


## Article

# Substitution of Building Components in Historic Buildings

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**Abstract:** Historic buildings that have survived to the present day have been subject to maintenance, repair, and overhaul. Repair work is being carried out so that it can be enjoyed by future generations. However, there have been changes in the construction technology: some construction products have been discontinued and replaced with others of different quality parameters, lower prices, etc. It is necessary to use substitute products during construction work—that is, replacement products that are shaped after the original. Therefore, there is a problem of selecting the best possible substitute material, taking into account many important factors, including the recommendations and requirements of the conservator. This paper presents a methodology for the process of material substitution planning and selection of a substitute with the use of multicriteria analysis, by implementing it in the refurbishment of a historic building façade.

**Keywords:** historic buildings; refurbishment; substitution of materials; multicriteria analysis



**Citation:** Sobotka, A.; Linczowski, K.; Radziejowska, A. Substitution of Building Components in Historic Buildings. *Sustainability* **2021**, *13*, 9211. <https://doi.org/10.3390/su13169211>

Academic Editors: Marc A. Rosen, Beata Nowogońska, Leonard Runkiewicz and Wojciech Bonenberg

Received: 27 May 2021

Accepted: 13 August 2021

Published: 17 August 2021

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## 1. Introduction

Construction artefacts are characterized by a long life cycle. The longest phase of this is exploitation. Although the scope of construction works in this phase is not extensive compared to the construction of a facility, decisions related to, e.g., refurbishment, reconstruction, extension, adaptation to a different room/facility use, and selection of material solutions (required for, i.e., structural strengthening, repair, replacement, or refurbishment of finishes), are difficult and require consideration of many factors.

In this article, the authors focus on the application of the possibility of construction products substitution. This solution might be needed due to variables such as the object's standard improvement, cost conditions, and limitations resulting from the lack of original materials available during construction. The latter aspect applies in particular to refurbishment works carried out on buildings found in the inventory of historic buildings.

The object's life cycle can be extended by repair and modernization policies [1–10]. There are many publications in the literature on the experience in this field, from practical applications to research (e.g., [11–14]). At the same time, due to the development of engineering materials, there is a wide range of building materials on the market [15–17]. However, there is a lack of readily available knowledge about them (their advantages and disadvantages when compared to other ones performing the same function) among the interested parties (investors, designers, etc.). These materials are a substitute that often allows refurbishment, modernization, and even restoration of buildings for which it is not possible to use original materials.

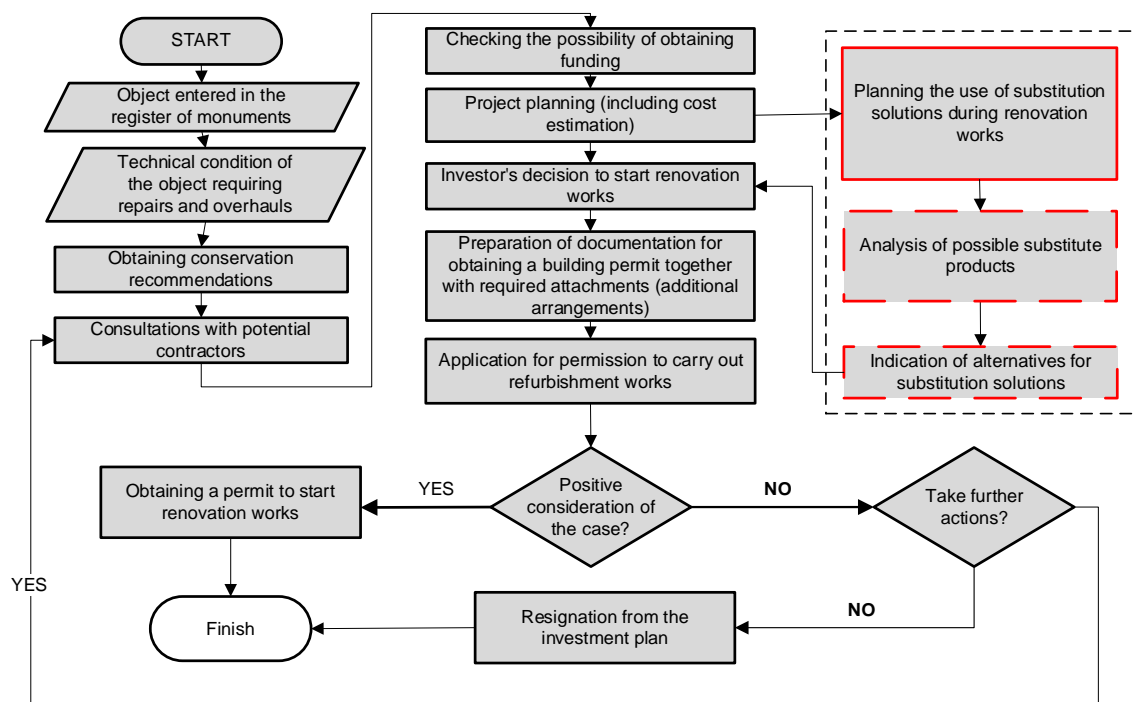
In construction, the use of substitution occurs throughout the life cycle of a building and involves various issues. Both in the preparation phase, e.g., during the variants of functions and/or structural changes and in the technology of planned refurbishment and/or modernization works, especially in historic buildings. Substitution can significantly affect the quality, cost, and time of individual construction projects. It also has a wider multifaceted impact on the delivery of construction works in environmental, economic,

and social aspects. For example, the use of material substitution may make it possible to meet a construction completion deadline or to purchase equally suitable but less expensive components. It can bring improvements in user comfort or the use of products whose manufacture and use do not generate pollutant emissions. This last example makes a very important contribution to environmental protection—the implementation of sustainable development principles [18].

