

NEW TRENDS IN CONSTRUCTION MANAGEMENT

Edited by
Edyta Plebankiewicz



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CHAPTER 7

THE SELECTION OF A MASONRY FAÇADE INSTALLATION METHOD FOR A BUILDING AT THE DESIGN STAGE

ABSTRACT

The main aim of this research is to offer a new modern method of masonry façade installation, but before practical implementation, it is necessary to compare it with traditional methods of installation and perform a detailed analysis. The authors present the detailed analysis of three alternative methods of masonry façade installation: the installation of suspend brackets for a masonry and brick lintel hook system, the installation of suspend brackets for masonry and brick slip lintels, the installation of prefabricated tension masonry panels with a thickness of 51 mm. The aim is to select the most reasonable method of masonry façade installation at the design stage according to three groups of criteria – architectural, structural and technological-economic – each group consisting of eight criteria. An expert survey is made to estimate the weights of criteria and the WASPAS (Weighted Aggregated Sum Product Assessment) method is applied to select the most suitable method for masonry façade installation at the design stage. It is observed that the analysed alternatives were ranked differently according to particular groups of criteria.

Keywords: masonry façade; methods of installation; design stage; MCDM; WASPAS

7.1. INTRODUCTION

Masonry bricks for a unique “face” of the building as the architectural design solution. Moreover, masonry brick buildings can be seen in every city, especially in historical parts and old towns. In European countries, the façade walls were characterised by single leaf walls until the mid-twentieth century, built with stone, brick or adobe ensuring the global stability of the buildings. By definition,

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a masonry veneer wall consists of an exterior masonry cladding separated from the structural backing by an air cavity, designed to form the skin of the structure (Martins et al., 2017). Looking from the outside, external cladding of ventilated façade is fixed with substructures and connectors to the supporting wall (Schabowicz, Zawislak 2020). Ingrao et al. (2016) proved that ventilated façade systems have better environmental properties compared to standard wall compositions in terms of environmental impact. In this study, the external cladding is masonry veneer bricks fixed to the supporting wall. Masonry bricks are an extremely flexible architectural material as it creates a style of a building and a unique architecture because the masonry veneer façade is not designed in compliance with the requirements of standards (Foster et al. 2019). Masonry bricks highlight the details of the buildings such as pylons, arches, lintels, cornices. Masonry bricks are used to make masonry veneer façades, have been known for centuries and do not lose their popularity. Moreover, there are the many advantages of masonry veneer façades such as the durability of bricks, easy maintenance, façade appearance, very good acoustic properties, high resistance to cold and heat, resistance to fire, vapour permeability, low porosity, low water absorption and resistance to pollution. It has been found that masonry veneer façades are the most cost-effective systems for most cities due to their low construction cost and relatively good thermal rating (Tam et al. 2018).

Nowadays, interest in flexible architectural solutions made by bricks is growing. However, to convey the architect's design with regard to the veneer façade vision and to provide more features of the brick terrain is not a simple task, as the masonry veneer façade is a non-structural wall and the masonry veneer façade is designed to support only its own weight (Martins et al., 2017). To solve this, a new method of masonry façade installation is needed, but before implementing it in practice, it is necessary to compare it with traditional methods of installation and make a detailed analysis. This problem may be solved by using prefabricated tension masonry panels of 51 mm thickness made of veneer bricks. The prefabricated veneer masonry panels may be used to ensure product quality and supply chain quality control so seasonality issues can be solved in advance. In addition, the installation of the veneer façade on the construction site can be accelerated and the application of a new method of installation for prefabricated veneer masonry panels can reduce the duration of the works and lower the costs (Lopes et al., 2017). Singhaputtangkul and Low (2015) determined that a concrete prefabricated block wall requires less energy and resources during the construction stage compared with brickwork walls. Gilani (2020) stated that a façade system which requires a minimum labour skill on the construction stage is economically independent.

