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Application of HBIM as a Research Tool for Historical Building Assessment

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Abstract

The benefits and challenges posed by Building Information Modelling in documenting the existing buildings comes from the development of the digital support to the needs, compatibility and interoperability of applied technologies and at the same time of the available knowledge and skills to use a wide range of necessary technologies. Within the scope of Heritage Building Information Modelling, the use of 3D views has become a common practice, often hindered by complex geometry and layered time changes of constructive systems. Implementation of BIM for heritage buildings is developed through the procedures of designing parametric objects and selecting compatible technologies to create a rich information model. The paper presents the application of the 3D BIM approach in researching, documenting and interpreting the historic building of the baroque Palace of the Slavonian General Command in the historic core of Osijek, Croatia. Applied recording technologies, laser scanning, and thermal scanning, as support for HBIM, have been chosen according to selective research goals of the Palace of the Slavonian General Command. The method of simulating non-existent constructive elements from assumptions and analogies is presented as the preceding procedure of creating a HBIM library that opens the possibility of the broader dissemination of information on the explored heritage. The results point to the advantages of the model building approach for valorisation and interpretation of constructive changes over time, through the modelling logic, closely relating to the logic of construction.

Keywords: HBIM; Genesis Modelling; Digital Library; Palace of the Slavonian General Command; Osijek.

1. Introduction

Construction industry is changing towards digital manipulation of building information, communication improvement, use of innovations in projects aimed at reducing resource consumption. Simultaneously the society evaluate historical buildings according to their meanings and identity generation. The application of Building Information Modelling (BIM) in the field of architectural heritage was introduced by architectural information modelling [1, 2], where joining of architectural features provides a new set of information on individual elements in the virtual space. In [3] British Standard PAS 1192-2:2013, BIM is defined as "the process of designing, constructing or operating a building or infrastructure asset using electronic object-oriented information." Since sequencing of projects has been identified as one of the causes of irrational project management, responses are being reconceptualised in the new integrated process. A legislative

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guidance at European Union level suggests using information modelling in order to save a resource as a supreme goal [4]. Today, it is common practice to use a three-dimensional view for the historic legacy of immovable heritage. Contributions are demonstrated in the field of improved building documentation, management by remediation, alteration or use.

Integration of Heritage Surveying and Recording and BIM is a suggested methodology for documenting and managing of the historic buildings where parametric objects are created taking into account historical data, all of them registered as building components, including geometric and non-geometric attributes and relationships [5-7]. The methodology of making a multidimensional model is being developed simultaneously for new buildings and existing buildings [7, 8].

Authors [9] define Information Modelling of Historical Buildings or HBIM (Historical or Heritage Building Information Modelling) by introducing a set of levels and techniques that the concept comprises, and consider HBIM as "a new prototype library of parametric objects based on historical architectural data, as well as a mapping system for plotting the library objects on laser scan survey data". Authors [2] list three advantages of digital documentation of historical buildings: automatic measurement, identification and modelling of damaged or non-existent architectural forms and a broad use of modelling results. Authors [10] point out that 3D modelling of heritage is only the first step, and that VR (virtual reality) applications, 3D repositories and catalogues, and Web GIS open up further opportunities to improve the management of heritage buildings. Authors [7] state that the main advantages of modelling historical buildings are in the integrity of design and visualization, cost estimation, conflict detection, full planning implementation, or improved stakeholder collaboration. It is considered that data management optimization can also contribute to decontamination processes or necessary deconstructions, reduce errors and financial risks through step planning and sequencing of deconstruction, cost accounting, resource management, optimization of deconstruction or data management. Complex decisions are multi-supported by the BIM approach through the smooth distribution of quantified data, so this methodology is also promoted as quality assurance [11]. The development of BIM technology for the HBIM area also gives its general contributions such as energy analysis, economic analysis up to multi-thematic analysis within sustainability [12, 13]. In addition, new aspects open where basic information is generated in synthetic services for new aspects such as culture, tourism and dissemination of historical heritage information [14].

