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ASSESSMENT OF DEFECTS IN MASONRY WALLS FOR THE RESIDENTIAL BUILDINGS IN LITHUANIA

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Abstract. This paper presents the assessment of masonry wall defects in residential buildings in Lithuania. The created model is based on a multi-attribute evaluation of wall defects in residential buildings in Lithuania, the determination of their optimality criterion values calculated according to Laplace'o rule. The developed defect assessment algorithm has advantages to be used by repair contractors and people or companies performing building maintenance. First, the model allows planning the course of repair works properly. When carrying out repair work in a building with recurring defects that mainly occur at the building site, proper workflow and its planning are essential. The proposed model could be applied further to a building owner to select the most damaged walls. A background and a description of the proposed model are provided, and several key findings from the data analyses are presented.

Keywords: masonry wall, defects, residential building, Laplace'o rule, priority line.

Introduction

Lithuania has a wide variety of buildings, and the new construction volumes are growing every year. In 2021, 7,200 new buildings were developed in the country, of which 6,600 were residential. Such figures suggest that a larger share of construction is taken by residential buildings. Masonry structures are among the most popular and oldest structures used in construction. This design is still popular today due to its durability and resistance to environmental effects. Besides, masonry structures are resistant to bending, crushing and various types of damage (Muresan, 2021). Based on various scientific sources, masonry structures in Lithuania amount to 70% of residential buildings (Juozaitienė, 2007). As this construction method is frequently used for residential buildings, defects in masonry structures are becoming more common as well. Various scientific sources suggest three main reasons behind such defects: 1) movement or sedimentation of structures; 2) an inadequate precipitation management system (Kvande & Lisø, 2003); and 3) poor quality of brick elements (Kvande & Lisø, 2009). Current Lithuanian regulations focus on a defect rather than its cause; consequently, the defects caused by the above-mentioned reasons are not always noticeable on time (Lietuvos Respublikos aplinkos ministerija, 2016). The aim to promote sustainable construction demands efforts in the repair of old buildings. Their repair depends on a number of actions taken by people or companies responsible for the maintenance of the buildings. As cities expand and the number of suitable construction sites decreases, the processes of sustainability and the life cycle of a building promote long-lasting construction and proper maintenance. Unsurprisingly, repairs are becoming an increasingly important phenomenon in real estate. However, opinions along the lines of "not worth repairing" and "a new building being cheaper than repairing an existing one" are becoming more common. Such situations occur with buildings that have been poorly maintained or even completely unmaintained. According to the Lithuanian practice, construction companies undertake complex repairs requiring vast human resources, high financial costs, and large amounts of materials and equipment. The complexity of repairs limits the number of active sites for the contractor, depriving them of flexibility and reducing the projected revenue. The solution to this problem requires analysing and evaluating the defects. Also, an algorithm is needed to determine the priority order of repairs.

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1. Causes of masonry defects

Masonry can be analysed by several aspects: selected materials (Navas-Sanchez & Bravo, 2022), masonry structural behaviour (Šlivinskas et al. 2016; Mohammed & Hughes, 2011; Mohammed et al., 2011), specimens geometry (Furtado et al., 2022), crack causing parameters, several type of the structural restraints (at the bottom of the wall, at the vertical edges of the wall; at the top of the wall, restraints and discontinuities in the middle part of the wall) and ect. (Martens & Vermeltfoort, 2001).

Masonry, like any other structure, is not fully protected against defects. Scientific sources list the following causes of such defects:

– Movement or sedimentation of structures (Figure 1). As explained in scientific sources, the movement or deposition of structures produces cracks in masonry elements.

The leading cause of such cracks is the exceeded tensile strength of the masonry structure due to two factors:

– Factors directly affecting the masonry structure: gravitational forces, wind load, ground pressure;
– Factors indirectly affecting the masonry structure: environmental changes (temperature, humidity), deformations of load-bearing structures, and the stabilisation of the foundation (Martens & Vermeltfoort, 2001).

Inadequate rainfall management systems (Figure 2). Based on various scientific sources, an inadequate drainage system (unsuitable rain barrier) allows the excess water to break down the joints in the masonry structure. This phenomenon occurs when water is not properly controlled or otherwise removed from the masonry structure. Water accumulates and washes the trace elements of the masonry structure, making the structure unstable (Kvande & Lisø, 2003).