The aim of the paper is to propose a methodology for selection of the most suitable substitute materials in the refurbishment and modernization of historic buildings. The selection process should take into account various conditions (legal, technical, economic, environmental, etc.) and the criteria for evaluation of the proposed material alternatives [2,13,19–22]. The problem of substitution application and selection of the type of substitute material is illustrated below for a specific case, using the multicriteria analysis method.

## 2. Conditions and Factors Affecting the Use of Substitution

The use of building product substitutes in this type of building is challenging, not only because of the difficulty of selecting a suitable substitute due to need of meeting the procedural requirements approved by the conservator. Hence, many factors and conditions of different natures influence the selection of the best substitute under the given conditions, bearing in mind the consequences in terms of durability, strength, etc., during the further use of the building. During planning of construction works in a historic building, variant solutions that take into account the use of substitute materials are worth analyzing (if the conservator allows such solutions) (Figure 1).

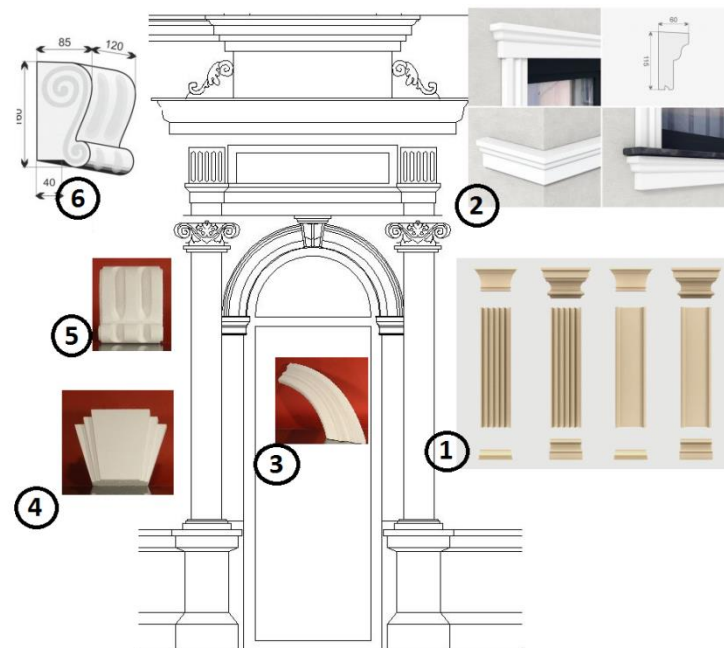


**Figure 1.** Methodology for the use of building product substitution in the refurbishment of historic buildings.

In some European countries, in historical construction, substitution of materials with the same ones that were originally used is obligatory. However, in Poland and some other countries, the law allows the use of substitutes depending on various conditions to be set by the conservator [10,23–31]. During work on historic buildings, the choice of material is determined by factors other than the lowest cost, which is often dominant [32,33]. In the case of historic buildings, the visual aspect, achieving adequate strength, appropriate product geometry, and durability and serviceability are important. The factors that influence the

possibility of using building product substitutes are specified in the so-called conservation program, which is developed for each refurbishment of an object that is entered in the inventory of historic monuments. Any proposed building product substitute must be prepared in the form of a sample and accepted by the conservator.

This offers the possibility of using, for example, clinker tiles on facades that were originally built with solid bricks, prefabricated cornices made of polystyrene or inserts of stone elements crafted to create a specific visual effect. Examples of façade element solutions are shown in Figure 2.



**Figure 2.** Examples of substitutes of building products used in refurbishment of elevations of historic buildings (1. pilasters, 2. cornices, 3. arch, 4. keystone, 5. and 6. brackets), drawings own elaboration, photos from internet resources [30,34,35].

The substitution of construction products may increase the progress of refurbishment works due to, among other things, less complex work technology, faster installation of built-in elements, and the possibility to carry out works in less favorable weather conditions. The rate of construction work can be increased by shortening supply chains (manufacturers of construction products are located within a short distance of the refurbishment) and by using substitutes that are smaller than the ones originally built, thus reducing the need for storage areas. In the case of refurbishment of historic buildings, this is particularly important as the construction site is often small due to the location of such buildings in strict and densely built-up city centers. In historic buildings, we not only have to deal with the problem of substitution of materials, e.g., finishing materials for refurbishment of facades or interiors of buildings, but also with entire building systems, e.g., ceilings and other missing or damaged structural fragments.