In the context of the aforementioned advantages for the implementation of HBIM to historic buildings, a number of challenges arise in the collection and processing of existing, not newly designed information: reliability of historical building documentation, information interpretation and intervention procedures, quality control, assessment and monitoring, space, management of data protection and renewal. Additional challenges are present in the processing of historic buildings: irregular geometry, non-homogeneous materials, variable morphology, not documented changes, damage and various stages of construction [15].

Recent extensive research also points to the barriers in using digital access: costs, awareness and competence as the three most important obstacles [16]. Interpretation of building heritage data over time provides a framework for the results and visualization of time changes in physical and social environments. Interpretation of historical documents goes in the opposite direction from modelling and simulation of its historical genesis present in adding vs. subtracting. The existing state is being used as a starting point and goes into the reverse engineering methodology. Ioannides et al. [16] described as follows: "The 3D object is almost separated into its structural elements in order to find the structure of the building, in addition to the irregularities, in the logic of" reverse engineering". 4D or information about changes of building through over time could be improved by using HBIM.

Recent findings highlight the problem of unconnected protocols and divergent techniques that causes "dispersion of information" [17], Significant efforts have been done in presenting critical review of divergent methodologies in HBIM that tries to structure the steps in surveying heritage [18]. In this article a set of techniques is presented as a hybrid approach combining image-based modelling techniques, thermal scanning and BIM in decision making about technique selection. The approach has been implemented into a 3D reconstruction tool dedicated to historical building genesis over time and reinterpretation of former findings. The proposed approach uses digitalized sources (point-cloud and digital images) in order to provide a rich support for the 3D modelling process while other techniques are led according to problem identification. This selective methodology tries to present new and innovative approach to HBIM growing pool of knowledge.

2. Set of Methodologies and Survey Techniques for HBIM

The methodological path of making models of historic buildings are not consistently applicable. One of the reasons is that every historical site is unique and customized methodology for measuring and interpreting historical facts and values must be developed. Another reason is the widespread use of various digital methods of documenting cultural heritage depending on the circumstances–availability of technology and competences of experts. In some cases, with the aim of a comprehensive interpretation of the building in a spatial context, the information chain for the construction of a historical building model undergoes interpretation in the regional environment, the urban environment and the interpretation and comparison of analogous building elements [17]. From these continuous standards, the authenticity and integrity of the heritage can be interpreted from a wider spatial and temporal context, in which GIS contribute to the database, spatial analysis and visualization. [6] (Dublin case) have proposed HBIM support using 3D GIS mapping of surveying environments as well as building data bases as catalogues for parametric objects of historic buildings. Multi-level research deepens the understanding of the authenticity of heritage and supports planning, revitalization and protection management. In a review article, [19] proposes a data collection framework for HBIM, for the scope of social domain, technology, processes, and regulation. Authors [20] set cultural heritage in the context of wide range of intangible and tangible significances of cultural heritage assets for assessing their resilience. There is a further development of disciplines so that social BIM and social HBIM terms are proposed as an addition to the technical information set for modelling [14, 22]. Authors [23] have proposed four major steps for constructing the existing building model using different technologies: 1) Selecting different technologies for documenting building geometry and creating 3D geometric models; 2) Data processing to create a complete and accurate 3D model; 3) Object recognition where 3D geometric models in the global coordinate system complement semantic information 4) Modelling in which the primary partial information model becomes a semantically rich BIM. In this spirit [24] is proposing the path of three questions to be answered – did we chose proper techniques for precise and accurate measuring; do we know what do we draw and does drawing present enough information and clear information to enable communication.

Authenticity is the value of heritage buildings that is much of the interest in dealing with heritage buildings. It is interpreted or demonstrated or wanted to be preserved. Contemporary techniques are developed today with the aim to be less harmful and invasive while producing as many reliable information. Photogrammetry has been used as a tool for collecting three-dimensional (3D) information of cultural heritage objects as well as texture and colour information.