The aim of the paper is to select the most reasonable method of masonry façade installation at the design stage. The paper analyses two traditional methods of installation (the installation of suspend brackets for masonry and a brick lintel hook system, the installation of suspend brackets for masonry and brick slip

lintels) as well as the newly suggested installation of prefabricated tension masonry panels with a thickness of 51 mm. The methods of installation are analysed according to three groups of criteria: architectural, structural and technological-economic. The WASPAS (Weighted Aggregated Sum Product Assessment) method is applied for multiple-criteria evaluation of alternative installation methods.

The remainder of this study is as follows: a literature review is presented in Section 2, the steps of the research and WASPAS methodology are listed in Section 3, the research results are described in Section 4, and Section 5 presents the conclusions and future research suggestions.

7.2. LITERATURE REVIEW

Literature analysis shows that there are a lot of studies for selecting the best material for façade, the best variant of façade and selecting the façade solution at the design stage. However, to the best of our knowledge, there are no studies about selecting the best method of installation for a masonry veneer façade. Furthermore, a variety of MCDM (Multi Criteria Decision Making) methods and models have been presented for decision-making problems in the selection of the material or façade design.

Hatefi et al. (2021) identified a sustainable façade building material based on four groups of criteria including economic, social, environmental, and technical. The results by applying ARAS (Additive Ratio Assessment) method shows the aluminium siding as the most optimal sustainable material, but masonry veneer bricks are in second place among the five analysed materials. A masonry veneer façade is a feasible solution for a commercial building compared with concrete bricks and composite façade panels. Despite the highest cost of one square metre Leśniak and Balicki (2016) and Mayhoub et al. (2021) defined the criteria for the selection of sustainable and ecological façade material. Sobotka et al. (2021) applied multicriteria methods in their methodology for the restoration of historical façades. The suggested method reduces the cost of renovations and facilitates the choice of a more sustainable and durable façade material. Migilinskas et al. (2017) identified the most significant technical, organisational and managerial problems in reconstruction projects, then analysed their consequences and suggested tools and actions that could help prevent the problems and increase the effectiveness of the projects. Additionally, Pavlovskis et al. (2017) proposed the application of a complex criteria system to select the best redevelopment alternative of a building using the WASPAS-G (Weighted Aggregated Sum Product Assessment) method with grey attributes scores.

As MCDM refers to mathematical models as support for decision makers to make subjective evaluations of alternatives under multiple criteria, Moghtadernejad et al. (2020) provided the necessary steps regarding how to achieve a high quality

for the design of façade systems through the application of MCDM methods for evaluation and decision making. Moussavi Nadoushani et al. (2017) discussed the relative performance of different façade systems in different sustainability performance areas and identified that it can vary considerably depending on the specific project conditions and requirements. It should be noted that the criteria and weights are specific to the project and their suitability for other projects should be evaluated prior to use. Moghtadernejad et al. (2021) proposed fuzzy PCA (Principal Component Analysis) and fuzzy NN (Neural Network) methods to determine the feasible façade design solution. Ivanova et al. (2020) identified the most optimal alternative for the design of vertical façade landscaping by applying the AHP (Analytic Hierarchy Process) method.

This paper is aimed at analysing how to choose the best masonry veneer installation method at the design stage, evaluating it according to many quantitative and qualitative criteria. Choosing the best option for a building façade is one of the most important issues in building design (Zavadskas et al., 2013). In the current paper, the authors apply the WASPAS method based on its benefits identified during a literature review. The WASPAS method is the combination of the results of two different models – the weighted sum model (WSM) and the weighted product model (WPM) (Zavadskas et al., 2012). This method is easy to use, and a combination of weighted sum model and weighted product model leads to high-ranking accuracy (Mulliner et al., 2016). Joint generalised criterion for each alternative is calculated, which is actually the weighted sum of additive and multiplicative relative importance values. The final ranking of the alternatives is done based on the joint generalised criterion values (Bandyopadhyay, 2021). This method is successfully applied in various areas and is currently one of the most important methods among MCMD techniques (Alipour-Vaezi, Tavakkoli-Moghaddam, 2020).