Moreover, due to the specific nature of refurbishment works in historic buildings, the contractor may encounter problems at every stage of the works which are unusual for the current construction technologies. The contractor should have extensive knowledge and experience. Selection of an inexperienced contractor may result in execution errors, even in correctly selected substitute building products. For this reason, an experienced contractor and supervision in refurbishment works on historic buildings are necessary.

It should also be noted that a prerequisite for considering the use of substitution is the conservation program, which includes information on the acceptability of material solutions other than those originally used. However, the indication of the possibility of using a substitute material should not be the determining factor for its use. Consideration

of the use of a substitute article should be preceded by an in-depth analysis of the pros and cons. The presented holistic approach to the application of substitution of material solutions in historical buildings is illustrated on the example of planning the method of refurbishment of the façade of an exemplary historical tenement house in Cracow.

### 3. Case Study

#### 3.1. Description of the Building, Its History, and the Scope of Refurbishment

The building is located in the city center in the Kazimierz district Figure 3a; it was built in 1878. There is not much information available in the national archives about the first years of its use; we only know that it was a tenement house serving as a dwelling house. Few photographs were found showing the whole street where the building is located (Figure 3b).



**Figure 3.** (a) Photo of the front elevation of the building August 2017, googlemaps (b). Photo taken by Ignacy Krieger in 1895.

It was not until the 1970s, practically 100 years later, that the building was thoroughly renovated. It was then that the following work was carried out:

- transformation of the ground floor elevation for shop windows, which resulted in the destruction of the original articulation of the walls, which, among other things, was accomplished by changing the geometry of the windows
- new reinforced concrete lintels, supported in the central part by reinforced concrete pillars (only the entrance gate and fragmentary rustication made in plaster remained from the original);
- steel joinery within the ground floor;
- minor restorations within the façade decoration, including one poorly restored cornice above the second floor window;
- restoration of plaster surfaces and cement render;
- repainting of the façade;
- cover plate of the cornice crowning the walls [36].

From the 1980s onward, the building continued to be used as a residential building with a service area on the ground floor. Only temporary repairs were carried out, thus allowing the building to slowly deteriorate.

An assessment of the technical condition of the building was carried out several years ago during the planning of refurbishment works. The building is listed in the inventory of historical monuments; thus, the conservation program was also developed along with the technical condition assessment studies. During the assessment, it was found that the condition of the structure showed no visible signs of weakness; however, there was a major problem with moisture within the walls of the building, particularly resulting from capillary action on the ground floor and basement. Unfortunately, the cement plaster

applied to the front wall in the 1970s caused it to deteriorate more rapidly. Given the fact that the richly decorated front elevation is one of its most valuable elements, it was decided to renovate it.

The condition assessment showed that the damage to the front elevation is:

- surface contamination;
- soiling with paint (graffiti) and pigeon droppings;
- defects in plaster, e.g., missing rustication of the lower right part of the ground floor and locally in the remaining parts of the elevation;
- partial flooding of the basement and ground floor rooms caused by leaks in the flashings and leaks in the balcony floors;
- grossly repainted: pedestal and stucco elements added in later years within the ground floor;
- locally occurring microorganisms and plants (cornices, balconies, and rustications) and localized salinization were also observed;
- apart from the ground floor, the original joinery was partially preserved;
- the biggest damage was observed on the ground floor, which was renovated in the 1970s, including the steel joinery.

The conservation program was prepared with the aim of fully preserving the architectural and historical values. The program allowed the use of substitute materials modelled on the original. It was also allowed to design new colors of the façade, taking into account historical premises.

### 3.2. Decision-Making Process in Building Façade Refurbishment

The actions that precede the decision to use a substitution (and later the correct choice) should involve, firstly, the identification of degradation causes of facility elements and, secondly, the corrective actions that bring the element to a good technical condition.

Before any actions are taken with respect to a historic building found in the inventory of historic monuments, it should be subjected to a comprehensive analysis taking into account all historical and technical conditions. Often such analyses provide information about a completely different architectural form of the building than in the original, the function performed, or the use of completely different materials than in the original during the refurbishment, reconstruction, or addition. Therefore, in the proposed inventory, work should be performed:

1. First, comprehensive assessment, in particular, a technical assessment of the historic building. The scope of such assessment is widely accepted in practice and described in numerous studies on the subject, e.g., [37];
2. Arrangement with the conservator of the scope of substitution in the planned refurbishment of the building and its elements [10];
3. Developing alternative structural and material solutions for the refurbishment of the facility elements;
4. Multicriteria analysis preceded by research and selection of criteria for evaluation of variant solutions. In this case, a SWOT matrix was developed (details were described in the article written by the same authors [18]), based on which the evaluation criteria were developed. Selection of the evaluation criteria and determination of their weights were conducted with the help of selected experts. Three methods of multicriteria analysis were used to rank the proposed solutions due to their subjectivity in the calculation processes. The methods used were the synthetic indicators method [38], AHP [8,39,40], and PROMETHEE [39];
5. Selection of a solution, development of a refurbishment project and its implementation;
6. Evaluation of the quality of the effect obtained, analysis of experience with the use of selected substitute materials for the future realizations.