Final products of digital scanning methods are clouds of dots varying in densities and accuracy that still depend on professional and manual interpretation. Modelling requires the creation of information saturated parametric models from the 3D point cloud. Cloud dots comprise quantitative spatial data of an existing object, while BIM approach provides quantitative and qualitative data with semantic support. The system to be established is a system for object modelling of physical components in building and designating elements. Such procedures are financially demanding as well as when considering human resources. Authors [25] suggested choosing of this method for complex surfaces and high detail levels. Authors [26] represent an approach that combines modelling techniques based on clouds of dots and images, and integrates them with architectural modelling features. 3D data can also be used in the reverse engineering process. Modelling of parametric objects adds complexity to the reconstruction of three-dimensional networks, since the software tools have not yet been sufficiently developed to automatically recognize and transform objects within the network into parametric objects.

Combining data obtained from digital scanning with data obtained by infrared passive thermography (IRT) the geometric, structural system and near surface properties of material composition, decay damages and moisture propagation complete information on the properties of building envelope can be obtained on non-destructive way. These data enable detection of near surface areas of different material properties what helps in planning of material sampling or detailed inspection of structure and non-structural parts of building with non-destructive or semi-destructive methods. Data obtained from material sampling are basis for building condition assessment. Inspection of historic building by the active infrared thermography the energy leakage can be identified and quantified enabling planning the measures for increasing of its the energy efficiency.

3. Case study–Baroque Heritage Military Administrative Building Modelling

The aim of the research is to develop a two-stage framework for the conceiving of information for the genesis of a historic building and to selectively verify the current interpretation of the building's genesis. The development of the Osijek historical part-the Fortress - derives from the presumptive locality of the medieval settlement, but for the context of the observed building, spatial development is more relevant, at the time of constructing of the baroque settlement ensemble. The observed baroque ensemble of the Fortress refers to the Osijek historical part of the city marked by historical continuity, preserved and emphasized by open space that divide it from the actual city centre. The Fortress is a planned constructed entity that consists of built-up parts (blocks) and open spaces (squares and streets) that create clear and predictable geometry in space. The main fortress square - the Holy Trinity Square already formed in the early period of the Fortress's construction, at the beginning of the 18th century, is positioned centrally and dominates the urban composition of the Fortress (Figure 1 and 2).

Figure 1. Aerial view of the Fortress Osijek

Figure 2. Photography of Baroque Palace of the Slavonian General Command in the main square, The Fortress Osijek

A perimeter construction contributes to the representativeness of the Square as well; there are situated the most important and most representative public buildings. The building of the Palace of the Slavonian General Command on the north front of the square was built in the period between 1723 and 1726 and it is assumed that in the first stage it was built as a one-floor building [27]. The closed form of the atrium was built till the 1765, and the fully closed block was accomplished in the second half of the 19th century. The time course of constructive changes on the largest civil baroque building in northern Croatia also brings stories from the social and economic life of the city. Implementing of all the components in one model was a challenge set to be carry out in a one-year project framework. The archive material review outlined four moments in the history of the building, crucial for the constructive changes of the observed building, as follows:

- Construction of one-floor building.
- Building of an additional floor and forming of the building block.
- Building of the second floor of the north wing.
- Removing the arcade in the atrium and replacing the part of the arcade by building a new concrete structure.

Although changes of the construction damaged the baroque characteristics of the building, it remained the largest public domain baroque building of the continental part of Croatia. The aim of the HBIM application to the building of the Palace of the Slavonian General Command was to align a series of 2D existing historical drafts and documentation made in the last ten years and allow further upgrading of information to create scenarios of protection and manage the building as well as to improve the communication concerning the building. The set of techniques were used to create the hierarchical structure of the building structure – building floors, building wing, construction, wall, pillar, vault, openings, etc. trying to create catalogue of main non existing structures of the building.

4. Methods

Based on the adapted methodology [28] (Figure 3) for the surveying of the complex and adapted methodology of Murphy et al. (2015) for the modelling of construction elements, the following framework for collecting and processing information within research was conceptualized:

- 3D BIM from 2D documentation.
- Laser scanning of baroque plastic entrance port and integration with 3D BIM model.
- Thermal energy assessment of atrium walls surfaces for interpretation of deconstruction of vaults.
- Interpretation of historical documentation over time in reverse engineering- four 3D HBIMs.