7.3. METHODOLOGY

The steps of the suggested approach for the selection of the masonry façade installation method are as below:

Step 1. developing an evaluation criteria system, including three groups of criteria – architectural, structural and technological-economic – with each group consisting of certain sub-criteria;

Step 2. conducting an expert survey to estimate the weights of groups of criteria as well as of every criterion in a group;

Step 3. describing the analysed masonry façade installation methods in terms of the criteria;

Step 4. ranking the alternative masonry façade installation methods by applying WASPAS.

The WASPAS method is presented below (Zavadskas et al., 2012).

Suppose that the problem is defined with m alternatives and n decision criteria. The relative significance (weight) of the criterion is denoted by w_j . Variable x_{ij} denotes the performance value of alternative i when it is evaluated in terms of criterion j .

The first criterion of optimality is based on WSM. The relative importance of alternative i , denoted as $Q_i^{(1)}$, is defined as follows (MacCrimon, 1968):

$$Q_i^{(1)} = \sum_{j=1}^n \bar{x}_{ij} w_j, \quad (1)$$

where linear normalisation of initial criteria values is applied, i.e.

$$\bar{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \quad (2)$$

if $\max_i x_{ij}$ value is preferable or

$$\bar{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}}, \quad (3)$$

if $\min_i x_{ij}$ value is preferable.

The second criterion of optimality, namely the multiplicative exponential generalised criterion, in general coincides with WPM (Triantaphyllou, 1989; Miller and Starr, 1969). The relative importance of alternative i , denoted as $Q_i^{(2)}$, is defined as follows:

$$Q_i^{(2)} = \prod_{j=1}^n (\bar{x}_{ij})^{w_j}. \quad (4)$$

Supposing the increase of ranking accuracy and, respectively, the effectiveness of decision making, a joint generalized criterion of WSM and WPM methods and methodology for optimization of weighted aggregated function was proposed (Zavadskas et al. 2012):

$$Q_i = \lambda \sum_{j=1}^n \bar{x}_{ij} w_j + (1 - \lambda) \prod_{j=1}^n (\bar{x}_{ij})^{w_j}, \quad \lambda = 0, \dots, 1. \quad (5)$$

In this research $\lambda = 0.5$; therefore, the following equation applies for further calculations:

$$Q_i = 0.5 Q_i^{(1)} + 0.5 Q_i^{(2)} = 0.5 \sum_{j=1}^n \bar{x}_{ij} w_j + 0.5 \prod_{j=1}^n (\bar{x}_{ij})^{w_j}. \quad (6)$$

7.4. RESEARCH RESULTS

7.4.1. CRITERIA DESCRIPTION

The main task in this article is to select the most reasonable method of masonry façade installation at the design stage analysing three groups of alternatives and three groups of criteria: architectural, structural and technological-economic. Each group of criteria consists of eight criteria (Table 1). The criteria represent architectural solutions and performance parameters, structural and physical properties and technological-economic decisions.

Table 1

Criteria description

Architectural group of criteria (G_1)		
Notation	Criteria	Description
X_1	The complexity of the architectural elements of the façade	The complexity of the architectural elements of the façade represents the ability to implement alternative solutions to make complex architectural forms.
X_2	Façade aesthetics	Façade aesthetics represents the capabilities of alternative solutions for the architectural style and brickwork pattern
X_3	Suitability for low-rise construction	Suitability for low-rise construction represents the adaptation of the alternatives to low-rise construction.
X_4	Suitability for multi-storey construction	Suitability for multi-storey construction represents the adaptation of alternatives to high-rise construction.
X_5	Applicability to residential buildings	Applicability to residential buildings represents the possibility of the alternatives for residential buildings.
X_6	Applicability to commercial buildings	Applicability to commercial buildings represents the possibility of the alternatives for commercial buildings.
X_7	Unified façade	Unified façade represents the adaptation of the alternatives to make repetitive changes of architectural elements.
X_8	Combined façade	Combined façade represents the adaptation of the alternatives to make the complex architectural structure of the first two floors of the façade and repetitive change of architectural elements other floors.
Structural group of criteria (G_2)		
X_1	Heat loss of suspension bracket	Heat loss of suspension bracket represents the losses of the alternative thermal structures. The influence of the stainless-steel suspension bracket system for the masonry veneer façade increases the wall heat transfer by $0.019 \text{ W}/(\text{m}^2 \cdot \text{K})$. Thus, all of the alternative method solutions require different quantities of masonry veneer brackets and wall ties.