### 3.3. Variant Proposals

Cleaning and preparation procedures for the refurbishment of the front elevation were common for all the considered variants. It was proposed to clean the façade from dirt and secondary layers in a mechanical manner; for this purpose, a pressure washer is used, and additionally the plaster is disinfected. Destroyed and poor-quality fragments of the facade should be subjected to thorough refurbishment procedures consisting in repairing and supplementing, i.e., restoration activities.

Three variants of the front elevation refurbishment were considered (Figures 2 and 4):

1. Façade stuccowork made with the use of pulled (wet) method;
2. Façade stuccowork made of prefabricated EPS polystyrene elements covered with a finishing layer;
3. Façade in lightweight concrete.



**Figure 4.** Architectural details of the renovated façade: 1. windowsill; 2. above-window stucco; 3. below-window stucco; and 4. building wall.

#### 3.3.1. Façade Stuccowork Made with the Use of Pulled (Wet) Method

The form of pulled decorative elements on the façades is a traditional method and the most preferred one in conservatory studies on façade refurbishments. Since the mortars used for the original decorative elements on the facades cannot be used, replacement repair and filling compounds adapted to the moisture level and the products are used. The main difficulty in this solution is ensuring adhesion. It depends on many factors that can occur in the facade layers. The final layer is the paint, which can be breathable or impermeable; it is an advantage when evaluating the durability of this solution. Due to the manner in which the repairs are carried out and the number of layers that need to be applied in an appropriate manner and with a certain precision, this option is burdened with high labor costs. The labor cost is also based on the need to hire specialized work teams who are experienced in the repair of historic buildings. Considering the scheduling components, the long lead time to achieve the right result affects the slow pace of the works, which consequently affects the high fixed costs of the refurbishment. The supply chain for building products needed for stucco elements repair and application.

Specialized products often require orders to be placed a long time in advance. Unfortunately, it is common for the order to be supplemented as a result of the impossibility of the material requirements estimation before work commences, which results in the repair work being significantly prolonged. However, the difficulty of the work is well compensated for by the visual effect, which is similar to the original, and the authenticity which this solution gives to the renovated façade. In addition, the pulling method provides a durable solution, which is why it is often found as the preferred solution in conservation studies.

From an environmental point of view, relatively little waste is generated in the pulling method, which is limited to bags and foils used as transport containers.

### 3.3.2. Façade Stuccowork Made of Prefabricated EPS Polystyrene Elements Covered with a Finishing Layer

The refurbishment of a historic façade using prefabricated expanded polystyrene elements (EPS) significantly influences the speed of execution. The installation of stuccowork elements on a façade is highly feasible but requires high precision. The accuracy of assembly can be improved at the design stage of prefabricated elements by the use of locks and a special form of elements at the joint of individual parts facilitating subsequent installation on the facade. Prefabricated EPS elements can be coated with polymer or cement layers depending on the manufacturer or design requirements. The accuracy of the finished façade elements depends on the degree of complexity and the method of applying the surface layer. The finishing of EPS can be conducted by spraying or by the pull method. The pull method gives better visual effects due to the possibility of obtaining sharp edges. With this solution, attention must be paid to the tightness of the finishing layer, as water migration and temperature changes can significantly accelerate the degradation process. The production process itself is not long, and the weight of the individual components and the fact that they can be divided up quite easily simplify logistics and allow for various deliveries depending on needs. A definite disadvantage of this solution is the loss of authenticity and historical value of the façade. The disadvantage of this solution is also the possible waste, greater than in the case of other methods, which may arise at the stage of cutting decorative elements on site. While the EPS itself can be recycled and used (e.g., in the form of panels), covering it with a finishing layer that is very strongly bonded to the polystyrene base, makes the recycling process much more difficult.

### 3.3.3. Façade Made of Prefabricated Elements Made of Light Concrete

The prefabrication of lightweight concrete elements is technologically more complex than that of polystyrene. Permanent forms with a low level of deformation are required to produce the finished element, in order to ensure that the repeatability of the elements produced is maintained. The decorative element produced in the form is the final element. It is assembled (glued and possibly nailed depending on its size) into an object without any additional reinforcing or strengthening layers, and the only coating is paint. Damage caused during transport can hardly be repaired on site. The curing time of the concrete, the protection of the elements and the packaging itself determine the logistics and necessitate individual orders. Possible completion of the order may extend the time of realization and negatively influence the progress of works (e.g., in case of damage to a decorative element during transport which may exclude the whole elevation fragment from realization). Concrete elements promise less degradation of the façade due to the negative effects of weather conditions. The installation of prefabricated elements is not complicated but requires the use of suitable glue and in some cases additional anchors. The historical value of this solution is more acceptable to conservationists than prefabricated polystyrene elements. Any damaged components and waste generated during the work can be easily recycled.

