


## Article

# Ranking of Heritage Building Conversion Alternatives by Applying BIM and MCDM: A Case of Sapieha Palace in Vilnius

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**Abstract:** A balance (symmetry) between socio-cultural and socio-economic benefits as a part of the economic, social, and cultural development policy of each city and country should be assured when converting built heritage. To anticipate building conversion priorities and opportunities, modern technologies can be employed. However, currently the activity of reconstruction of heritage buildings is part of the construction domain wherein modern digital technologies have been the least ever applied. Therefore, photogrammetry and the 3D modeling of existing heritage buildings was suggested. A case study of Sapieha Palace, built in the Baroque style in 1689–1691 in Vilnius, Lithuania was explored in this research. The applied technologies and software (Agisoft Photoscan, Autodesk ReCap and Autodesk Revit) allowed for the creation of a high quality and accurate model involving both the textured exterior of the building and the interior layout. In addition, the valuable features of a building were identified and marked in a three-dimensional digital model. Based on the model, the authors formulated possible conversion alternatives of the building and identified the associated decision-making criteria, as well as determined their relative significance by an expert survey method. The authors suggested the application of the multiple criteria decision making (MCDM) method under uncertainty, namely the rough weighted aggregated sum product assessment (WASPAS), for ranking alternatives according to multiple criteria. Therefore, the suggested integration of modern digital technologies and decision-making models helps to assure the rational conversion decision of built cultural heritage based on high accuracy data as well as contributing to the sustainable development of engineering processes.

**Keywords:** heritage building; photogrammetry; 3D modelling; MCDM; Rough WASPAS; expert survey

## 1. Introduction

In the modern conditions of commercialization, the problems of reconstruction and restoration of historic buildings have become especially important. Parts of historic monuments have been disappearing due to real estate developers who are eagerly destroying the existing building and building a new one, because it is usually faster and cheaper than reconstructing the old one. Moreover, this is not only due to the greed of new owners, but also because of the complexity of conversion processes. However, lately a so-called global real estate revolution has been transforming the urban landscape everywhere. Development and redevelopment projects have mixed up in real estate construction [1]. While in previous years, the practical challenges of promoting built heritage protection and sustainable urban development were conceived of as discrete, contemporary conceptualizations and policies view the two as interrelated and mutually enforcing [2].

Cultural heritage is an important cultural asset taken over by the state and its inhabitants over several generations. Heritage diversity and peculiarity is linked to the state's history. Heritage means

what is inherited both materially and spiritually. Materially cultural heritage is considered the ancient objects and their surroundings surviving from ancient times. Such artifacts or places have historical, archaeological, ethnological, mythological, memorial, religious, architectural, urban, artistic, and scientific value. The material cultural heritage relatively can be divided to movable or immovable heritage [3].

The built cultural heritage is also understood as real estate, i.e., the immovable material property that was created during the construction process and everything that is related to the construction activity and now used by the public. Heritage objects can be classified into several groups: buildings (residential houses, industrial buildings, special purpose buildings, etc.); objects of urban heritage (historical parts of the city, old towns, their districts, small towns); sites of historical events, also buildings and related objects that are associated with famous state persons, writers, artists, scientists, history of science and technology; works of fine monumentalism, applied and decorative art [3,4].

The built cultural heritage has a unique educational and socio-economic benefit. Heritage may be used for promoting urban sustainability [5], thus managing and using heritage buildings creates new jobs and resources for the economy. In addition, cultural heritage forms an exceptional benefit associated with the socio-cultural and socio-economic good, as part of the economic, social, and cultural development policy of each country [6].

The use and maintenance of the objects of the cultural heritage must be beneficial not only socially, but also economically. Ideally, cultural heritage objects should be continually used for their primary purpose, especially for small-scale enterprises working in traditional methods. In this case, the historic buildings would become the company's brand. Naturally, facilities should be upgraded in the heritage sites. Engineering communications need investments in energy efficiency improvements of a building and sometimes site cleaning from soil contamination is needed. Nevertheless, the valuable properties of cultural heritage would be preserved [4].

To anticipate building development/redevelopment priorities and opportunities, modern technologies can be employed. However, currently the activity of restoration and reconstruction of historic buildings is the area of construction where modern digital technologies are the least ever applied. Nowadays, building information modelling (BIM) technology is usually applied to new buildings. Due to the specific nature of the tasks to be solved and the lack of spatial data for the use of BIM, there are not many examples of its application for existing buildings, but this is a rapidly expanding area in the context of research and professional practice. The documentation of 3D historical buildings (HB) is a necessity for the preservation and proper management of built heritage [7–9].

The use of BIM technologies in the renovation and restoration processes of existing historic buildings is called the Historical Building Information Modeling (HBIM) [10] or heritage building information modelling (HBIM) [11]. In general, the use of BIM technologies in historical, cultural heritage, and reconstruction of old reconstructed buildings is similar as it differs only at the level of available information and potential intervention. The same information technology and the same equipment are used: advanced computing equipment, the latest data processing software packages, high-precision laser scanning devices, high definition and photogrammetric capture, reliable positioning and precise orthophotogrammetry/aerial photography techniques (airplanes, flying and drones). However, it is not enough to have the most advanced and accurate equipment, it is necessary to have sufficient competence, skills and qualifications.

When initial documentation (3DHB) is prepared, a question arises how to select the most efficient sustainable development strategy of a building or urban territory. Making research or performing construction or building maintenance works, the question often arises as to how to make effective and rational decisions to solve technological and management tasks by simultaneously evaluating alternative solutions according to several contradictory criteria. In search of the best alternative to possible solutions, multiple criteria decision making (MCDM) methods are increasingly being used to solve theoretical and practical problems, as the large number of indicators and alternatives that are evaluated make the formal decision-making process insufficient. Multiple criteria decision-making methods are a way

of simultaneously evaluating several alternatives according to several often-conflicting performance indicators. A key feature of MCDM methods is that their solution cannot be the best for all criteria. A result is appropriate for all criteria but not ideal for each criterion individually. There are many methods for solving multi-criteria problems that differ by solved problems and their complexity, by the type of data used, or by the number of individuals involved in the decision-making process. Each method has its own advantages and disadvantages, an algorithm, and highlights a different aspect of the analyzed object or situation. A comprehensive overview of MCDM methods and their application for engineering and sustainability issues can be found in several review publications [12–16].

The authors presented one of the first attempts to apply BIM and MCDM for building redevelopment possibilities in 2016 [17]. The weighted aggregated sum product assessment method with grey attributes scores (WASPAS-G) for ranking redevelopment alternatives of currently inactive factory has been applied. In the current research, the authors focus to a precise 3D model preparation of the existing historical building by applying aerial photography techniques. Next, they suggest the application of the novel Rough WASPAS method developed in 2018 for ranking alternatives under uncertain conditions.

The paper is structured in five sections. In the first section, introductory considerations about a concept of built heritage, importance of its preserving and the need of applying HBIM as well as MCDM for effective HB development are provided. In the second section, a literature review is carried out presenting preparation peculiarities of 3DHB, application of MCDM for HB, and demonstrating application of Rough WASPAS method in different areas. The third section presents research methodology, consisting of the principal scheme of the research, 3DHB preparation steps and Rough WASPAS approach. The fourth section presents a case study of Sapieha Palace: 3D modelling results, description of possible redevelopment alternatives, development of criteria system and alternatives ranking results. The fifth section contains concluding remarks.

## 2. Literature Review

A short literature review is carried out presenting 3DHB preparation peculiarities, the application of MCDM for HB, and the application of the WASPAS method under an uncertain environment, including Rough WASPAS.

### 2.1. Application of 3D Modelling and BIM Technologies to Built Heritage

The study of built heritage requires a lot of analytical work with archival and design documentation and old photographs. The result of digitization of this material is the creation of databases of parametric objects, which include volumetric models of architectural monuments and sets of their elements, as well as general information about the object: description, photos, cartographic information, etc. Archives of such databases allow an increase in search speed and accuracy in order to obtain reliable information about the object.

Ilter and Ergen [18] divide research of existing buildings into the following stages:

- building data collection and “as-built” model development;
- energy consumption modeling and management;
- evaluation of structures;
- access to and integration of technical information and data;
- exchange and interoperability of information.

Geometric and topographical information has to be collected to create a BIM model for a building under reconstruction. In a case if a reliable data acquisition technique can provide a fully informative BIM model, information about the existing building can be used to manage documents or other tools [19].

In practice, this process begins with data collection and data processing, e.g., by laser scanning or photogrammetry, by using structural details and construction materials from historical and architectural

books, databases of object elements are created. The correlation of parameter objects with laser scanning data allows for the creation of the final virtual 3D model of a historic building. This detailed 3D model can provide most of the information about the object and the elements of the object, such as used building materials, operating cost reduction schedules, energy consumption, visualization, drawings, section planes, etc. [20].

According to Dore and Murphy [10], HBIM simply can be described as a system designed for modeling built heritage objects from remotely obtained data (laser scanning or photogrammetry) using BIM software. While, Reinoso-Gordo et al. [11] observe that the HBIM development process requires additional features that are lacking in standard BIM software packages, such as the lack of tools to model highly complex and irregular shapes, sloped walls or variable geometry elements. HBIM is a new approach to historical building modeling, which consists of a library of parametric objects based on historical architectural data.

Each historic building has its own architectural identity and valuable qualities, original or emergent due to historical changes over time. It is a feature or an element of a building that is valuable from an ethnic, historical, aesthetic or scientific point of view. By modeling a building, valuable properties can be divided into the following groups:

- structural: walls, columns, floors, beams, roof;
- architectural: parapets, balconies, windows and doors, architectural solution of facades;
- artistic: interior decoration, molding, painting, geometric elements.

HBIM, respectively, can be divided into three major sub-models: structural, architectural and engineering [11]. Assigning valuable properties of a building to the appropriate sub model helps proper maintain and manage a building.