The model was created in the Autodesk Revit software with imported 2D layouts from AutoCAD. The compliance of the spatial model gained from current 2D documentation and historical documentation was additionally conducted by overlapping with the point cloud of the entrance segment of the building selected due to complex plastic. The modelling of the previous phases by subtracting elements set the task of simulating the construction of the southern part of the inner atrium and the way of extending the east and west wings with new constructive parts. The mismatch of the geometry of the arcade system that was knocked down during the early 20th century, and the current geometry of the wall cladding led to the need for additional research of the composition structures. As a non-invasive preview method, a thermal camera scan was used to determine differences in materials and create new assumptions.

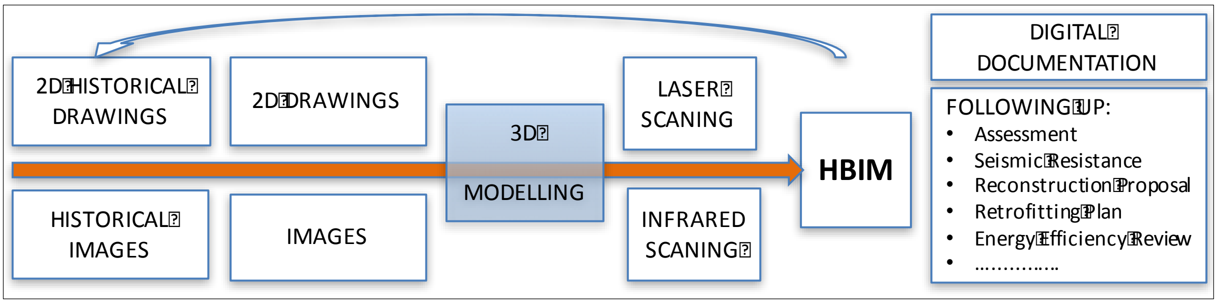


Figure 3. Adaptation of JHBIM approach–from 2D documentation to HBIM [28]

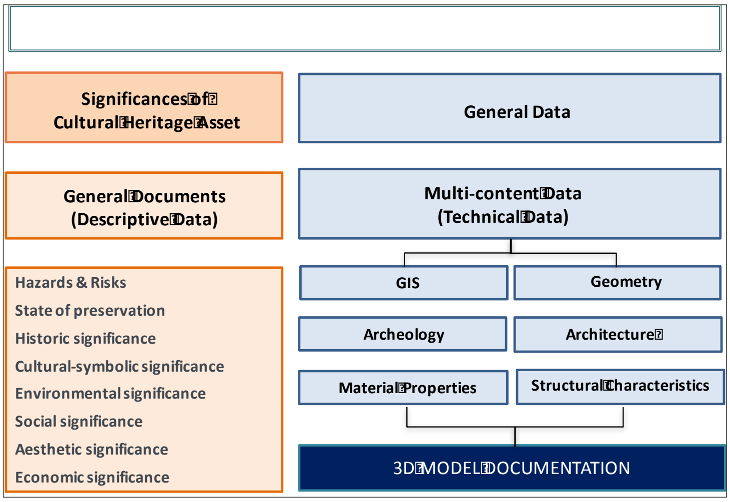


Figure 4. Content of digital documentation (H2020 INCEPTION [19])

The model presented in Figure 3 is based on the well-established approach to understanding of HBIM. However, it is mainly concentrated on part of tangible aspects of heritage asset. The main characteristic of heritage asset is its "story telling" ability, which is not yet enough recognized among the HBIM experts. The step forward in this direction is one of the main objectives of the on-going H2020 project INCEPTION (2015-2019) where both tangible and intangible aspects are integrated in 4D model (development of heritage site and heritage asset in time). The model, briefly presented in Figure 4, introduces the idea of two-folded HBIM model addressing both physical and intangible properties of cultural heritage assets. The 3D data are relatively easy to collect and process to be included in the 3D documentation. On the other side, more demanding set of data that largely introduces the 4th dimension (time) and intangible aspects and properties of CH asset, has a descriptive character. The main challenge is in including these data in HBIM traditional model. There are dispersed data available from public sources (internet, libraries etc.) and protected data (archives, heritage owners' collections etc.). One of critical questions is related to public availability of well-developed model of concrete heritage asset because it can content some critical data, which the owners and heritage managers are not willing to reveal because of different reasons (security, economic issues, legal issues etc.).