## 3.4. Multicriteria Analysis and Its Results

This section presents the research results from the application of the multicriteria analysis in the case studies described below. The algorithms of the methods used are not presented in detail due to the availability of their description in the literature and their widespread familiarity by engineers and managers and use in decision support practice (e.g., the synthetic indicators method, AHP, and PROMETHEE) [41,42]. The authors present the application of three selected methods, each of which belongs to a different group, differing, among other things, in the approach and method of searching for an optimal solution. The first of them, and at the same time the oldest, is listed among the taximetrics methods; it consists in the construction of a scalar, the numerical value of which constitutes a synthetic evaluation index. Another method the authors propose to use is the analytic

hierarchy process (AHP) method, whose creator is Thomas L. Saaty. The method consists in decomposing a problem into its simplest possible components and then processing a sequence of evaluations of a person/group of people based on pairwise comparisons (in this case, experts). The last method that was used to analyze the multicriteria problem was PROMETHEE II, which belongs to the group of methods that use dependencies by defining superiority relations. The PROMETHEE method is used to provide information to what extent (on average) a given alternative is preferred to the rest of alternatives (positive preference flow) and to what extent the rest of alternatives are preferred to the given one (negative preference flow).

The weights of the criteria were determined by a group of seven experts in civil engineering. Each expert assessed the validity of the criteria by applying a matrix of pairwise comparisons known as pairwise analysis. The results obtained were then averaged. The final weights are shown in Table 1.

**Table 1.** Assessment of the options analyzed.

Criteria	Weight	Variants			Nature of the Criterion <sup>1</sup>
		$w_1$ Pulled (Wet) Method	$w_2$ Prefabricated Polystyrene	$w_3$ Prefabricated Light Concrete	
$K_1$ —refurbishment costs	0.17	5	3	4	D
$K_2$ —faster progress of construction works (less complicated technology),	0.08	1	3	2	S
$K_3$ —obtaining the desired visual effect	0.14	5	2	3	S
$K_4$ —length of the supply chain (shortened, e.g., by establishing cooperation with local entrepreneurs)	0.06	4	1	3	D
$K_5$ —faster degradation of the substance of the object	0.14	2	5	4	D
$K_6$ —necessity to involve specialist companies in the execution of works	0.03	4	1	2	D
$K_7$ —environmental friendliness (e.g., recycled products)	0.14	3	1	5	S
$K_8$ —authenticity and historical value of the object after using the product,	0.22	5	1	3	S
$K_9$ —special requirements concerning the performance of works (during unfavorable weather conditions)	0.03	4	1	2	D

<sup>1</sup> D—destimulant (disadvantage); S—stimulant (advantage).

The three variants of the building façade refurbishment method considered were evaluated according to nine criteria (Table 1). The ratings were recorded on a 5-point discrete scale (where 5 is the highest mark and 1 the lowest), taking into account the character of the criteria. Advantages (stimulant) are the criteria; the examined feature is rated “the higher, the better” (on a scale of 1–5), while disadvantages (destimulant) are features for which the rule “the higher, the worse” applies.



The results obtained from the appraisal of the alternatives using the above methods are presented below (Tables 2–6). Table 2 presents the results of the multicriteria analysis carried out using the synthetic indicators method. Three indicators were selected: the adjusted summation index and the harmonic and geometric averages. Each of them indicated the first variant ( $w_1$ ) as the most favorable solution to be used for the refurbishment of the façade of the building under analysis.

**Table 2.** Results obtained by the synthetic indicators method.

Criteria	VARIANTS Encoded with Standardization		
	$w_1$	$w_2$	$w_3$
$K_1$	1.00	1.67	1.25
$K_2$	0.33	1.00	0.67
$K_3$	1.00	0.40	0.60
$K_4$	1.00	4.00	1.33
$K_5$	2.50	1.00	1.25
$K_6$	1.00	4.00	2.00
$K_7$	0.60	0.20	1.00
$K_8$	1.00	0.20	0.60
$K_9$	1.00	4.00	2.00
Synthetic indicators adjusted			
Summation indicator	1.0972	1.0722	0.9782
Weighted harmonic mean	0.8504	0.3996	0.8477
Weighted geometric mean	0.9654	0.6255	0.9088

**Table 3.** Results of the AHP method.

Criteria	Local Priorities	$w_1$	$w_2$	$w_3$
$K_1$	0.2	0.1199	0.61	0.27
$K_2$	0.09	0.0703	0.58	0.35
$K_3$	0.11	0.6333	0.26	0.11
$K_4$	0.05	0.0982	0.57	0.33
$K_5$	0.11	0.608	0.12	0.27
$K_6$	0.03	0.0738	0.64	0.28
$K_7$	0.11	0.2344	0.08	0.69
$K_8$	0.27	0.6555	0.08	0.26
$K_9$	0.04	0.0738	0.64	0.28
Global priorities		0.378	0.312	0.308

**Table 4.** Aggregated preference indexes.

$\pi(w_1, w_1) = 0.0$	$\pi(w_1, w_2) = 0.4$	$\pi(w_1, w_3) = 0.2$
$\pi(w_2, w_1) = 0.15$	$\pi(w_2, w_2) = 0.0$	$\pi(w_2, w_3) = 0.09$
$\pi(w_3, w_1) = 0.14$	$\pi(w_3, w_2) = 0.23$	$\pi(w_3, w_3) = 0.0$

The second method used to select the best solution for the façade refurbishment was the AHP method. The results of the calculations are presented in Table 3. The global priorities determined for each of the variants showed that the first variant ( $w_1$ ) is the most advantageous solution in the analyzed case.