With regard to the use of built cultural heritage, the value of HBIM for historical and architectural monuments must be appreciated. In addition to all the above benefits, BIM provides new opportunities for the participants in the construction project to monitor and research [8,21–23]:

- This is a new way to capture and store information about cultural heritage. The building model can be used as a documentation database and as a navigation timeline, which introduces the phases of an object's history. An "electronic passport" is assigned to each historic or architectural monument.
- The ability to create a global cultural heritage information system that, along with the model, includes historical manuscripts or architectural book clippings. "Inside" information about a building becomes publicly available through multimedia content, such as virtual reality.
- The model allows for analysis of the object in complex, or in parts, and it is applied at all stages of work with the object.
- A new "technological bridge" between the past and the present has emerged; libraries of parametric elements make technologically accessible "old" architectural ideas for new design and construction.

The main reason that determines the limited information modeling of historical buildings is the cost of the procedures. Even when large construction companies use BIM in their projects, small businesses do not have enough resources to invest in HBIM when working with historic buildings [23,24].

## 2.2. MCDM for Built Heritage

Construction heritage is an important part of social, economic, historical, architectural and cultural uniqueness in many countries. Historical buildings differ from other buildings in two main ways, which can affect their conservation or use:

(1) Physical properties, as these buildings may have a complex and unusual geometry, unconventional building materials used for construction of these buildings, they can be diverse in their composition, buildings have no insulation, and use passive and natural ventilation.

(2) Principles of preservation, as the reconstruction of built heritage is regulated by established principles and procedures of conservation, which require protection of historical value and characteristics of a building [25].

Because of these differences, revitalization technologies used in present-day buildings can be useless for and may cause damage to traditionally constructed buildings, leading to loss of cultural heritage. As the refurbishment of heritage buildings is described by multiple criteria, multi-criteria decision making (MCDM) methods can be applied to find rational solutions for construction heritage revitalization or conservation [26].

MCDM methods suggested to use for built heritage decisions are becoming more applicable for various problems in civil engineering, construction and building technology. After analyzing Clarivate Analytic Web of Science publications, it can be stated that the topic of heritage buildings is widely analyzed in engineering civil, construction building technology, materials science multidisciplinary, architecture, computer science interdisciplinary applications and computer science categories [26].

MCDM for heritage buildings most often used for: evaluation process of historic building revitalization [27–29], planning reconstruction of a historical building [30], cultural heritage preservation, renovation and adaptation to social needs of population [31].

Most commonly used criteria systems for evaluation of assets refurbishment solutions are [14,27–29,31–36]:

- Architectural criteria (building's physical condition, architectural features, technological value, materials and decorations of the building, by-laws, codes).
- Environmental criteria (location, scenic/contextual value and environmental effect, regional development policies, potential environmental quality of surroundings).
- Economic criteria (financial possibilities, subsidize, investments, profit margins, benefits of exemption).
- Technological criteria (project preparation and coordination, construction work duration, building lifetime, possibilities of building adaptation to current needs).
- Social criteria (suitable with public interest reuse, social value, increasing public awareness, enhancing role of communities).
- Cultural criteria (historical value, artistic value, conditions of integrity, originality).
- Continuity criteria (adequate protection and management system, feasibility of future change, ecological and cultural sustainability).

The three most often used MCDM methods in the area are the analytic hierarchy process (AHP), the analytic network process (ANP) and fuzzy Delphi. Experts' knowledge is also used for assessment of cultural heritage value and selection of optimal alternative for its conservation or refurbishment [26].

Therefore, the direction of built heritage research applying MCDM was established as follows: evaluation of historic building reconstruction alternatives, examine reuse adaptability of each case, research in possibility to use a particular solution in future for different objects of built heritage. It is also established that MCDM is practically not used contemporaneously with BIM or HBIM technology.

### 2.3. Application of WASPAS Method under Uncertain Environment

The crisp WASPAS method was proposed by Zavadskas et al. in 2012 [37]. Since now, its applications have been comprehensively reviewed in a number of publications, including a research of Stojic et al. [38].

In addition, several extensions of the method under uncertain environment have been proposed recently. Two basic extensions, WASPAS with grey numbers (WASPAS-G) and WASPAS under fuzzy environment (WASPAS-F) were developed in 2015 [39,40]. The WASPAS method with interval type-2 fuzzy sets was developed in 2016 [41]. Integration of the WASPAS and single-valued neutrosophic set is suggested as well as applied in [42,43]. Zavadskas et al. [44] developed a combination of the



WASPAS method with an interval valued intuitionistic fuzzy numbers (WASPAS-IVIF). A paper of Nie et al. proposing the WASPAS method with interval neutrosophic sets was published in 2017 [45].

Many research papers apply crisp or uncertain WASPAS, or the method in combination with other MCDM methods in the domain of civil engineering. Several groups of problems can be identified: location or site selection [39,43,44,46]; energy supply, renewable energy sources, optimal indoor environment, nearly zero-energy buildings [47–51]; logistic problems and supplier selection [41,52,53]; contractors or personnel selection [40,54].

A single paper is related assessing building redevelopment possibilities by applying WASPAS-G [14].

As regard to assessment of relative weights of criteria, WASPAS the most often is applied in combination with AHP [14,39,55–58] and SWARA [40,59,60].

The newest development of the method with rough numbers (Rough-WASPAS) was suggested by Stojić et al. last year [38]. It does not yet have many applications [61,62], therefore, it is worth further investigation.

### 3. Research Methodology

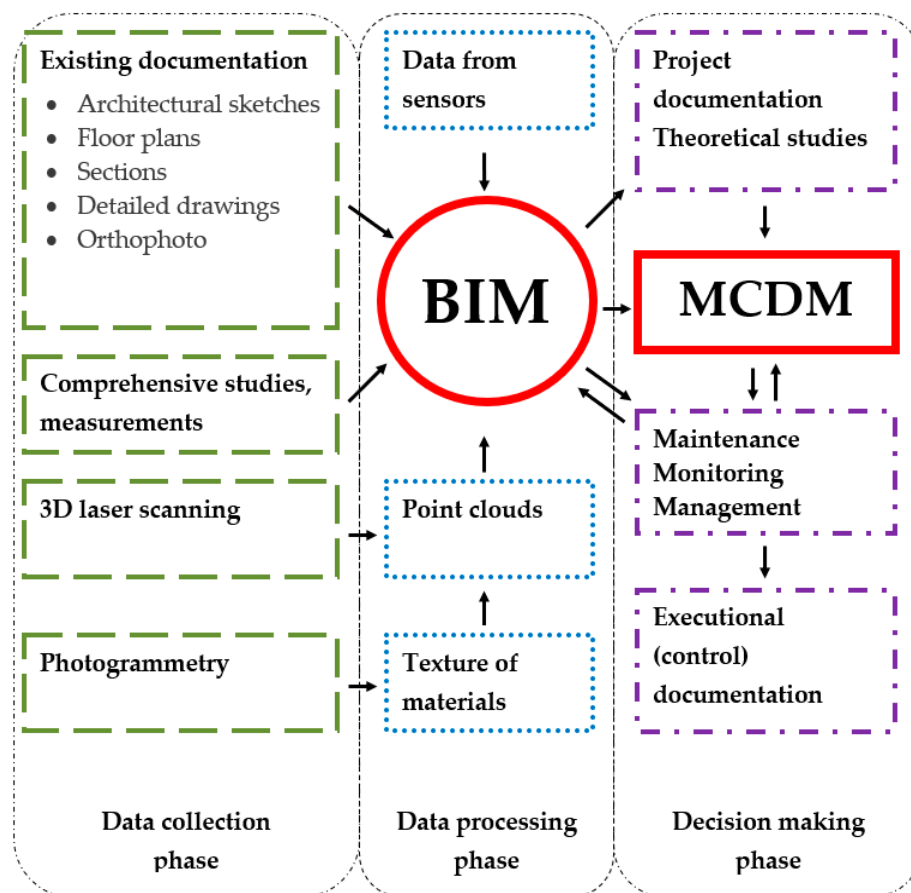
Research methodology is presented, consisting of the principal scheme of the research, 3DHB preparation steps and detailed rough WASPAS approach.

#### 3.1. Principal Block-diagram of the Research

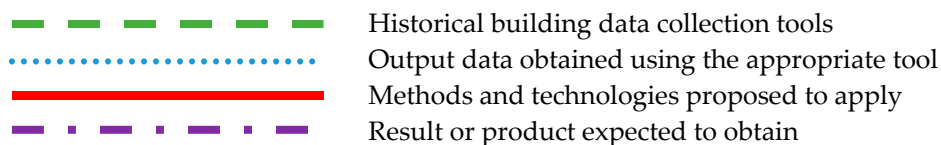
It is important to make the most appropriate solution for a specific task when performing construction heritage maintenance or planning a particular management work. Multiple criteria decision-making (MCDM) methods help to solve a problem, but they require accurate and reliable information. The information can be obtained from documentation or the BIM model, which also requires relevant data. A part of the information is obtained from sensor readings, other measurements or test results. Therefore, the goal of all participants implementing the project is to collect, process and analyze data properly.

The suggested model of operation and management of heritage buildings is shown in Figure 1. Model elements are grouped into four blocks according to their attributes. Blocks with green line represent historical data collection tools. Blocks bounded by blue line reflect the output data obtained using the appropriate tool. Red blocks name the methods and technologies proposed to apply for the operation and management of heritage buildings in the research. While purple blocks indicate the result or product expected to be obtained.

The model can be used to determine which methods, tools and technologies are best suited to a particular phase of the research to solve the tasks of extending a lifetime of a heritage building, ensuring integrated data collection and comprehensive analysis of objects. The model shows a flow of information, and a data exchange cycle is constantly taking place to select an optimal solution. The model also clearly demonstrates that optimal results can only be achieved by using all of the methods and tools together.