Table I continued

X_2	Heat loss of stainless-steel wall ties	With regard to the heat loss of stainless-steel wall ties, there are 5.5 pcs/m ² of wall ties to connect the two layers of the structure. The heat transfer between the veneer masonry layer and the load-bearing structure layer 0.004 W/(m ² ·K) for one wall tie.
X_3	Fire resistance	The fire resistance of the alternatives for the masonry veneer façade is very high because it is completely fire resistant.
X_4	Requirements for building structures	Requirements for building structures represents the solution for installation on the base structure.
X_5	Weight of m ² of façade	This is the criteria to define the weight of 1m ² of the façade area.
X_6	Masonry thickness	Usually, the thickness of the masonry veneer layer is 85–120 mm, but there is a tendency to use a thin masonry veneer layer of up to 50–60 mm.
X_7	Maximum offset from the building structures	Identification of maximum distance of the finishing layer from the building structures
X_8	Maximum height of the masonry veneer layer from the suspension system support	This is the identification of the maximum height of the masonry veneer layer from the solution method support system.
Technological-economic group of criteria (G_3)		
X_1	Speed of installation	This refers to the speed of installation for the alternative methods.
X_2	Complexity of installation	This is the indicator to define the complexity of the installation methods.
X_3	Transportation of the masonry veneer system to the site	This is the criteria relating to the logistics to construction site.
X_4	Design price	This is the price of the design.
X_5	Design time	This is the time needed to prepare the design.
X_6	Qualification of employee	Qualification of employee represents the indicator of the assessment of skilled labour.
X_7	Maintenance of façade	This represents the maintenance costs of the alternative masonry veneer systems.
X_8	Price per m ² of façade system	This is the total price of the façade system per 1 m ² .

7.4.2. DESCRIPTION OF ALTERNATIVES

Alternative No. 1 – Installation of suspension brackets for masonry and brick lintel hook system.

Masonry suspension brackets are made of stainless steel and are fixed to the load-bearing reinforced concrete structure. The bottom row of bricks is laid on the suspension brackets and is reinforced with the mortar above the first row of bricks; the other two rows of veneer masonry are also reinforced (see Fig. 1).

Brick lintels are installed using lintel hooks and reinforcement. Jonaitis and Zavalis (2017) calculated that the load-bearing capacity of the masonry lintel is sufficient according to EN 1996-1 (see Fig. 2).



Fig. 1. Installation of masonry suspension brackets [own study]

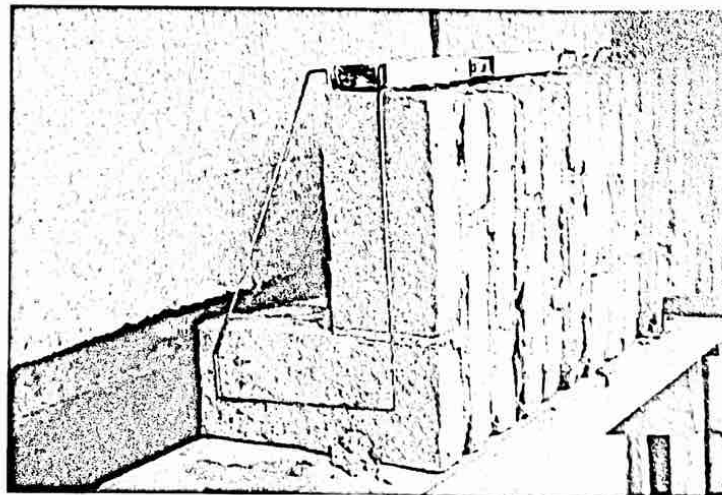


Fig. 2. Installation of brick lintel [own study]

Alternative No. 2 – Installation of suspend brackets for masonry and brick slip lintels

The installation of suspension brackets is performed as in the case of Alternative No. 1, but the masonry lintels are prefabricated before the construction stage. It is a stainless-steel construction completed with brick slips attached (Fig. 3).