**Table 5.** Positive and negative preference flows.

$\Phi^+(w_1) = 0.300$	$\Phi^-(w_1) = 0.114$
$\Phi^+(w_2) = 0.119$	$\Phi^-(w_2) = 0.314$
$\Phi^+(w_3) = 0.183$	$\Phi^-(w_3) = 0.144$

**Table 6.** Net flow.

$\Phi(w_1) = 0.16$
$\Phi(w_2) = -0.2$
$\Phi(w_3) = 0.04$

The last method used to determine the best refurbishment solution was the PROMETHEE II method, in which the final ranking is expressed in terms of net flow. The calculations carried out showed that the best solution in the analyzed case would also be variant  $w_1$ . Partial results of the calculations carried out with the PROMETHEE II method are shown in Tables 4–6.

The calculations performed with the use of three methods of multicriteria analysis showed that the application of the  $W_1$  solution would be the most advantageous in this facility. This result was achieved due to the very high weighting of the criterion concerning the authenticity of the solution used ( $K_8$ ), which was strongly demonstrated by solution 1 for the options considered. The use of three methods belonging to different groups of multicriteria analysis allows one to reduce the subjectivity of the results obtained. However, it should be noticed that when using multicriteria analysis methods, the specificity of the case under analysis should always be taken into account. This is often important due to the individual/unique selection of criteria weights, as well as, in the case of historic buildings, the conservation guidelines and the technical condition of the object itself.

The use of multicriteria analysis to evaluate substitute options in refurbished buildings, especially historic buildings, allows for a better analysis of the considered solutions and can often be a helpful tool to make an informed and correct decision on the works carried out.

The solution that was identified as the best in each method was implemented in reality; the final effect of which can be admired recently (Figure 5a,b). As can be seen, the applied solution reflects the authenticity of the historic façade in a very realistic manner. In addition, the use of substitute products made it possible to carry out a larger scope of refurbishment due to the lower costs of the solutions used, which is an additional advantage.



**Figure 5.** (a) Fragment of reconstructed rustication on the facade 29 April 2021; (b) tenement house after refurbishment 29 April 2021, authors' archive.

#### 4. Conclusions

Substitution of construction products is a common practice at every stage of the life cycle of a building. In particular, substitution occurs in the further exploitation of facilities, especially when carrying out any repair and refurbishment works in facilities used for several dozens or even several hundred years.

One of the ways of prolonging the life cycle of buildings is precisely by pursuing a refurbishment policy, during which, above all, care should be taken when selecting appropriate material solutions. A special case is substitution in the refurbishment works of objects entered in the inventory of historic monuments, which offers the possibility of securing the historic substance while maintaining the structural and aesthetic values.

The paper presents a methodology for proceeding with the selection of solutions other than what was originally applied. In order to reduce the subjectivity of the selection of a substitution solution, the authors propose to use several methods of multicriteria analysis simultaneously. In particular, the use of methods from different groups is recommended, as shown in the example. Due to the highly individual nature of heritage buildings, it is recommended that the conservation program is analyzed in each case before any calculations are made using multicriteria analysis methods. The methodology presented in this paper assumes a prior agreement with the conservator on the scope of the planned substitution, which can be followed by a final selection of possible substitution options. Of course, the use of substitution should only be considered if it is not possible to use original materials on the historic building.

The final stage of the proposed methodology is to assess the quality of the result obtained (in this example, the façade). It is also advisable to collect the experiences of each project during which substitute solutions were used. The analysis of the experiences of already-realized projects will allow in the future the better selection of both: the variants themselves and the importance of the criteria taken into account in the assessment.

The article presents an example where the use of substitution achieved the desired effect and extended the life cycle of the building. In this example, the advantages of substitution outweighed its disadvantages. In addition, the use of substitution in the building made it possible to carry out the refurbishment at a lower cost, while maintaining the original appearance of the covering/elevation. Moreover, the substitute used in the object is a product with better features than the original one, which makes it possible, among other things, to achieve longer durability of the object without the need to interfere with the historic fabric for a longer period of time.

**Author Contributions:** Conceptualization, A.S., K.L. and A.R.; methodology, A.S., K.L. and A.R.; validation, A.S., K.L. and A.R.; formal analysis, A.S., K.L. and A.R.; investigation, A.S., K.L. and A.R.; resources, K.L. and A.R.; writing—original draft preparation, A.S., K.L. and A.R.; writing—review and editing, A.S. and A.R.; visualization, K.L. and A.R.; supervision, A.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data sharing not applicable.