**Figure 1.** Model of operation and management of heritage buildings applying BIM and MCDM.



### 3.2. Preparation of 3DHB Model

Summarizing a global practice, one can distinguish the following HBIM data collection and processing steps that are needed to successfully use BIM technologies for historic and cultural heritage buildings:

- Collect historical descriptive and graphical information of existing building;
- Collect project design solutions of existing building (design drawings, executive documentation, etc.);
- Collect or restore the details of the building's measurements (plans, sections, facades, etc.);
- Perform photogrammetric fixations of external constructions using positioning drones and high-definition photography;
- Perform high precision laser scanning measurements on building's internal and external constructions;
- Carry out an assessment of existing building bearing structures and provide reinforcement solutions;
- Assess the valuable features of cultural heritage and possible changes in restoring or adapting a building for use;
- Additional polychromic studies performed to restore color and structural parameters of cultural heritage value;
- Process and combine internal and external laser scanning and photogrammetric point clouds;
- Create a geometric model (HBIM) of existing historic building bearing structures;

- To complement the HBIM model of a building with parameters and properties of cultural heritage values;
- Perform error analysis and evaluate their reduction potential;
- Perform graphic analysis of the model;
- Create a library of parametric elements of an object;
- Export parametric elements to a joint library of heritage items;
- Complement the HBIM model of building with structural reinforcement solutions;
- Complement building's HBIM model with engineering systems adapting the building for use and preserving its valuable properties;
- View the HBIM model of the building and check / fix collisions of existing historic building and new solutions;
- Finalize or modify "as built" HBIM model after construction works and preserve the information for the future.

### 3.3. Alternatives Ranking Method: Rough WASPAS

The proposed steps of Rough WASPAS method are presented according to Stojić et al. [38]:

Step 1: Description of a problem consisting of  $m$  alternatives and  $n$  criteria.

Step 2: Selection of  $k$  experts. Experts need to evaluate the alternatives according to all the criteria using the linguistic scale as presented in Table 1 [38,63].

**Table 1.** A scale for evaluation of alternatives in terms of criteria [38].

Linguistic Scale	For Benefit Criteria (Minimizing)	For Cost Criteria (Maximizing)
Very Poor—VP	1	9
Poor—P	3	7
Medium—M	5	5
Good—G	7	3
Very Good—VG	9	1

Step 3: Making expert survey. Filling in expert evaluation matrices.

Step 4: Converting individual matrices of experts  $k_1, k_2, \dots, k_n$  into a rough group matrix (RGM):

$$RGM = \begin{bmatrix} \begin{bmatrix} x_{11}^L, x_{11}^U \end{bmatrix} & \begin{bmatrix} x_{12}^L, x_{12}^U \end{bmatrix} & \dots & \begin{bmatrix} x_{1n}^L, x_{1n}^U \end{bmatrix} \\ \begin{bmatrix} x_{21}^L, x_{21}^U \end{bmatrix} & \begin{bmatrix} x_{22}^L, x_{22}^U \end{bmatrix} & \dots & \begin{bmatrix} x_{2n}^L, x_{2n}^U \end{bmatrix} \\ \vdots & \vdots & \ddots & \vdots \\ \begin{bmatrix} x_{m1}^L, x_{m1}^U \end{bmatrix} & \begin{bmatrix} x_{m2}^L, x_{m2}^U \end{bmatrix} & \dots & \begin{bmatrix} x_{mn}^L, x_{mn}^U \end{bmatrix} \end{bmatrix}. \quad (1)$$

Step 5: Normalization of the matrix:

$$n_{ij} = \frac{\begin{bmatrix} x_{ij}^L, x_{ij}^U \end{bmatrix}}{\max \begin{bmatrix} x_{ij}^{+L}, x_{ij}^{+U} \end{bmatrix}} \text{ for } C_1, C_2, \dots, C_n \in B, \quad (2)$$

$$n_{ij} = \frac{\min \begin{bmatrix} x_{ij}^{-L}, x_{ij}^{-U} \end{bmatrix}}{\begin{bmatrix} x_{ij}^L, x_{ij}^U \end{bmatrix}} \text{ for } C_1, C_2, \dots, C_n \in C, \quad (3)$$

where  $B$  represents a set of benefit criteria and  $C$  represents a set of cost criteria.

Step 6: Obtaining a weighted normalized matrix, by multiplying a normalized matrix (Equation (4)) by a weight of each criterion  $w_j$ :



$$NM = \begin{bmatrix} \begin{bmatrix} n_{11}^L, n_{11}^U \\ n_{21}^L, n_{21}^U \\ \vdots \\ n_{m1}^L, n_{m1}^U \end{bmatrix} & \begin{bmatrix} n_{12}^L, n_{12}^U \\ n_{22}^L, n_{22}^U \\ \vdots \\ n_{m2}^L, n_{m2}^U \end{bmatrix} & \cdots & \begin{bmatrix} n_{1n}^L, n_{1n}^U \\ n_{2n}^L, n_{2n}^U \\ \vdots \\ n_{mn}^L, n_{mn}^U \end{bmatrix} \\ \vdots & \vdots & \ddots & \vdots \end{bmatrix}, \quad (4)$$

$$Vn = \left[ v_{ij}^L; v_{ij}^U \right]_{m \times n}, \quad (5)$$

$$v_{ij}^L = w_j \times n_{ij}^L, \quad i = 1, 2, \dots, m, j,$$

$$v_{ij}^U = w_j \times n_{ij}^U, \quad i = 1, 2, \dots, m, j.$$

Step 7: Calculating weighted sum result for each alternative:

$$Q_i = \left[ q_{ij}^L; q_{ij}^U \right]_{1 \times m}, \quad (6)$$

$$q_{ij}^L = \sum_{j=1}^n v_{ij}^L; \quad q_{ij}^U = \sum_{j=1}^n v_{ij}^U.$$

Step 8: Calculating a weighted product result:

$$P_i = \left[ p_{ij}^L; p_{ij}^U \right]_{1 \times m}, \quad (7)$$

$$p_{ij}^L = \prod_{j=1}^n (v_{ij}^L)^{w_j},$$

$$p_{ij}^U = \prod_{j=1}^n (v_{ij}^U)^{w_j}.$$

Step 9: Calculating values of each alternative  $A_i$ :

$$A_i = \left[ a_{ij}^L; a_{ij}^U \right]_{1 \times m}, \quad (8)$$

$$A_i = \lambda \times Q_i + (1 - \lambda) \times P_i,$$

where coefficient  $\lambda$  is calculated:

$$\lambda = \frac{\sum P_i}{\sum Q_i + \sum P_i} = \frac{\sum [p_{ij}^L; p_{ij}^U]}{\sum [q_{ij}^L; q_{ij}^U] + \sum [p_{ij}^L; p_{ij}^U]}. \quad (9)$$

Step 10. Ranking of alternatives according to values  $A_i$ .

#### 4. Case Study and Research Results

In this section, a historical description of the case study—Sapieha Palace in Vilnius—is provided. Its valuable features are distinguished, and the conversion alternatives preserving these valuable features are suggested. Criteria system for evaluation of potential conversion alternatives is suggested. Calculations applying Rough WASPAS multiple criteria decision-making method are made and the alternatives are ranked.

##### 4.1. Description of the Case Study: Sapieha Palace

Sapieha Palace and its surrounding park is the only Baroque palace and park ensemble that remained in Lithuania. It is situated in Antakalnis district in Vilnius—capital of Lithuania. There is not

much to know about the history and architecture of the Sapieha Palace, but it is well known that a wooden palace was already in this place in the early 17th century. As Kirkoras [64] wrote, “according to a legend, the Sapieha Palace was built from a Pagan temple or from ruins of Pantheon of all Gods of Lithuania. . .”.

The remaining palace and park complex was built in 1689–1692 according to the project of architect Giovanni Battista Frediani and funded by Polish prince and Great Lithuanian Etmon Jan Kazimierz Sapieha the Younger (1642–1720). The palace was decorated by Giovanni Pietro Perti and with frescos by Michelangelo Palloni. Then it was reconstructed several times [64,65].

Construction of Antakalnis Palace is related to dynastic plans of Kazimieras Jonas Sapieha, to visual representing and demonstrating meaningfulness of his social positions. The marriage of the son of Sapieha Alexander to Maria Catherina de Bethune, the daughter of King Louis XIV’s envoy to Poland, could have been held in the palace in 1691. It is also mentioned that Kazimieras Jonas Sapieha, who was separated from the Church by the Bishop of Vilnius, Konstantin Kazimierz Bzostovsky, raised a feast in this palace for his supporters with music and shoots of cannons in 1694 [64,65].

The oldest plan of the complex is from the Vilnius city plan at the beginning of the 18th century, known as G. Fiurstenhof’s plan. This plan dates back to 1737 and shows rather detailed picture of this time (Figure 2). An important part of the complex were springs outside the palace. There, two ponds were installed from which water flowed into the palace and the park, including fountains [66].



Figure 2. Extract from G. Fiurstenhof’s Vilnius city plan [67].

In 1794, during the uprising and its suppression, a Russian army was staying at the Sapieha residence. The palace and also other buildings, as well as the park, were strongly destroyed. The palace belonged to the Sapieha family until the end of the 18th century, 1797, when Franciskus Sapieha sold the Palace with a land plot and forest to Kossakowski family, and so Sapieha links with this estate ended. In 1806 the entire jurisdiction of Antakalnis was bought by state adviser Vaitiekus Puslovskis, who sold the main part of it with the palace and the park to the city of Vilnius in 1808 [65,68].

Since the beginning of the 19th century, the process of decaying the former residence began. Very big losses were made by the war in 1812, when the French army occupied not only the Sapieha residence, but also a monastery and a church. The French army then used the premises of the palace for hospital purposes.

At the beginning of the 19th century the Sapieha residence and the whole environment changed. When the residence was established, Antakalnis was a picturesque countryside covered with forest. At the beginning of the 19th century, the Sapieha estate was already surrounded by residential plots. By order of Governor-General in 1809, a military hospital was established in the Palace and in a surrounding area. According to Kirkoras [64], a hospital, a hospital office and a church was opened on

15 February 1829 and started a new stage in the life of the palace and surrounding area. The project was completed in 1843 and during 1843–1848 reconstruction the palace gained its present appearance. Figure 3 presents 1830 drawing with uploaded authentic architectural elements and demolished elements that are intended to be restored according to the palace restoration project. It is presented according to architectural research in 2009 [64,65].