The poor-quality masonry elements are presented in Figure 3. They can be the reason behind a partial decomposition of the structure. Because masonry products are porous, they absorb water. As water turns into ice during the cold season, it presses on the pores' walls. Inadequately prepared masonry structure elements fail to withstand the pressure, resulting in micro-cracks and cracks in the arc.

Various scientific sources suggest that these defects are the most frequently recorded for masonry structures, accounting for about 20% of all defects. Defects in drainage systems and poor-quality masonry elements account for a small proportion (14%) of the total number of defects (Kvande & Lisø, 2008).

2. Developed algorithm for the assessment of defects

Nowadays, MCDM methods are used for decision making and calculation processes (Zavadskas et al., 2004). Priority lines help with final decision making (Namazian et al., 2019; Hatefi & Tamosaitiene, 2019; Hatefi et al., 2019; Zavadskas et al., 2008), and the game theory is useful for strategic solutions (Zavadskas et al., 2002). However, the minimum criterion is the most important rule in calculating optimal strategies. This criterion has variants, e.g., Savage and Niehaus. In solved situations, Wald, Laplace and Bayes' rules apply to the choice of the solution. The most accurate possible solution to a problem requires developing an algorithm (Figure 4), which must include such processes as defect analysis, calculations, and determination of critical criteria.

A certain criterion is applied depending on the purpose of the task. The best criterion has not been clarified (Zavadskas et al., 2004).

$$S_1^* = \left\{ S_{1i} \mid S_{1i} \in S_1 \cap \left\{ S_{1i0} \mid \frac{1}{n}\sum_{j=1}^{n} a_{i0j} = \max_i \left(\frac{1}{n}\sum_{j=1}^{n} a_{ij} \right) \right\} \right\}, \quad (1)$$

where S_1^* – solved situation / case; S_{1i} – number of the situation or case. It does not matter here whether the factor $\frac{1}{n}$ is considered or not. If the coefficient is $\frac{1}{n}$, then the average of the line is obtained, which can be considered when making a decision. The results of the assessment and evaluation are used to construct the priority line.

Figure 1. Defects in the movement of structures

Figure 2. Defects in masonry walls due to inadequate drainage systems

Figure 3. Developed algorithm for the assessment of defects

Figure 4. Developed algorithm for the assessment of defects

3. Assessment of defects in residential building

Construction technology challenges are diverse. Their overview and further theoretical developments were provided by Fiedler, who identified the creation of the foundations for the organisation (management) of production techniques and technology in construction as the most important task. These foundations are implemented in modelling the technological construction process and in the theoretical study of the process.

In terms of the gambling theory application, two types of tasks can be distinguished:

1) Tasks with the fully available required information, which is a task group based only on the theoretically ideal case. Such tasks do not consider unreliability or deviation; therefore, technologists must provide representative values where it is difficult to predict the full impact of such a decision;
2) Tasks with only partially available required information. To achieve the globally formulated goal, information is needed on the objectives of the solution and the alternatives for action to achieve this goal (Zavadskas et al., 2004).

The minimax theorem ensures the existence of optimal strategies in a two-person zero-sum game but says nothing about their calculation.

Since there are many models, it would be a mistake to suggest that every model is suitable for every occasion. Therefore, a proper assessment of a defect requires its proper analysis first. Table 1 provides analyses of the most common masonry defect cases:

3) The depth of masonry breaking (%);
4) Crack width (mm.);
5) Crack length (mm);
6) Wet area of the wall (% of the total wall area);
7) The content of free-moving bricks in the wall area (%).

Defect measurements considered that the brick dimensions were 25 cm long, 12 cm wide and 9 cm high. Moisture was recorded if it was visually visible (darkening, wet). Measuring instruments: calliper, tape measure, and ruler. The depth and fracture of the masonry were calculated from fixed measurements.

Calculation of masonry breakage depth:

$$A^* = \frac{B \cdot 100\%}{c}, \tag{2}$$

where A^* – depth of masonry breakage; B – breakage depth (m), c – brick width (m). Calculation of fixed in the wall of free-moving bricks:

$$A^*_{md} = \frac{B \cdot 100\%}{c}, \tag{3}$$

where A^*_{md} – fixed in the wall of free-moving bricks; B – free-moving bricks in the wall; c – the area of the wall. Other sizes were calculated mechanically using a roulette wheel, calliper, and ruler. The estimated damage values can be taken from Table 1. Damage levels are given in Table 2.