**Acknowledgments:** The work was carried out as part of statutory research no. 11.11.100.197 in the Department of Geomechanics, Civil Engineering, and Geotechnics of Faculty of Mining and Geoengineering, AGH University of Science and Technology in Cracow.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Teh, S.H.; Wiedmann, T.; Schinabeck, J.; Moore, S. Replacement Scenarios for Construction Materials Based on Economy-wide Hybrid LCA. *Procedia Eng.* **2017**, *180*, 179–189. [CrossRef]
2. Mathur, V.K. Composite materials from local resources. *Constr. Build. Mater.* **2006**, *20*, 470–477. [CrossRef]
3. Iucolano, F.; Boccarusso, L.; Langella, A. Hemp as eco-friendly substitute of glass fibres for gypsum reinforcement: Impact and flexural behaviour. *Compos. Part B Eng.* **2019**, *175*, 107073. [CrossRef]
4. Liu, L.; Li, H.; Lazzaretto, A.; Manente, G.; Tong, C.; Liu, Q.; Li, N. The development history and prospects of biomass-based insulation materials for buildings. *Renew. Sustain. Energy Rev.* **2017**, *69*, 912–932. [CrossRef]
5. Razakhanova, F.M. Issues concerning import substitution of building materials in the construction market. *Her. Dagestan State Tech. Univ. Tech. Sci.* **2018**, *44*, 223–233. [CrossRef]
6. Chen, C.-S.; Chiu, Y.-H.; Tsai, L. Evaluating the adaptive reuse of historic buildings through multicriteria decision-making. *Habitat Int.* **2018**, *81*, 12–23. [CrossRef]
7. Cheng, J.C.P.; Ma, L.Y.H. A BIM-based system for demolition and renovation waste estimation and planning. *Waste Manag.* **2013**, *33*, 1539–1551. [CrossRef]
8. Kijewska, K.; Torbacki, W.; Iwan, S. Application of AHP and DEMATEL Methods in Choosing and Analysing the Measures for the Distribution of Goods in Szczecin Region. *Sustainability* **2018**, *10*, 2365. [CrossRef]
9. Wene, C.-O. The optimum mix of conservation and substitution: An example from retrofitting of old buildings. *Int. J. Energy Res.* **1980**, *4*, 271–282. [CrossRef]
10. Journal of Laws, Act on the Protection and Care of Historical Monuments, Old Monuments Law (Ustawa, o Ochronie Zabytków; Opiece nad Zabytkami). Available online: <https://isap.sejm.gov.pl> (accessed on 12 June 2021).
11. Sobotka, A.; Linczowski, K. Relations between Substitution in Technological Processes and Construction Supply Logistics (Powiązania Pomiędzy Substytucją w Procesach Technologicznych a Logistyką Zaopatrzenia Budowy). *Logistics* **2014**, *6*, 9816–9825.
12. Gustavsson, L.; Sathre, R. Energy and CO<sub>2</sub> analysis of wood substitution in construction. *Clim. Chang.* **2011**, *105*, 129–153. [CrossRef]
13. Jandl, H.W. The Use of Substitute Materials on Historic Buildings Exteriors. Preservation briefs, 16 NV-14 p.: 22 figs., 35 b&w ill., bibliog. 1988. Available online: <https://www.nps.gov/tps/how-to-preserve/briefs/16-substitute-materials.htm> (accessed on 12 June 2021).
14. New Zealand Government, Ministry of Business Innovation & Employment. *Quick Guide to Product Substitution*; New Zealand Government, Ministry of Business Innovation & Employment: Wellington, New Zealand, 2004. Available online: <https://www.tcdc.govt.nz> (accessed on 25 May 2021).
15. Demir, I. An investigation on the production of construction brick with processed waste tea. *Build. Environ.* **2006**, *41*, 1274–1278. [CrossRef]
16. D’Amico, B.; Pomponi, F.; Hart, J. Global potential for material substitution in building construction: The case of cross laminated timber. *J. Clean. Prod.* **2021**, *279*, 123487. [CrossRef]
17. Patel, D.; Shrivastava, R.; Tiwari, R.P.; Yadav, R.K. Properties of cement mortar in substitution with waste fine glass powder and environmental impact study. *J. Build. Eng.* **2020**, *27*, 100940. [CrossRef]
18. Sobotka, A.; Linczowski, K.; Radziejowska, A. Substitution of material solutions in the operating phase of a building. *Appl. Sci.* **2021**, *11*, 2812. [CrossRef]
19. Dierickx, M.B. Substitute Materials for Wooden Buildings: The System or the Artifact? *Bull. Assoc. Preserv. Technol.* **1986**, *18*, 4. [CrossRef]
20. Piccardo, C.; Dodoo, A.; Gustavsson, L.; Tetey, U.Y.A. Retrofitting with different building materials: Life-cycle primary energy implications. *Energy* **2020**, *192*, 116648. [CrossRef]
21. Gustavsson, L.; Nguyen, T.; Sathre, R.; Tetey, U.Y.A. Climate effects of forestry and substitution of concrete buildings and fossil energy. *Renew. Sustain. Energy Rev.* **2021**, *136*, 110435. [CrossRef]
22. Veiga, M.d.R.; Fragata, A.; Velosa, A.L.; Magalhães, A.C.; Margalha, G. Lime-Based Mortars: Viability for Use as Substitution Renders in Historical Buildings. *Int. J. Archit. Herit.* **2010**, *4*, 177–195. [CrossRef]
23. Sejm. USTAWA z Dnia 7 Lipca 1994 r. Prawo Budowlane. 2021, pp. 1–140. Available online: <https://www.powiat-wielun.finn.pl/bipkod/25708237> (accessed on 12 June 2021).
24. Gmiter, M. *Guide to the Investment Process in Historic Buildings (Przewodnik po Procesie Inwestycyjnym w Obiektach Zabytkowych)*; Presscom Sp. Z.o.o.: Wrocław, Poland, 2018.
25. Technical Preservation Services. Evaluating Substitute Materials in Historic Buildings. 2007. Available online: <https://www.nps.gov/tps/standards/applying-rehabilitation/successful-rehab/substitute-materials.htm> (accessed on 25 May 2021).
26. Blomqvist, S.; la Fleur, L.; Amiri, S.; Rohdin, P.; Ödlund, L. The impact on system performance when renovating a multifamily building stock in a district heated region. *Sustainability* **2019**, *11*, 2199. [CrossRef]
27. Van Domelen, S.K. *The Choice Is Yours: Considerations & Methods for the Evaluation & Selection of Substitute Materials for Historic Preservation*; University of Pennsylvania: Philadelphia, PA, USA, 2009.
28. Myers, J.H.; Hume, G.L. Aluminum and Vinyl Siding on Historic Buildings. The Appropriateness of Substitute Materials for Resurfacing Historic Wood Frame Buildings. 1984. Available online: <https://www.nps.gov/TPS/how-to-preserve/briefs/8-aluminumvinyl-siding.htm> (accessed on 14 May 2021).