Figure 3. Sapieha Palace main façade: technical restoration project [65].

Situation in the area has not changed substantially until World War II. From 1919 to 1927, there was Stephen Báthory University hospital. Any major changes have not been implemented during the period. Some internal restructuring was carried out, adapting premises to needs of this time. In 1927–1928, the complex was adapted to needs of University’s Ophthalmology Institute, which operated here until the World War II. During the World War II, the military hospital was adapted to the needs of the German army.

In 1945, after the war, the whole territory went to the Soviet army. The whole area was fenced, and it became completely enclosed [66].

After the restoration of Lithuania’s independence in 1992, the Sapieha Palace was handed over to Lithuanian National Martynas Mažvydas Library, and in 2005—to the State Property Fund. In 2010, the building was handed over to the Department of Cultural Heritage. Then, the ensemble’s restoration plans and a palace restoration project were presented in 2011. So far, one project has already been implemented at Sapieha Palace entitled “Reconstruction and restoration of Sapieha Palace in Vilnius, stage I: Restoration of authentic Baroque volumes, masonry restoration, other exterior management works, covered galleries, roofs”. In 2018, Sapieha Palace was transferred to the Contemporary Art Center [69]. Nevertheless, a question of its entire reconstruction and restoration as well as its contemporary effective use still has not been solved.

Heritage building conversion should be made preserving valuable properties of the Sapieha residence. According to the Law on the Protection of the Real Cultural Heritage of the Republic of Lithuania, a valuable feature is a cultural heritage object, its location, part, or an element of it that is valuable from an ethnic, historical, aesthetic, or scientific point of view.

According to the data of the Register of Cultural Property, the Sapieha residence is considered a cultural monument of national significance. Its valuable properties are architectural, historical and artistic.

The most valuable properties of the Sapieha Palace are grouped by attributes presented in Table 2. Table 2 is composed based on the data of the Department of Cultural Heritage [69].

**Table 2.** The most valuable properties of the Sapieha Palace [69].

Valuable Properties	Objects	Description; Location	State
Volume	Compact, rectangular plan, 3 floors, with 4 corner rackets and basement under west part of the building	The height of the building is marked by survived XVII century masonry; walls raised in 19th century, tops of corner towers above the cornice demolished during reconstruction I	Satisfactory
Floor layout	Network of capital walls	Formed at the end of the 17th century, slightly changed	Satisfactory
	Wall openings, niches-openings, niches in internal walls; 2nd floor window openings	Remained in W, N and S facades; 1st floor window openings reduced; 3rd floor lashes dismantled during reconstruction I, hole size and places determined by architectural studies	
Volumetric details of facade architecture	Angular risates for N and S facades		Satisfactory
	N and S facades 1st floor brick masonry arcades	Bricked up in the 2nd decade of the 19th century	
	N and S facades 2st floor brick masonry arcades	Bricked up in the 2nd half of the 18th century; dismantled by installing 3rd floor windows during the 1st reconstruction	
	Outside stairs and ramps—remains of Palace west stairs		Satisfactory
	Facade decoration—remnants of 17th century brick masonry crowned cornice, frizz and profiled strips		Unsatisfactory
	Brick masonry, plaster piles with pedestals	The location and architectural solution of pilasters' capitals changed after reconstruction I	Satisfactory
	1st floor plaster rust	In all 1st floor facades; survived on W, N, S facades	Satisfactory
	2nd floor (N) arcade and railing molding	Not survived on S facade	
	1st floor window openings with decor	Survived on W, N, S facades	Unsatisfactory
	2nd floor window openings plaster edges, sandriks, stucco sculptural decor	Survived on W, N, S facades	Satisfactory/unsatisfactory
	Fragments of facade polychrome decoration		Unsatisfactory
	XVII century plaster		Unsatisfactory
	Epitaph with a Latin record “Antakalnis is for rest of heroes. A huge palace rose up from the ruins, and it will protect in peace everybody who tired in a war. 1691—The Year of the Lord”.	It was in the W facade of the palace, now only on the 1st floor	Unsatisfactory
Structures	Brick and stone masonry foundation with plinth		Satisfactory
	The foundation of the brick and stone masonry of the central stairs in front of the W facade		
	The brick and stone masonry foundation of the staircase at the E facade	Dismantled during the 1st reconstruction	
	Arch foundation remains in the central part of the palace		Unsatisfactory
	Basement and 1st floor vaulted brick masonry ceilings		Satisfactory
	Space of 2st and 3nd floor wooden floor		
	Basement stone and brick walls		Satisfactory
	1–3 floor brick walls		Satisfactory
	Remains of annex of the first palace and fragments of architectural elements in the North part		Satisfactory
	Functional equipment - location of palace's central stairs		
	Location of screw ladders at SW and NW risalites		
	Remains of brick staircase to the basement in the central part of the palace		Unsatisfactory
	Stair remains in the basement		Unsatisfactory
	Remains of the foundation of NE stairway and remains of toilet (latrine) reservoir		Satisfactory
	Remains of toilet (latrine) with sewer channels in the walls at 1st and 2nd floor staircase of SW palace		Unsatisfactory
	Technological equipment—the furnace remains in the central part of the palace		Unsatisfactory
	Engineering equipment—fireplace openings		Unsatisfactory

Table 2. Cont.

Valuable Properties	Objects	Description; Location	State
Interior decor	XVII century polychrome décor of interior and painting fragments at 2nd floor premises		Unsatisfactory
	Molding		Unsatisfactory
	Ceiling, wall, column decoration—1st floor vaults, 1–3 floor interior wall plaster		Satisfactory
	Floor, ramp, stair treads or pavement material—stone-based basement floors and their fragments in four rooms in the NW part of palace		Satisfactory

#### 4.2. 3D modelling Results

As BIM modeling is founded on development of a 3D parametric model that is gradually updated during different stages using various methods [16,19] and technologies [24,70], the process of creating a 3D model is described below.

Digitalization of the heritage buildings is influenced by several properties such as [70,71]:

- complexity in size and shape;
- morphological complexity (level of detail);
- diversity of raw materials;
- size and applicability;
- budget.

There is no final solution for how to model the objects of built heritage. An issue of 3D modelling cannot be always resolved by using a single technique. The choice of a correct method depends on the kind of building and level of detail of the BIM model to be created.

The particular heritage building modeling algorithm was created after researching various methods, technologies, and software. The phases of the presented Sapieha Palace model creation are as follow:

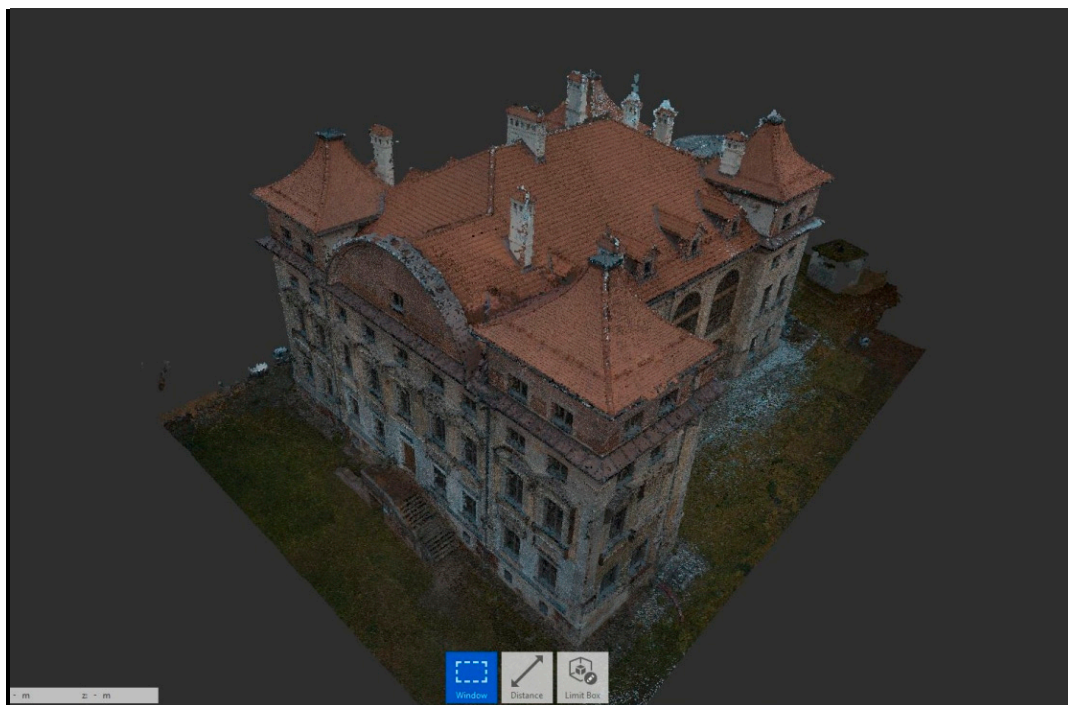
The first phase consisted on survey of the existing building and collection of archival data “as built”. We have got and analyzed design of the building, drawings, section planes, materials used, documentation related to the repair works of the building for different periods from 1718 to 2012 when was the last restoration of the palace.

During the second phase, photographic survey, we used the DJI Mavic Pro drone with a DJI FC220 digital camera with a three-axis stabilization system and a navigation system for positioning. To limit the hidden areas, the building was photographed in a circle on different levels.

The third phase was devoted to creating a dense point cloud. For this, all 339 photos taken with a drone were used. For photo processing Agisoft PhotoScan software was applied.

