maintenance works.

As a result, an HBIM model was obtained with precise spatial dimensions, parameterized as efficiently as possible (with elements such as walls, windows, ceilings, details of cornices). Rather than being only a record of geometry, these objects carry material and physical properties, defined at the classifying and defining stage of each objects' properties. Hence, the applied software can identify a specific geometry (modeled window or wall) within object specifications created for selected parameters. In the case of HBIM modeling, the classification of historical and conservation aspects is particularly extensive, as it comprises information on such aspects as the state of preservation, integrity, or individual element dating.

The issue of interoperability arises when data is used multiple times in various systems. As it is possible to exchange data and use open formats (such as IFC – Industry Foundation Classes), each subsequent user will not be confined to specific software to view the properties and classification of objects. It also enables long-term model development with geometric and semantic data, enriching it with new information, for example, data obtained as a result of further research.

As the semantic data is present in the classification and properties, integrated HBIM models facilitate effective conservation and design analysis (Fig. 5), facility management (thanks to the CDE platform mentioned above), and heritage popularization. Above all, modeling the monument information is characterized by a high detailedness of geometric and semantic information. This facilitates substantively appropriate and effective implementation of the design process and the precise planning and management of the various stages in conservation design.

Conclusion

Architectural heritage models may constitute a source database for the potential transformation of historical substance and active protection of this resource. Understanding the examined object, together with planning and managing design works, is likely accelerated and facilitated by integrating semantic information with parameterized 3D geometry. The integrated HBIM digital environment enables flexible modification and application of related resources, supporting the monument's protection in popularization, research, design, and documentation.

It should be emphasized that the documentation activities are in line with Andrzej Tomaszewski's predictions. As he stated in 1997, "Apart from preventive and integrated maintenance, the future of our discipline will be determined by conservation through documentation."[32] In a broader sense, this documentation can also be applied to virtual models, i.e., hypothetical reconstructions, being research tools.[33]

In architecture and conservation, HBIM models offer a new quality and allow the multi-faceted integration of activities and information in the design process. As such, the models require further research and discussion on developing information exchange standards and methods.

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Abstract

The article presents the issues concerning architectural heritage digital models' applications in conservation practice. These considerations are discussed in the context of the commencement of creating virtual models regarding no-longer existing historical buildings in the first half of the 1980s. Such models' applications and possible uses are analyzed within the adopted criteria that distinguish the following model types. Firstly, the popularization, research, and design models can be determined depending on the planned application. Secondly, depending on the status of the modeled object, models related to existing or no-longer existing buildings can be identified. The virtual models potential in the context of cultural heritage societal values is also discussed in the article. In such context, the authors discuss the creation of HBIM (Historic Building Information Modeling) models for the conservation activities purposes. The potential of semantically enriched object modeling is indicated based on the example of the Sztorch Tenement in Jarosław, for which a laser scan and its model were prepared.

Streszczenie

Artykuł przedstawia problematykę zastosowań cyfrowych modeli dziedzictwa architektonicznego w kontekście działalności konserwatorskiej. Jako tło rozważań przedstawione zostały początki tworzenia wirtualnych modeli nieistniejących budowli historycznych, sięgające pierwszej połowy lat osiemdziesiątych XX wieku. Zastosowanie i możliwości wykorzystania takich modeli analizowane są w ramach przyjętych kryteriów wyróżniających ich rodzaje: w zależności od planowanego zastosowania modelu – popularyzatorskiego, badawczego, projektowego oraz w zależności od statusu modelowanego obiektu – istniejący bądź nieistniejący. W tekście omówiono także potencjał wirtualnych modeli w kontekście społecznych wartości dziedzictwa oraz tematykę tworzenia modeli w technologii HBIM (Historic Building Information Modeling) na potrzeby działań konserwatorskich. Na przykładzie Kamienicy Sztorcha w Jarosławiu, dla której wykonany został skan laserowy obiektu oraz jego model, wskazano potencjał modelowania obiektowego wzbogaconego semantycznie.