5. Results

5.1. 3D Historical BIM (HBIM)

The 3D BIM model LoD 1 was created in the first step for the whole building from the 2D documentation of existing structure (Figure 5). Parts that re architecturally most valuable, that carry the authenticity of the historic building were identified, followed by geometrically most complex parts and parts that need to be reinterpreted were identified regard limited time framework of the project. The baroque portal with the vestibule, the atrium and the roof construction were selected as structures to be additionally surveyed and upgraded to LoD3 levels.

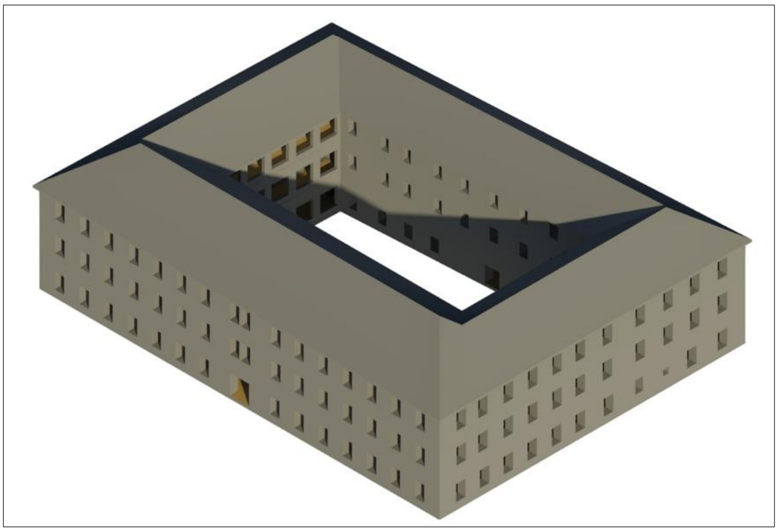


Figure 5. 3D BIM LoD 1 of existing building

Today's state of the building is the result of a series of changes, of which only those in the second half of the 20th century had the goal of maintaining and promoting the authentic baroque value of the building as well as the result of continuous use and alteration of use. The building was constructed as a residential and administrative house for military administration, government headquarters, a theatre, and today is the centre of higher education in Osijek. A constructive change matrix for modelling according to BIM logic and hierarchy, presented in Table 1 has been developed. In the first phase, the model of the existing building was designed and in reverse steps were previous phases reconstructed. Merging of the archive information interpreted from the analogue drawings were deeply examined as they were not fully overlapping. 3D representation through time stages enable multidisciplinary communication and information exchange within the team of art historian, architects, civil engineers and BIM technicians.

Table 1. Dynamic of the building changes over the BIM hierarchy

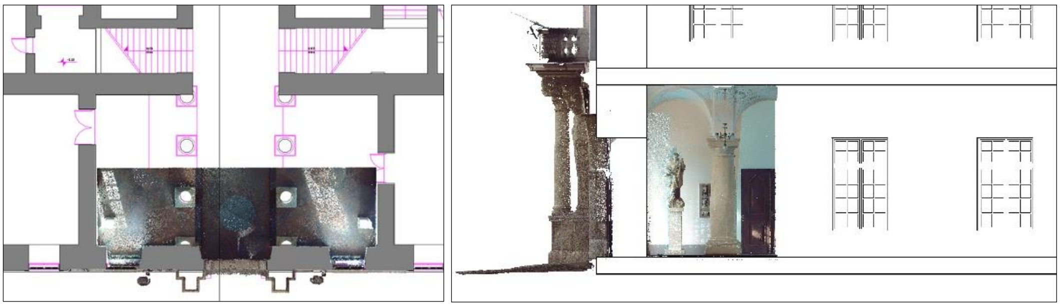
Year	Volume	Level	Construction	Openings	Facade plastic	Colour
1930	△	-	◆	△◆	△	◆
1889	▲	▲	◆	△◆	△	-
1765	▲	▲	▲	▲	▲	-
1726	-	-	-	-	-	-