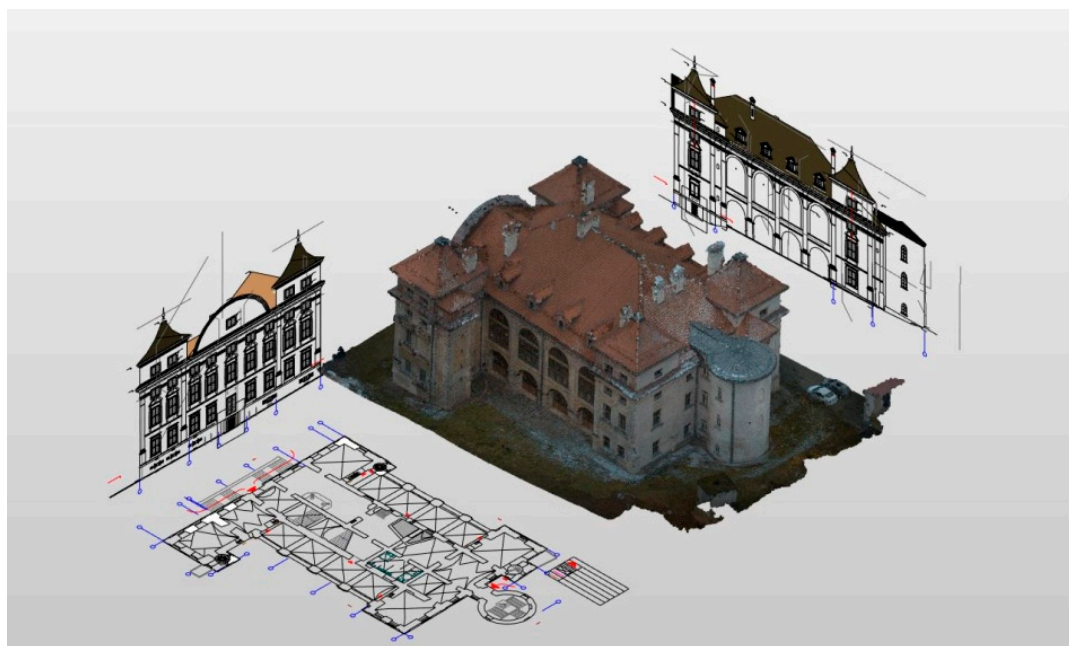
Then point cloud was transformed and imported it into Autodesk Revit software (Figure 4).





**Figure 4.** Point cloud converted with Autodesk ReCap software.

During the fourth phase, a point cloud is combined with drawings (Figure 5).

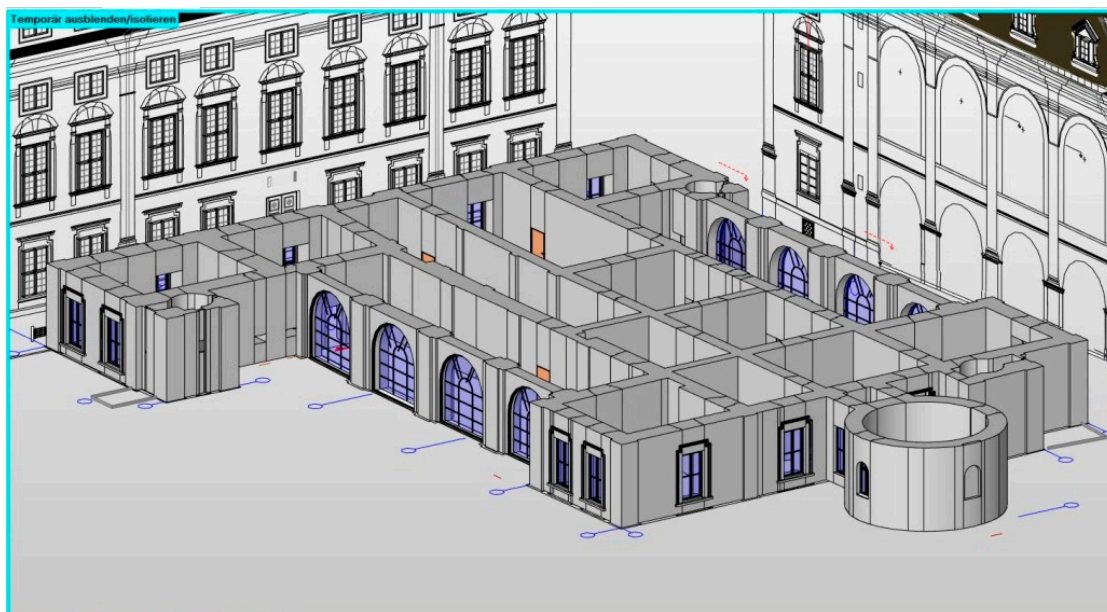


**Figure 5.** Drawings and point cloud combination in Floors modelling in Autodesk Revit software.

After that, the floors, walls and roof of the palace are modeled. All elements are parameterized, and information about materials, functions and valuable properties is entered (Figure 6).

After the modeling phase, a high quality and accurate 3D model involving both the textured exterior of the building and the interior layout is obtained. Further, it is used to determine possible conversion alternatives and building life cycle simulations.





**Figure 6.** Floors modelling in Autodesk Revit software.

#### 4.3. Description of Possible Redevelopment Alternatives

Improving economic situation, increasing quality of life create preconditions for development of culture and art and promote adaptation of abandoned buildings having historic or architectural value such as the Sapieha Palace to the needs of local population, municipality, science or business.

Alternative conversion variants should be prepared considering authenticity of a building. Cultural heritage is a witness to history, and its authenticity is particularly important. It is a very broad concept that encompasses historical features of an object, its functions, artistic forms and composition, materials and constructions, as well as the environmental aspect. Preserving authenticity is one of the most important features in determining the conversion value of a built heritage object.

The authors suggest three possible conversion alternatives for Sapieha Palace.

The first alternative ( $A_1$ ) involves the establishment of a Tourist Information Center with a permanent Museum. The Sapieha Palace would become a center of cultural knowledge, the purpose of which is to acquaint the public with Museum's values and their collections, to organize permanent and temporary exhibitions, to prepare Museum-promoting publications, catalogs of Museum values, and to work on education. The history of the Sapieha Palace allows us to cover different periods, to reveal historical dynamics of cultural and artistic development. The Baroque ensemble of the Sapieha Palace and the frescoes remaining in the palace are a great starting point for creating educational stories about values of culture and society in various contexts and periods.

The second alternative ( $A_2$ ) constitutes an option for the conversion of Sapieha palace into a Research Institution, the main tasks of which would be to explore the history of heritage, other areas of architecture, contemporary trends in science and education. Currently, increasing attention is being paid to the links between different research disciplines. Therefore, this new institution should reflect this trend and contribute to modern education.

The third alternative ( $A_3$ ) entails the adaption of the Sapieha Palace for a hotel with a conference center. So-called business tourism is popular worldwide. Countries with an advanced conference center system attract a number of international events, meetings, and conferences. Hundreds of international business representatives usually attend such events. However, there is no abundance of large conference centers in Lithuania. Therefore, this alternative has a real demand, especially because the Sapieha Palace is grateful for the purpose of a Hotel.

The building is raised on a high base; the main portal leads to a two-sided staircase that creates a solemn mood. Almost all the rooms on the second floor of the palace communicate with each

other. Especially distinguish the large hall, decorated with stickers and painted ceilings. Painting, molding, ornamental stoves, fireplaces also are found in other premises. Such a large decoration outside the palace was not a frequent phenomenon; it expresses the representative nature of the building, demonstrates the taste and financial capacity of the palace owner. Up to the present day, the majority of second floor windows decoration have been preserved. The motifs and elements, as well as the details of the park gate decorations can be used to judge the high artistic level of the palace's equipment. Overall, the beauty of the Sapieha Palace and the area equipped with the right infrastructure provide an opportunity for a very high standard hotel with conference center.

#### 4.4. Criteria System

Most commonly used criteria systems for evaluation of built heritage preservation and conversion solutions were discussed in Section 2.2. Seven main groups of criteria were distinguished, consisting of 4–5 criteria each group [27–29,31–36].

As our research is aimed at enhancing sustainable development, of course three main sub-systems of sustainability are evaluated: economic value of changes, impact on natural environment and influence to social environment. As our case study is a built heritage and a priority is given to its proper preservation, the historical-cultural value criteria group is involved. At least, when analyzing building reconstruction works, we certainly need to involve technological–architectural criteria group.

The suggested criteria system, consisting of five groups of criteria  $G_1$ – $G_5$  and a number of criteria  $X_j, j = 1, \dots, m$  presented in Figure 7.