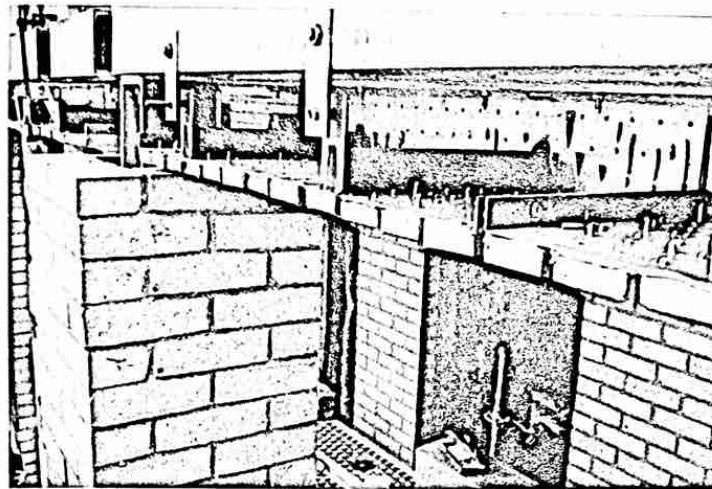


Fig. 3. Installation of brick slip lintels [own study]

Alternative No. 3 – Installation of prefabricated tension masonry panels

The masonry veneer panels are prefabricated, reinforced with vertical prestresses reinforcement and their thickness is 51 mm. The panels are produced in the factory using special perforated bricks and general-purpose mortar (Fig. 4).

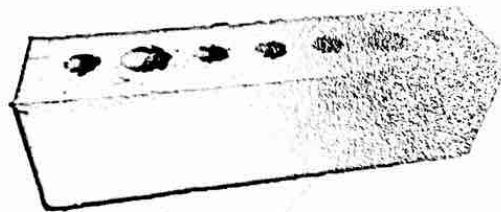


Fig. 4. Special perforated bricks [own study]

With the use of small-width masonry bricks, it possible to install a masonry veneer façade on an area that is up to twice as large with the same volume of materials. Prefabricated veneer layers can be produced in various configurations (Zavalis, Jonaitis, 2018). This can solve technological problems on the construction site and ensures the quality of the façades. Thus, the purpose of the product is universal. The prefabricated finishing masonry panels can be used both for the new building construction and for the renovation of existing buildings (Fig. 5).



Fig. 5. Prototype production of the prefabricated masonry panel [own study]

7.4.3. EXPERT SURVEY

The research for the selection of the installation method applies an expert survey to determine the relative weights of the criteria. Furthermore, in connection with the chosen methodology for the assessment of alternatives (WASPAS), the expert survey is used to determine certain criteria values based on the analysed installation alternatives. Fourteen experts were selected who work in the design of fastening elements of brickwork for the masonry veneer façade. These are all employed in the AEC (architecture, engineering and construction) industry. The distribution of experts is presented in Table 2.

Table 2

Distribution of experts

By Degree	By specialty	By area of AEC
Master 72%	Structural designer 30%	Design 50%
PhD 14%	Architect 21%	Construction 21%
Bachelor 14%	Engineer 21%	Production 21%
	Project manager 14%	Procurement 8%
	Construction manager 7%	
	Mason contractor 7%	

First, the experts were asked to rank groups of criteria and also to rank a criterion in each group. The experts had to assign scores to groups of criteria based on the scoring scale 1–3, where 3 denotes the highest importance and 1 means that the group has the lowest importance with regard to the given problem. Additionally, the criteria in each group were ranked. The experts had to assign scores to criteria in each group of criteria based on the scoring scale 1–8, where 8 denotes the highest importance

and 1 means that the criterion has the lowest importance to with regard to the given problem. The experts were then asked to complete a questionnaire for architectural and technological-economic groups for criteria values; as with the structural group, the criteria values are quantitative and the data relates to 350 m² of masonry veneer façade (Table 3).