29. Historical Building Construction: Design, Materials, and Technology. Available online: <https://www.amazon.com/Historical-Building-Construction-Materials-Technology/dp/0393732681> (accessed on 25 May 2021).
30. S & D Design Guidelines for Landmark. *Guidelines for Preserving Historic Buildings—Alterations to Landmark Structures and Contributing Structures in Historic Districts*; S & D Design Guidelines for Landmark: Denver, CO, USA, 2016.
31. Capen, J. Using Substitute Materials in a Historic District. *Hill Rag* **2008**, *5*, 134–135.
32. Petersen, A.K.; Solberg, B. Environmental and economic impacts of substitution between wood products and alternative materials: A review of micro-level analyses from Norway and Sweden. *For. Policy Econ.* **2005**, *7*, 249–259. [[CrossRef](#)]
33. Nowogonska, B.; Korentz, J. Value of technical wear and costs of restoring performance characteristics to residential buildings. *Buildings* **2020**, *10*, 9. [[CrossRef](#)]
34. Sztukateria Elewacyjna. Sztukateria Styropianowa—Listwy SKLEP. Available online: <https://decorsystem.pl/> (accessed on 26 May 2021).
35. Producent Sztukaterii i Profili Elewacyjnych—Gzymisy i Listwy Styropianowe, Sztukateria Gipsowa, Sztukateria. Available online: <http://www.prof-bud.pl/> (accessed on 26 May 2021).
36. Graboś, E. Conservation Programme (Program konserwatorski). Unpublished work, 2016.
37. Banaszak, J.; Halicka, A. Kompleksowa ocena techniczna budynku zabytkowego na przykładzie plebanii w Wojsławicach. *Bud. Archít.* **2011**, *9*, 51–68. [[CrossRef](#)]
38. Deszcz, J.S.J. *Metody Wielokryterialnej Analizy Porównawczej: Podstawy Teoretyczne i Przykłady Zastosowań w Budownictwie*; Wydawnictwo Politechniki Śląskiej: Gliwice, Poland, 2001.
39. Saaty, T. *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process*; RWS Publications: Pittsburgh, PA, USA, 2000.
40. Radziejowska, A.; Zima, K. Multicriteria analysis in selecting the optimal variant of solar system. *E3S Web Conf.* **2016**, *10*, 00078. [[CrossRef](#)]
41. Caterino, N.; Iervolino, I.; Manfredi, G.; Cosenza, E. Multi-criteria decision making for seismic retrofitting of RC structures. *J. Earthq. Eng.* **2008**, *12*, 555–583. [[CrossRef](#)]
42. Stellacci, S.; Rato, V.; Poletti, E.; Vasconcelos, G.; Borsoi, G. Multi-criteria analysis of rehabilitation techniques for traditional timber frame walls in Pombalino buildings (Lisbon). *J. Build. Eng.* **2018**, *16*, 184–198. [[CrossRef](#)]