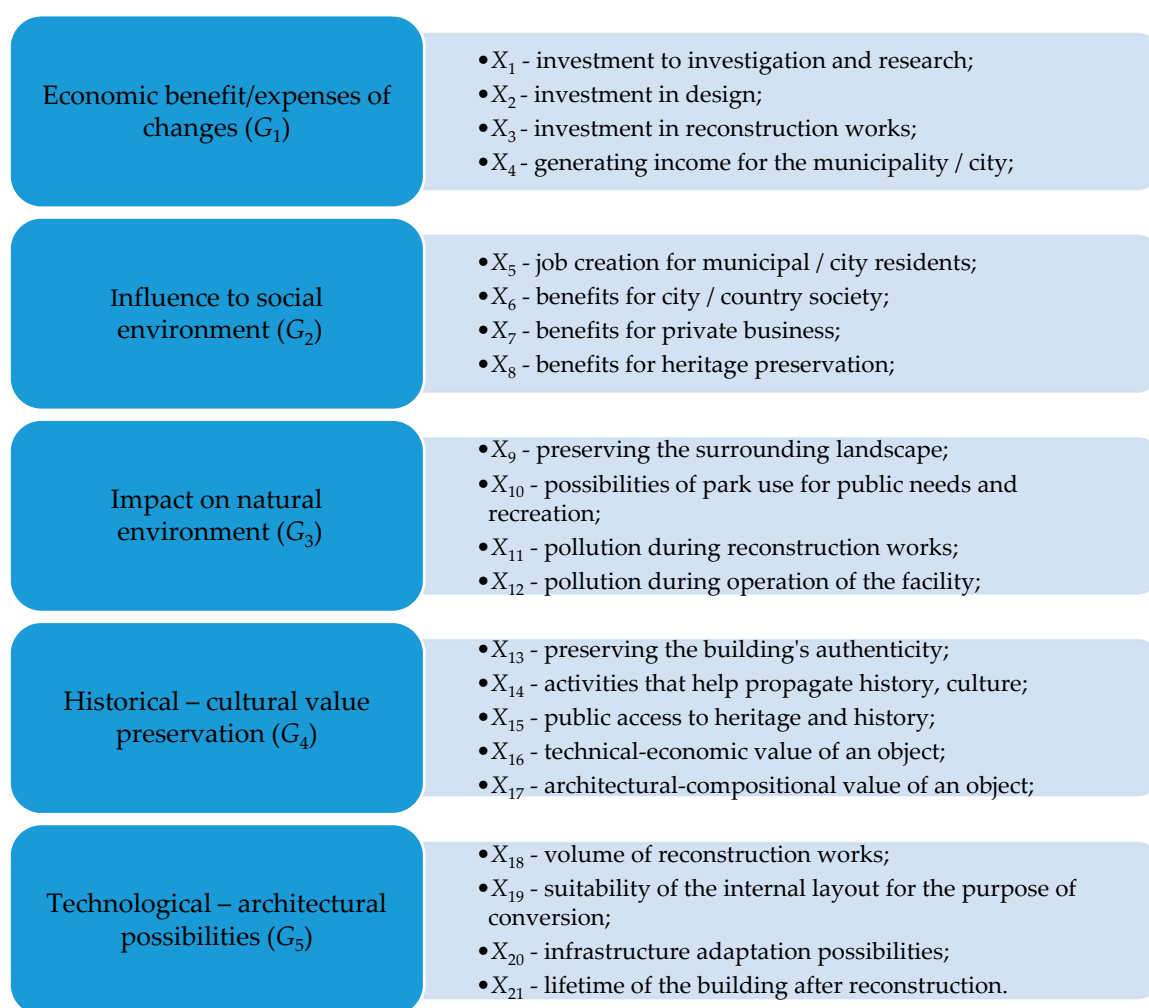


Figure 7. Criteria system for assessing built heritage conversion solutions.

Part of the criteria are benefit criteria or maximizing, i.e., their larger value is better, and part of the criteria are cost criteria or minimizing, i.e., their lower value is better.

The first group of criteria—Economic benefit/expenses of changes ( $G_1$ )—consists of four criteria. Three of them are cost criteria—investment in investigation and research, design and reconstruction work. The peculiarity of our problem of conversion of heritage building requires involving investment to investigation and research besides usual investments in design and construction. The last criterion in the group is benefit criterion and describes the possibility of generating income for the municipality/city after conversion.

The next group of criteria is entitled: influence on social environment ( $G_2$ ). The group also consists of four criteria. All the four criteria are benefit (maximizing) criteria in the current case. They evaluate benefits for city/country and benefits for private business after implementing a particular conversion alternative. Additionally, is presented criterion of job creation, contributing to reducing unemployment for municipal/city residents. The peculiarity of our considered problem is reflected by a specific criterion, namely the benefits for heritage preservation when implementing a particular conversion alternative.

The third component of sustainable development - Impact on natural environment ( $G_3$ ). The group involves two maximizing and two minimizing criteria. Maximizing criteria are related to entire complex of the Palace and its surroundings, including the old park, and express possibilities of preserving the surrounding landscape, and possibilities of park use for public needs and recreation. Conversely, minimizing criteria are of another nature and they express a negative attitude to expected pollution during construction works as well as the operation of new facility.

The next group of criteria is closely related to our specific task of conversion of built heritage, namely historical-cultural value preservation ( $G_4$ ). It consist of five benefit criteria: preserving the building's authenticity after reconstruction; preserving architectural-compositional value of an object; new activities that help propagate history, culture, architecture; free public access to values of heritage and history; technical-economic value of an object, consisting of heritage categories as building construction technique and quality as well as periods of evolution of building.

The last group of criteria is related to the intended construction works and is entitled technological-architectural possibilities ( $G_5$ ). The group has one minimizing criterion in terms of time and cost—volume of reconstruction works. The next two criteria are maximizing, and they reflect a suitability of the internal layout of a building and its infrastructure adaptation possibilities for an intended purpose of conversion. The last criterion is lifetime of the building after reconstruction. It is a maximizing criterion and is determined according to purpose of a converted building.

All criteria are measured by a linguistic scale as presented in Table 1. An expert survey is applied to evaluate performance of each alternative in terms of every criterion.

#### 4.5. Expert Survey: Relative Weights and Values of Criteria

The research applies expert survey for determining relative weights of criteria. In addition, because of selected methodology of evaluation of alternatives (Rough WASPAS), expert survey is applied for determining particular values of criteria considering analyzed conversion alternatives.

Ten experts were selected. They all are professionals in built heritage. They all are employed in science and research state institutions and all having a respective scientific degree as well as work experience of 5–20 years. The distribution of experts is presented in Table 3.

**Table 3.** Distribution of experts.

By Countries		By Degree		By Area of Expertize		By Workplace	
Germany	40%	Bachelor	10%	Engineering	21%	University	62%
Italy	30%	Master	20%	Architecture	26%	Industry	15%
Lithuania	10%	PhD	40%	Heritage conservation	32%	Consultant/self-employed	15%
Poland	10%	Prof	30%	Construction	10%	Other	8%
Russia	10%			Other	11%		

At first, the experts considering their knowledge and experience were asked to fill a questionnaire and rank groups of criteria as well as to rank criteria in each group as presented in Figure 7. They had to assign scores based on the scoring scale 1–5, where 5 means the highest importance and 1 means that the criterion has the lowest importance to a problem solution.

The relative importance (weight) of groups of criteria, of each criterion in a group and overall importance of every criterion was calculated using to the above-presented methodology (Equations (1)–(9)). The results of calculation are provided in Tables 4 and 5.

The most important group of criteria according to experts' opinion is  $G_4$ —historical and cultural value preservation, with a weight  $w_j' = 1.03$ . The next follow economic benefit/expenses of changes and influence on social environment with equal weights of 0.66. Technological—architectural possibilities gained almost the same result (0.65). The least important according to experts is the impact on natural environment criteria group, but it is not far behind (0.60) (Table 4).

The most important criterion among 21 investigated criteria according to experts is Preserving the building's authenticity, the next follow activities that help to propagate history, culture, and public access to heritage and history (Table 5).

Table 4. Weights of the groups of criteria.

Groups of Criteria	$G_1$	$G_2$	$G_3$	$G_4$	$G_5$
Experts					
Expert 1	2	4	1	5	3
Expert 2	5	4	3	2	1
Expert 3	1	2	3	5	4
Expert 4	1	2	4	5	3
Expert 5	3	1	4	5	2
Expert 6	1	2	4	5	3
Expert 7	4	3	1	5	2
Expert 8	4	2	1	5	3
Expert 9	2	5	3	4	1
Expert 10	4	2	1	3	5
Normalized Weight $w_j'$	[0.36; 0.96]	[0.40; 0.91]	[0.35; 0.85]	[0.78; 1.28]	[0.39; 0.92]
Crisp Weight $w_j$	0.66	0.66	0.60	1.03	0.65
Rank	2/3	2/3	5	1	4

Table 5. Weights of criteria in the groups and the overall weights.

Groups of Criteria	Criteria	Normalized Weight in the Group $w_j'$	Rank in the Group	Overall Weight of Criterion $w_j''$	Crisp $w_j$
$G_1$	$X_1$	[0.70; 1.31]	1/2	[0.46; 0.86]	0.66
	$X_2$	[0.41; 1.11]	4	[0.27; 0.73]	0.50
	$X_3$	[0.57; 1.43]	1/2	[0.37; 0.94]	0.66
	$X_4$	[0.49; 1.23]	3	[0.32; 0.81]	0.57
$G_2$	$X_5$	[0.66; 1.46]	2	[0.43; 0.96]	0.70
	$X_6$	[0.56; 1.23]	3	[0.37; 0.81]	0.59
	$X_7$	[0.34; 0.90]	4	[0.22; 0.59]	0.41
	$X_8$	[0.68; 1.48]	1	[0.44; 0.97]	0.71
$G_3$	$X_9$	[0.66; 1.51]	1	[0.40; 0.90]	0.65
	$X_{10}$	[0.42; 1.30]	3	[0.25; 0.78]	0.51
	$X_{11}$	[0.48; 1.14]	4	[0.29; 0.68]	0.48
	$X_{12}$	[0.55; 1.45]	2	[0.33; 0.87]	0.60
$G_4$	$X_{13}$	[0.66; 1.49]	1	[0.68; 1.53]	1.11
	$X_{14}$	[0.67; 1.37]	2	[0.69; 1.41]	1.05
	$X_{15}$	[0.56; 1.30]	3	[0.57; 1.34]	0.96
	$X_{16}$	[0.27; 0.93]	5	[0.28; 0.96]	0.62
	$X_{17}$	[0.35; 1.03]	4	[0.36; 1.06]	0.71
$G_5$	$X_{18}$	[0.37; 0.91]	4	[0.24; 0.60]	0.42
	$X_{19}$	[0.68; 1.37]	2	[0.45; 0.90]	0.67
	$X_{20}$	[0.51; 1.16]	3	[0.34; 0.76]	0.55
	$X_{21}$	[0.67; 1.47]	1	[0.44; 0.96]	0.70

Next, the experts were asked to evaluate three potential conversion alternatives  $A_1$ ,  $A_2$  and  $A_3$  (see Section 4.2) according to all the criteria  $X_1$ – $X_{21}$  (see Figure 7) and using the evaluation scale as

presented in Table 1. The evaluations are presented in Table 6. These evaluations further are processed using Equations (1)–(9) and the results are presented in the next chapter.