Table 3

Structural G_2 group of criteria

Criteria	Alternative No. 1	Alternative No. 2	Alternative No. 3
X_1	3.781 W/(m ² ·K)	2.261 W/(m ² ·K)	1.582 W/(m ² ·K)
X_2	7.722 W/(m ² ·K)	7.722 W/(m ² ·K)	1.404 W/(m ² ·K)
X_3	A	A	A
X_4	C20/25 or higher	C20/25 or higher, or brick wall 1500 kg/m ³	C20/25 or higher
X_5	180–220 kg	20–220 kg	95–110 kg
X_6	50–120 mm	20–85 mm	65 mm
X_7	590 mm	590–1000 mm	320 mm
X_8	3–6 m	3–6 m	3.3 m

The next step is the calculation of weights of groups of criteria and of each criterion. The results of the calculation are provided in Tables 4 and 5. The most important group of criteria according to the experts' survey is G_1 – architectural group of criteria. The second group is G_2 – structural, and the least important is G_3 – technological-economic (Table 4).

Table 4

Weights of the groups of criteria

	Architectural group of criteria (G_1)	Structural group of criteria (G_2)	Technological-economic group of criteria (G_3)
Weight w_j	0.36	0.33	0.31
Rank	1	2	3

The experts were then asked to fill a questionnaire with answers to evaluate alternatives in terms of G_1 and G_3 group criteria. For each criterion, the experts answered 3–5 questions, so these evaluations are further processed using Equations (1)–(6). The results are presented in the next section.

Table 5

Weights of criteria in the groups

Groups of Criteria	Criteria	Rank in the group	Weight w_j
G_1	X_1	1	0.19
	X_2	2	0.16
	X_3	7	0.10
	X_4	3	0.13
	X_5	4	0.11
	X_6	5	0.10
	X_7	4	0.11
	X_8	6	0.10
G_2	X_1	6	0.10
	X_2	7	0.06
	X_3	4	0.12
	X_4	1	0.17
	X_5	2	0.13
	X_6	5	0.12
	X_7	1	0.17
	X_8	3	0.13
G_3	X_1	2	0.17
	X_2	3	0.16
	X_3	8	0.07
	X_4	7	0.09
	X_5	6	0.10
	X_6	4	0.13
	X_7	5	0.11
	X_8	1	0.17

7.4.4. CALCULATION RESULTS APPLYING WASPAS

The evaluation of alternatives is made using the experts' average scores according to the answered questions and applying WASPAS methodology (Zavadskas et al., 2012). An initial decision-making matrix for the architectural group of criteria is presented in Table 6.

Table 6

Group G_1 matrix

Criteria	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Optimisation	max	max	max	max	max	max	max	max
Weight w_j	0.19	0.16	0.10	0.13	0.11	0.10	0.11	0.10
Alternative No. 1	3.21	3.34	3.48	3.07	3.36	3.19	3.17	3.36
Alternative No. 2	3.21	3.13	2.86	2.95	3.07	3.07	3.10	3.00
Alternative No. 3	2.43	2.86	2.62	2.83	2.55	2.98	2.95	2.62

The final step is calculating WSM, WPM and the joint criterion of optimality Q_i . Coefficient λ is accepted as $\lambda = 0.5$ (Eq. 6). The final evaluation and ranking of alternatives in G_1 group is presented in Table 7.