deconstruction△ construction▲ replacement◆

5.2. HBIM Portal and Vestibule Scan

Prior to scanning, the default location was prepared (Figure 6), markers and spheres were distributed to allow following steps in merging individual scans into one full cloud point. It was planned to collect information on entrance sculpture and the inner area of vestibule, circa 50 m^2 of the façade and 80 m^2 of the ground floor of the entrance. Preparation of the location lasts for two hours while the scanning was done in ten hours. Scanner Faro Focus 3D S120 was employed to scan the building façade segment and vestibule. The Focus3D S120 scanner emits a laser ray using a rotating mirror to the scanning area, then the device scatters the laser ray vertically in the range of 305 ° and 360 ° horizontally. From the object, it is reflected back towards the scanner. To deal with the laser scanning point cloud, Faro Scene and Autodesk Recap software were used for the registration process and removing noise from the laser scanning data.

a) **b)**



c) **d)**

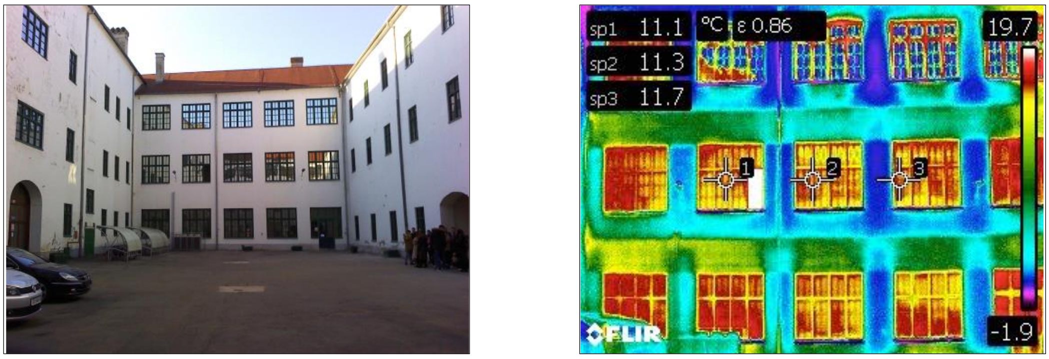
Figure 6. a) Spheres and marks for laser scanning Scanner Faro Focus 3D S120 b) Laser scanning process with Scanner Faro Focus 3D S120 c) Ground plan of merged model and cloud points d) Cross section of the merged model and cloud points

A wide range of data is collected by laser scanning: dimension, texture and colour represented in 3D coordinates, and resulted in 'point cloud data'. In addition, HBIM model was built by using Autodesk Revit 2017 and point cloud was inserted in the model. Model was slightly adapted to the dimension data provided by point clouds.

5.3. Infrared Inspection of Facades

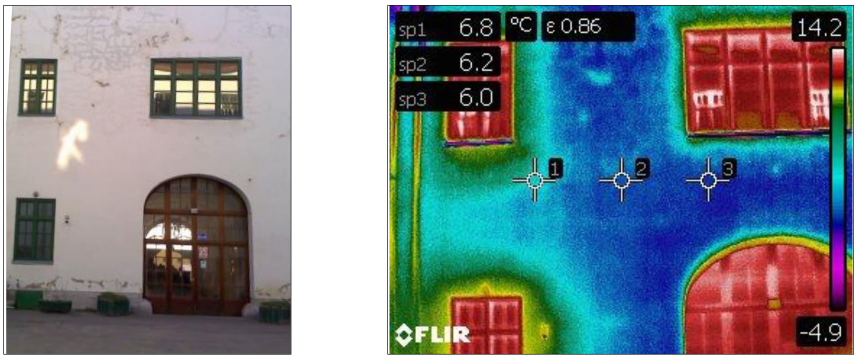
Infrared passive thermography has been used to identify the invisible structural system of the atrium facade of the western wing of building (Figure 7a and 9). Thermal picture (Figure 7b) clearly shows the reinforced concrete frame structure covered by render. The differences in depth of pillars and upper and lower parts of parapets, the materials from which they are constructed as well as the moisture content of render influence the thermal response of structure. The boundary between upper and lower part of parapet is clearly seen what shows the differences of materials. The upper part of parapet is constructed of reinforced concrete while the lower part is masonry. The coldest parts of structure are reinforced concrete pillars.