**Table 6.** Evaluation of alternatives according to criteria.

A <sub>1</sub>										
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
X <sub>1</sub>	3	7	7	5	5	5	3	5	3	5
X <sub>2</sub>	3	3	5	5	3	5	9	5	5	3
X <sub>3</sub>	1	3	3	5	7	5	3	5	3	3
X <sub>4</sub>	7	7	3	7	5	5	5	9	7	5
X <sub>5</sub>	7	7	5	7	7	3	7	5	9	7
X <sub>6</sub>	9	7	3	9	5	5	7	7	7	9
X <sub>7</sub>	5	3	7	7	5	1	3	1	9	3
X <sub>8</sub>	9	9	1	9	5	5	7	9	9	9
X <sub>9</sub>	5	7	9	5	3	5	5	5	9	9
X <sub>10</sub>	7	5	1	7	5	5	5	3	9	9
X <sub>11</sub>	3	1	1	7	7	5	7	3	5	5
X <sub>12</sub>	3	1	1	7	7	5	7	5	5	7
X <sub>13</sub>	7	9	1	9	3	5	9	9	9	9
X <sub>14</sub>	9	9	1	7	3	5	9	9	9	9
X <sub>15</sub>	9	9	1	9	5	5	9	9	9	9
X <sub>16</sub>	9	7	7	5	5	5	5	5	7	7
X <sub>17</sub>	7	9	1	7	3	5	9	5	9	7
X <sub>18</sub>	3	1	5	7	7	3	1	7	7	5
X <sub>19</sub>	7	7	7	9	5	5	9	7	9	5
X <sub>20</sub>	7	5	5	7	5	3	7	3	9	5
X <sub>21</sub>	7	7	3	9	5	3	7	5	9	9
A <sub>2</sub>										
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
X <sub>1</sub>	1	1	3	5	5	5	1	7	1	5
X <sub>2</sub>	5	3	3	5	9	9	9	5	5	5
X <sub>3</sub>	3	3	1	5	5	7	1	7	7	5
X <sub>4</sub>	3	9	1	7	7	5	7	3	5	5
X <sub>5</sub>	3	9	7	9	5	3	9	1	9	7
X <sub>6</sub>	5	7	7	7	7	5	7	5	9	5
X <sub>7</sub>	3	5	5	5	7	3	1	5	9	5
X <sub>8</sub>	5	7	1	9	9	9	5	5	9	3
X <sub>9</sub>	5	3	9	7	9	9	5	9	9	3
X <sub>10</sub>	1	3	5	5	7	7	5	3	9	3
X <sub>11</sub>	3	1	3	5	3	3	5	9	5	5
X <sub>12</sub>	5	1	1	5	3	5	5	7	5	3
X <sub>13</sub>	5	9	1	7	9	7	9	5	9	5
X <sub>14</sub>	3	5	3	5	7	7	7	7	9	5
X <sub>15</sub>	5	5	3	5	7	7	7	7	9	7
X <sub>16</sub>	5	7	5	5	5	7	5	5	5	5
X <sub>17</sub>	3	9	1	7	9	5	7	5	9	5
X <sub>18</sub>	3	3	9	5	1	3	3	5	7	5
X <sub>19</sub>	7	7	3	7	5	7	7	7	9	7
X <sub>20</sub>	7	7	3	7	7	7	5	5	9	9
X <sub>21</sub>	7	5	5	9	5	9	5	3	9	5
A <sub>3</sub>										
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
X <sub>1</sub>	7	5	9	5	5	5	1	1	7	7
X <sub>2</sub>	1	1	1	5	1	7	7	3	1	7
X <sub>3</sub>	1	1	9	3	9	7	1	3	1	7
X <sub>4</sub>	5	9	9	5	9	5	9	7	7	9
X <sub>5</sub>	7	9	1	5	9	3	9	9	9	7
X <sub>6</sub>	3	3	9	7	9	5	9	3	7	5
X <sub>7</sub>	9	5	9	9	9	1	9	9	9	9
X <sub>8</sub>	3	7	1	3	1	7	9	1	9	5
X <sub>9</sub>	5	3	7	3	3	7	3	1	9	5
X <sub>10</sub>	5	5	9	3	9	5	9	1	9	5
X <sub>11</sub>	3	1	1	3	9	5	5	1	5	7
X <sub>12</sub>	5	1	1	3	9	5	3	1	5	7
X <sub>13</sub>	3	9	1	3	1	7	7	1	9	5
X <sub>14</sub>	3	5	5	3	3	5	7	3	9	5
X <sub>15</sub>	3	5	5	1	5	7	5	3	9	3
X <sub>16</sub>	9	7	9	7	7	5	9	5	9	7
X <sub>17</sub>	5	9	1	5	1	7	7	5	9	5
X <sub>18</sub>	5	3	1	3	9	3	5	1	7	7
X <sub>19</sub>	3	7	1	5	5	5	5	3	9	5
X <sub>20</sub>	3	7	1	5	3	5	9	3	9	5
X <sub>21</sub>	5	5	1	5	7	3	9	7	9	5

#### 4.6. Calculation Results Applying Rough WASPAS

The evaluation of alternatives is made by using expert scores and by applying Rough WASPAS methodology according to presented Equations (1)–(9) based on source [38].

Group rough matrix is presented in Table 7. The normalized matrix is presented in Table 8. The weighted normalized matrix is obtained using weights, calculated in Section 4.4, and presented in Table 9.

**Table 7.** Group rough matrix.

	$x_1$	$x_2$	$x_3$	$x_4$	$x_5$	$x_6$	$x_7$
$A_1$	[4.43; 6.25]	[4.13; 6.19]	[3.16; 5.32]	[5.56; 7.77]	[6.08; 8.07]	[6.17; 8.85]	[2.98; 6.90]
$A_2$	[2.31; 5.24]	[5.06; 7.90]	[3.23; 6.48]	[4.02; 7.48]	[4.68; 8.92]	[6.33; 7.92]	[3.87; 6.84]
$A_3$	[4.02; 7.43]	[2.04; 5.59]	[2.41; 7.05]	[7.07; 9.34]	[5.47; 9.34]	[4.89; 8.44]	[7.38; 9.82]
	$x_8$	$x_9$	$x_{10}$	$x_{11}$	$x_{12}$	$x_{13}$	$x_{14}$
$A_1$	[6.23; 9.52]	[5.55; 8.28]	[4.05; 7.92]	[3.23; 6.48]	[3.65; 6.86]	[5.78; 9.51]	[5.78; 9.51]
$A_2$	[4.84; 8.81]	[5.84; 9.20]	[3.63; 7.09]	[3.36; 6.07]	[3.15; 5.69]	[5.49; 8.99]	[5.13; 7.74]
$A_3$	[2.79; 7.50]	[3.42; 6.90]	[4.78; 8.51]	[2.56; 6.46]	[2.56; 6.46]	[2.79; 7.50]	[4.13; 6.69]
	$x_{15}$	$x_{16}$	$x_{17}$	$x_{18}$	$x_{19}$	$x_{20}$	$x_{21}$
$A_1$	[6.68; 9.62]	[6.08; 7.73]	[4.84; 8.72]	[3.38; 6.76]	[6.73; 8.83]	[4.96; 7.52]	[5.45; 8.70]
$A_2$	[5.79; 7.95]	[5.64; 6.36]	[4.65; 8.55]	[3.35; 6.57]	[6.44; 8.15]	[6.10; 8.50]	[5.55; 8.28]
$A_3$	[3.58; 6.73]	[7.21; 9.20]	[4.05; 7.87]	[2.98; 6.90]	[3.87; 6.84]	[3.69; 7.52]	[4.41; 7.97]

**Table 8.** Normalized matrix.

	$x_1$	$x_2$	$x_3$	$x_4$	$x_5$	$x_6$	$x_7$
$A_1$	[0.48; 1.20]	[0.48; 1.29]	[0.56; 1.68]	[0.58; 1.15]	[0.63; 1.20]	[0.64; 1.32]	[0.31; 1.02]
$A_2$	[0.44; 2.27]	[0.29; 1.04]	[0.36; 1.62]	[0.44; 1.16]	[0.51; 1.39]	[0.69; 1.23]	[0.42; 1.06]
$A_3$	[0.27; 1.39]	[0.37; 2.74]	[0.29; 2.31]	[0.72; 1.27]	[0.56; 1.27]	[0.5; 1.14]	[0.75; 1.33]
	$x_8$	$x_9$	$x_{10}$	$x_{11}$	$x_{12}$	$x_{13}$	$x_{14}$
$A_1$	[0.65; 1.41]	[0.58; 1.23]	[0.42; 1.18]	[0.46; 1.65]	[0.43; 1.46]	[0.60; 1.41]	[0.60; 1.41]
$A_2$	[0.53; 1.37]	[0.64; 1.43]	[0.39; 1.10]	[0.38; 1.56]	[0.41; 1.67]	[0.60; 1.40]	[0.56; 1.20]
$A_3$	[0.28; 1.02]	[0.35; 0.94]	[0.49; 1.15]	[0.32; 2.18]	[0.32; 2.18]	[0.28; 1.02]	[0.42; 0.91]
	$x_{15}$	$x_{16}$	$x_{17}$	$x_{18}$	$x_{19}$	$x_{20}$	$x_{21}$
$A_1$	[0.69; 1.43]	[0.63; 1.15]	[0.50; 1.30]	[0.44; 1.57]	[0.7; 1.31]	[0.51; 1.12]	[0.34; 0.98]
$A_2$	[0.63; 1.23]	[0.61; 0.99]	[0.51; 1.33]	[0.35; 1.56]	[0.7; 1.27]	[0.66; 1.32]	[0.28; 0.95]
$A_3$	[0.36; 0.91]	[0.73; 1.25]	[0.41; 1.07]	[0.30; 1.88]	[0.39; 0.93]	[0.38; 1.02]	[0.26; 1.27]