Table 7

Ranking of G_1 group alternatives by the WASPAS method

	WSM	WPM	Final score	Rank
Alternative No. 1	0.133	1.000	0.566	1
Alternative No. 2	0.126	0.939	0.533	2
Alternative No. 3	0.110	0.830	0.470	3

The calculation results of G_1 group show that the first alternative – installation of suspend brackets for masonry and brick lintel hook system – gained the first rank. The second ranked alternative is the installation of suspend brackets for masonry and mounting brick slip lintels is behind the first alternative by only 5.8%. And the third alternative – installation of prefabricated tension masonry panels of 51 mm thickness – is 16.96% behind the first alternative. Finally, we can state that Alternative No. 1 and Alternative No. 2 are evaluated almost equally in the G_1 group, and the implementation of Alternative No. 3 is not rational according to the evaluation based on architectural criteria.

An initial decision-making matrix for the structural group of criteria is presented in Table 8.

Table 8

Group G_2 matrix

Criteria	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Optimisation	min	min	max	min	min	min	max	max
Weight w_j	0.10	0.06	0.12	0.17	0.13	0.12	0.17	0.13
Alternative No. 1	3.781	7.722	3	2	180	85	340	6
Alternative No. 2	2.261	7.722	3	1	180	85	340	6
Alternative No. 3	1.582	1.404	3	2	110	51	300	3

The final step is calculating WSM, WPM and the joint criterion of optimality Q_i . Coefficient λ is accepted as $\lambda = 0.5$ (Eq. 6). The final evaluation and ranking of alternatives in G_2 group is presented in Table 9.

Table 9

Ranking of G_2 group alternatives by the WASPAS method

	WSM	WPM	Final score	Rank
Alternative No. 1	0.709	0.649	0.679	3
Alternative No. 2	0.822	0.768	0.795	2
Alternative No. 3	0.830	0.795	0.813	1

The calculation results of the G_2 group show that the third alternative – installation of prefabricated tension masonry panels of 51 mm thickness – gained the first rank. The second ranked alternative is the installation of suspend brackets for masonry and mounting brick slip lintels is behind the first alternative by only 2.21%. And the third alternative – installation of suspend brackets for masonry and brick lintel hook system is 16.48% behind the first alternative. Finally, we can state that Alternative No. 3 and Alternative No. 2 are evaluated almost equally in the G_2 group, but the implementation of Alternative No. 1 is not rational according to an evaluation based on structural criteria.

An initial decision-making matrix for the architectural group of criteria is presented in Table 10.

Table 10

Group G_3 matrix

Criteria	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Optimisation	min	min	max	min	min	min	max	max
Weight w_j	0.17	0.16	0.07	0.09	0.1	0.13	0.11	0.17
Alternative No. 1	2.34	2.52	1.12	2.29	2.32	4.36	1.93	2.48
Alternative No. 2	2.17	2.41	1.84	2.21	2.29	4.24	2.02	2.52
Alternative No. 3	2.39	2.27	2.12	2.14	2.16	3.94	1.93	2.45

The final step is calculating WSM, WPM and the joint criterion of optimality Q_i . Coefficient λ is accepted as $\lambda = 0.5$ (Eq. 6). The final evaluation and ranking of alternatives in G_3 group is presented in Table 11.

The calculation results of G_3 group show that the third alternative – the installation of prefabricated tension masonry panels of 51 mm thickness – gained the first rank. The second ranked alternative is the installation of suspend brackets for masonry and brick lintel hook system is behind the first alternative by only 0.93%. The third alternative – installation of suspend brackets for masonry and

mounting brick slip lintels is 4.57% behind the first alternative. Finally, we can state that Alternative No. 3 and Alternative No. 1 are evaluated almost equally in the G_3 group and Alternative No. 1 implementation can also be a rational option.