The atrium facade of the south wing of building (Figure 8a and 9) is constructed from the same type of material. The various moisture content in facade render and temperature bridges around the windows influence the differences in thermal response (Figure 8b).



a) **b)**

Figure 7. The atrium facade of the western wing (View A, Figure 9): (a) photography and (b) thermal picture



a) **b)**

Figure 8. The atrium facade of the southern wing (View B, Figure 9): (a) photography and (b) thermal picture

5.4. Modelling of the Atrium and Pillars

Construction changes in the atrium area occurred at the beginning of the 20th century mostly due to the adaptation of space to new uses. Figure 9 shows the first floor of the building with marked changes-the courtyard arcades on the eastern and western edges of the building were demolished and replaced by concrete corridors while the arcades of the southern wing were demolished and not rebuilt. This deconstruction significantly damaged the baroque principle of the continuity of outer and inner space; the exit from the main staircase to the open atrium space was disabled and the atrium has lost its representativeness.

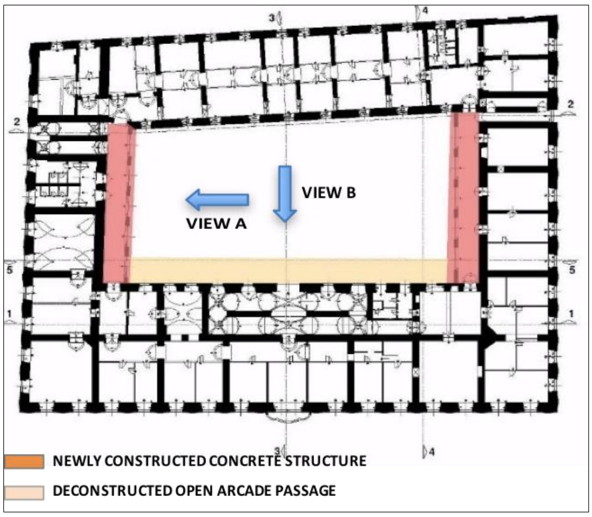


Figure 9. Drawing of the first floor of The Baroque Palace of the Slavonian General Command Osijek

The assumed dimensions of the pillars in the atrium space arise from the interpretation of the existing pillars of the entrance vestibule acquired in by laser scanning, 1906 photographs and modelling in the Autodesk Revit software. Modelling procedures are described in detail [6, 30, 31] suggesting procedures that derive from the logic and geometry of the classical column forms read from the Vitruvius Pattern book.

Within this research project, the family of constructive elements of the atrium were developed to allow for comparisons and evaluations and set up a hypothesis for reconstruction. The laser scan of the entrance vestibule provided a detailed analysis of the column geometry and the logic of its formulation for the assumption and modelling of the atrium column (Figure 10).

Figure 10. Development of the column in the atrium

6. Conclusion

BIM is a complex but multi benefit tool for exploring architectural heritage. Although time, knowledge and skill consuming it offers additional results that stem from the modelling process and possibility to constantly upgrade result. To reduce the negative issues of using new techniques (Ioannides et al., 2017) techniques should be rationally used for research purposes. Emergence situation or time and finance limited surveys are situation in which techniques should be selected to meet the need of the heritage building research. Nevertheless, clear and consequent procedures in modelling should be followed to enable transparent data building and to allow comparison with buildings of similar characteristics or from similar historic period. Modelling procedures could also provide the insight for authenticity and regional originality or indicate the work of artist or craftsman from wider area.

In this paper set of techniques for building of 3D HBIM were presented. Selection of the non-destructive techniques was established to bring new insight for the most valuable parts of the building; the one that remained as well as for those that were only documented in the archive. While modelling methodology is closer to building process than handling vector documentation it contributed to the reinterpretation of heritage construction. A series of historical sources were inscribed into one model and new assumptions could be established. Some new conclusion about building genesis of Palace of the Slavonian General Command, in Osijek, enabled by 3D simulation, were brought and further investigation were planned accordingly.

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