**Table 9.** Weighted normalized matrix.

	$x_1$	$x_2$	$x_3$	$x_4$	$x_5$	$x_6$	$x_7$
$A_1$	[0.31; 0.79]	[0.24; 0.64]	[0.37; 1.10]	[0.33; 0.65]	[0.44; 0.84]	[0.38; 0.78]	[0.13; 0.42]
$A_2$	[0.29; 1.50]	[0.15; 0.52]	[0.23; 1.07]	[0.25; 0.66]	[0.35; 0.96]	[0.41; 0.72]	[0.17; 0.43]
$A_3$	[0.18; 0.92]	[0.18; 1.37]	[0.19; 1.52]	[0.41; 0.72]	[0.39; 0.88]	[0.29; 0.67]	[0.31; 0.54]
	$x_8$	$x_9$	$x_{10}$	$x_{11}$	$x_{12}$	$x_{13}$	$x_{14}$
$A_1$	[0.46; 1.00]	[0.37; 0.80]	[0.22; 0.61]	[0.22; 0.8]	[0.26; 0.87]	[0.67; 1.57]	[0.63; 1.49]
$A_2$	[0.37; 0.97]	[0.41; 0.93]	[0.20; 0.57]	[0.18; 0.75]	[0.24; 1.00]	[0.66; 1.55]	[0.59; 1.27]
$A_3$	[0.20; 0.72]	[0.23; 0.61]	[0.25; 0.59]	[0.15; 1.06]	[0.19; 1.31]	[0.32; 1.13]	[0.44; 0.95]
	$x_{15}$	$x_{16}$	$x_{17}$	$x_{18}$	$x_{19}$	$x_{20}$	$x_{21}$
$A_1$	[0.66; 1.37]	[0.39; 0.71]	[0.36; 0.92]	[0.19; 0.66]	[0.47; 0.88]	[0.28; 0.61]	[0.24; 0.68]
$A_2$	[0.60; 1.18]	[0.38; 0.61]	[0.36; 0.94]	[0.15; 0.66]	[0.47; 0.85]	[0.36; 0.72]	[0.2; 0.66]
$A_3$	[0.35; 0.87]	[0.45; 0.77]	[0.29; 0.76]	[0.12; 0.79]	[0.26; 0.62]	[0.21; 0.56]	[0.18; 0.89]

The next two steps are calculating WSM (summing all the values of the alternatives obtained (summing by rows)) and calculating WPM (Tables 10 and 11).



**Table 10.** Summing all the values of the alternatives obtained (summing by rows).

WSM	
$A_1$	[7.62; 18.19]
$A_2$	[7.02; 18.52]
$A_3$	[5.59; 18.25]

**Table 11.** Determination of the weighted product model.

WPM	
$A_1$	[10.98; 19.97]
$A_2$	[10.39; 20.02]
$A_3$	[8.69; 19.15]

Next, coefficient  $\lambda$  is calculated:  $\lambda = [0.597; 0.518]$ .

The final determination of the relative values of the alternatives and their ranking is provided in Table 12.

**Table 12.** Determining the relative values of the alternatives and their ranking.

	$\lambda \times Q_i$	$(1-\lambda) \times P_i$	$A_i$	Crisp $A_i$	Rank
$A_1$	[4.55; 9.43]	[4.42; 9.62]	[8.97; 19.05]	14.01	1
$A_2$	[4.20; 9.60]	[4.18; 9.64]	[8.38; 19.24]	13.81	2
$A_3$	[3.34; 9.46]	[3.5; 9.22]	[6.84; 18.68]	12.76	3

The calculation results show that the first alternative  $A_1$ —the establishment of a tourism information center with a permanent museum—gained the first rank. The second ranked alternative ( $A_2$ —conversion of Sapieha palace to a Research Institution) is behind the first alternative only by 1.4 percent. Accordingly, we can state that the both alternatives are evaluated almost equally. While, the third alternative ( $A_3$ —adaption of the Sapieha Palace for a hotel with a conference center) is 9% behind the best ranked alternative, therefore its implementation should not be rational.

For sensitivity analysis, relative values of the alternatives depending on the value of the coefficient  $\lambda$  are calculated (Table 13, Figure 8).

**Table 13.** Relative values of the alternatives depending on the value of the coefficient  $\lambda$ .

$\lambda =$	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
$A_1$	15.48	15.22	14.96	14.70	14.45	14.19	13.93	13.68	13.42	13.16	12.91
$A_2$	15.21	14.96	14.72	14.47	14.23	13.99	13.74	13.50	13.26	13.01	12.77
$A_3$	13.92	13.72	13.52	13.32	13.12	12.92	12.72	12.52	12.32	12.12	11.92

After the sensitivity analysis, we can state that the ranking order of alternatives is stable and is  $A_1 > A_2 > A_3$ . While, difference between alternatives is varying depending on a value of coefficient  $\lambda$ . The difference between the first and the second alternatives varies from 1.7% to 1.1% when  $\lambda$  varies from 0 to 1. The difference between the first and the third alternatives varies from 10.1% to 7.7% when  $\lambda$  varies from 0 to 1. We can state that the larger is  $\lambda$ , the lower is the difference between the alternatives.

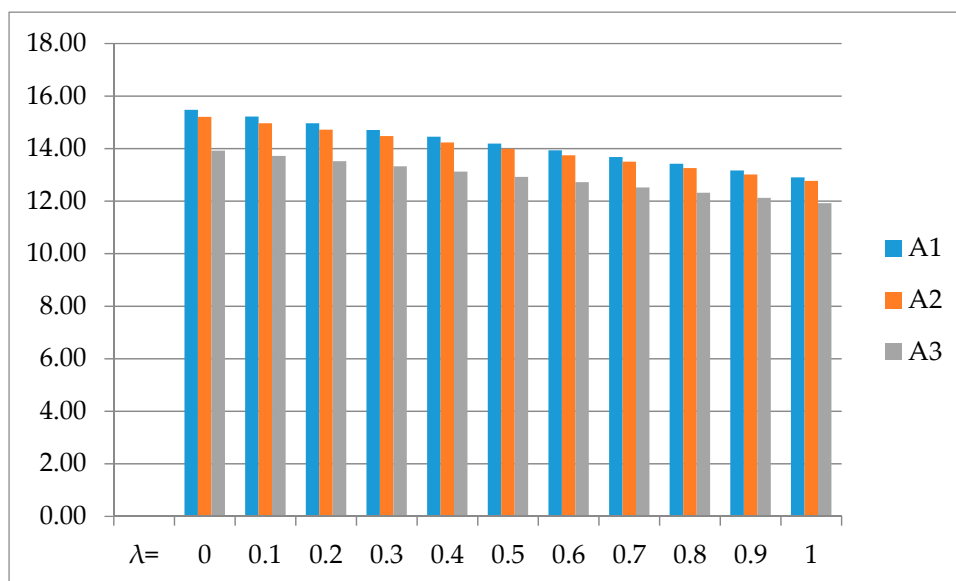


Figure 8. Results of sensitivity analysis dependent on coefficient  $\lambda$ .

## 5. Conclusions

The authors suggested the integration of modern digital technologies and multi-criteria decision-making (MCDM) models to achieve the rational and sustainable conversion decision of built heritage based on high accuracy data.

A case study of Sapieha Palace built in Baroque style in 1689–1691 in Vilnius, Lithuania was explored. The most valuable properties of the Sapieha Palace were grouped by attributes and the state level of them was between “satisfactory” for structure elements and “unsatisfactory” for decorative elements. To restore this, building deep analysis needs to be made and advanced tools can be used to ensure the high efficiency of detail reconstruction.

The authors suggested applying photogrammetry and the 3D modeling of the existing heritage building. The applied technologies and software (Agisoft Photoscan, Autodesk ReCap and Autodesk Revit) allowed for the creation of a high quality and accurate model involving both the textured exterior of the building and the interior layout. In addition, the valuable features of a building were identified and marked in three-dimensional digital model.

Based on the model, the authors formulated three possible conversion alternatives: the establishment of a tourism information center with a permanent Museum, a center of cultural cognition; a research institution, whose main tasks are to explore the history of heritage, other areas of architecture, and contemporary trends in science and education; and finally, the adaption of the Sapieha Palace to a hotel with a conference center.

The associated criteria of rationality of alternatives were identified, and their weights determined by the expert survey method. An international team of very well experienced experts from several European countries was gathered, whose experience lies in engineering, architecture, heritage preservation and construction, and they are representatives of research institutions and industry.

Preserving the building’s authenticity was determined as the most important criterion among 21 investigated criteria according to experts. The next criteria follow activities that help to propagate history and culture, and its weight is 5.4% lower compared to the weight of the highly ranked criterion. The lowest weight was assigned to benefits for private business criterion and it makes up only 37% compared to the highest weight.

The authors suggested the application of a novel MCDM method under uncertainty, namely the rough weighted aggregated sum product assessment (WASPAS), for ranking alternatives according to multiple criteria. The mentioned experts were involved in evaluating of alternatives in terms of criteria.

Calculation results showed that the first alternative  $A_1$ —the establishment of a tourism information center with a permanent museum—gained the first rank. The second ranked alternative ( $A_2$ —the conversion of Sapieha palace to a research institution) is behind the first alternative only by 1.4%. Accordingly, we can state that the both alternatives are evaluated almost equally. While, the third alternative ( $A_3$ —adaption of the Sapieha Palace for a Hotel with a Conference Center) is 9 percent behind the best ranked alternative, therefore its implementation should be not rational.

As the sensitivity analysis shows that the ranking order of alternatives is stable and two alternatives gain almost the same importance with the difference in degree of utility varying from 1.1% to 1.7%, the authors suggest the conversion of the Sapieha Palace to a combined purpose building—a research institution, whose main tasks are to explore the history of heritage and other areas of architecture, with a museum and possible tourism information center.

The suggested research methodology can be employed in other case studies for ranking heritage building conversion alternatives. The suggested criteria system and established weights of criteria can be used for evaluating potential redevelopment alternatives of the analyzed building. Appropriate experts can be involved to evaluate alternatives in terms of criteria, and the rough WASPAS method can be applied for the ranking of alternative scenarios.

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