Table 11

Ranking of the G_3 group alternatives the WASPAS method

	WSM	WPM	Final Score	Rank
Alternative No. 1	0.953	0.952	0.953	2
Alternative No. 2	0.920	0.915	0.918	3
Alternative No. 3	0.967	0.956	0.962	1

The final determination of the selection of the masonry façade installation method at the design stage is presented in Table 12. The weights of groups of criteria in the design stage are of importance for the final rank. Calculations that take into account the group weights and the ranks of alternatives in every group show that Alternative No. 2 gained the first rank. The second ranked alternative is Alternative No. 3, and this is behind the first alternative by only 0.54 %. The third alternative is Alternative No. 1 – the installation of suspend brackets for masonry and brick lintel hook system. This is 2.16 % behind the first alternative.

Table 12

The total rank of the masonry façade installation method for a commercial building at the design stage

	G_1	G_2	G_3	Final score	Rank
Weight w_j	0.36	0.33	0.31		
Alternative No. 1	0.566	0.679	0.953	0.723	3
Alternative No. 2	0.533	0.795	0.918	0.739	1
Alternative No. 3	0.470	0.813	0.962	0.735	2

7.5. CONCLUSIONS

Based on the construction methods, the authors compared three possible alternatives for the installation of masonry veneer façades. The authors suggested applying a new method of the installation of prefabricated tension masonry panels with a thickness of 51 mm for masonry veneer façades and compared it with two traditional methods of façade installation applying multiple-criteria evaluation.

To evaluate the alternative façade-installation methods at the design stage, the authors suggested a complex criteria system consisting of three groups of criteria: architectural, structural and technological-economic.

An expert survey was suggested to estimate the weights of criteria groups and of criteria in each group and Lithuanian masonry industry experts were questioned. According to the expert survey, the G_1 architectural group of criteria was the most important group with the weight $w_j = 0.36$. According to experts' opinion, the most important criteria among the twenty-four criteria from the three groups were determined as: the complexity of the architectural elements of the façade from the architectural group (weight $w_j = 0.19$); the requirements for building structures and the maximum distance of the finishing layer from the building structures from structural group (weight $w_j = 0.17$); the speed of installation and price per m^2 of the façade system (weight $w_j = 0.17$) from the technological-economic group.

The authors suggested the application of the MCDM method, WASPAS, for the ranking of alternatives according to multiple criteria. The calculation results showed that the analysed alternatives were ranked differently according to particular groups of criteria: the first alternative – installation of suspend brackets for masonry and mounting brick slip lintels – gained the first rank according to G_1 group criteria, the third alternative – installation of prefabricated tension masonry panels of 51 mm thickness – gained the first rank according to G_2 and G_3 groups of criteria.

According to the final calculations considering the weights of the groups of criteria at the design stage, Alternative No. 2 – the installation of suspend brackets for masonry and mounting brick slip lintels gained the first rank; Alternative No. 3 – the installation of prefabricated tension masonry panels of 51 mm thickness gained the second rank behind Alternative No. 1 by only 0.54% and Alternative No. 1 – the installation of suspend brackets for masonry and mounting brick slip lintels gained the third rank 2.16% behind the first alternative. According to the final results, the authors conclude that Alternative No. 2 and Alternative No. 3 are rational methods for the installation of masonry veneer façade. Alternative No. 2 offers time saving on-site to arrange the brickwork lintels, while Alternative No. 1 requires the construction of formwork to arrange the brickwork lintel. Secondly, Alternative No. 2 is more flexible as the brick slip masonry lintel supports a large range of bond pattern, moreover, negating the need for skilled labour. Alternative No. 3 is less flexible, but a prefabricated tension masonry panel can be produced in various configurations and enables the solving of technological problems on the construction site; it ensures the quality and solves the issues of seasonality. Moreover, Alternative No. 3 is less negating the need for skilled labour. To sum up: alternative No. 1 is a traditional way of installation of masonry veneer façades is the third in ranking, the alternative No. 2 is a traditional way with additional flexibility and time-saving proposals is the first in ranking, and the alternative No. 3 is a modern prototype which can allow to solve technological problems is the second in ranking. According to this evaluation in the design stage it is suggest able to choose the alternative No. 2.

The suggested new method of installation for masonry veneer façade will be studied and compared with traditional methods at the production and construction stages in future research.

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