To perform the calculations, an initial data matrix needs to be constructed. The matrix must reflect the value of X_i for each selected indicator and any considered alternatives or cases. The direction of optimisation is determined by the value of the criterion and the desired result. In this case, the criteria are minimised because the goal is to eliminate the defects.

To perform the calculations, it is necessary to convert the values of the matrix indicators into dimensionless quantities, thus unifying all the indicators. The following formula is used for normalisation (Mohammed et al., 2011).

$$X_{ix} = \frac{A_{ij} - A_{ix}}{A_{ij} - A_{ik}}, \tag{4}$$

where A_{ij} is the maximum value of the indicator, A_{ik} is the minimum value of the indicator, A_{ix} is the normalised indicator. LEVI 3.0 software was used for all calculations (Zavadskas et al., 2002).

Dimensional quantities were obtained in the normalised matrix (Figure 5). These values continue to be used for the application of Laplace's rule. Laplace's rule is defined as the probability that all opponents' strategies are the same. The line with the maximum amount is selected.

Thus, calculations were performed, and results were obtained using the LEVI 3.0 software (Zavadskas et al., 2002) are presented in the Figure 6.

Based on the obtained results (Figure 6), when calculating with the LEVI 3.0 software, using Laplace's rule, the priority order of repair works is as listed in Table 4.

The obtained results are shown in Table 3. The analysis of obtained results demonstrates that Case 3, which is the first case in the order of precedence, seems to be the worst, both according to the calculations using the Laplace's rule and in general. According to the calculation results, the article's authors recommend construction companies perform the work in the following sequence: Case 3, $\prec$ Case 2, $\prec$ Case 4, $\prec$ Case 1, $\prec$ Case 5. The priority line recommends the order in which the removal of masonry defects is necessary.

Table 1. Cases of masonry defects

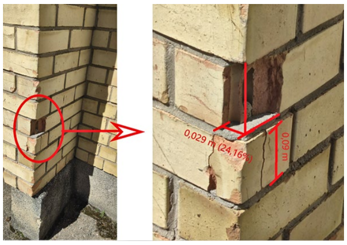
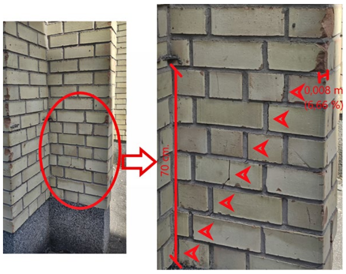
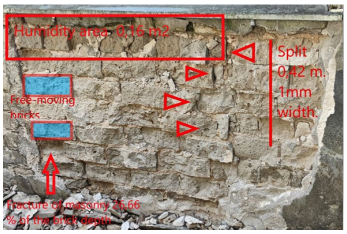
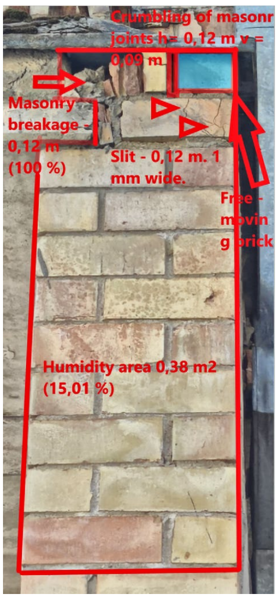
<table>
<tr><th>Cases</th><th>Figures / pictures</th><th>Description / Visible masonry damage:</th></tr>
<tr><td>Case 1</td><td>
</td><td>Masonry fracture amounting to 24.16% of the brick depth;
Vertical masonry slit of 9 cm long and 2 mm wide.
Crumbling of masonry joints, not fixed;
Wall humidity, not fixed;
In the wall of free-moving bricks, not fixed.</td></tr>
<tr><td>Case 2</td><td></td><td>Fracture of the masonry amounting to 6.66% of the brick depth;
Vertical masonry slit of 70 cm long and 1 mm wide.
Crumbling of masonry joints, not fixed;
Wall humidity, not fixed;
In the wall of free-moving bricks, not fixed.</td></tr>
<tr><td>Case 3</td><td>
</td><td>Fracture of the masonry amounting to 58.33% of the brick depth;
Vertical masonry slit of 63 cm long and 2 mm wide.
Crumbling of masonry joints, not fixed;
Wall humidity of 3.8% of the total wall area is fixed;
In the wall of free-moving bricks, not fixed.</td></tr>
<tr><td>Case 4</td><td>
</td><td>Fracture of the masonry amounting to 26.66% of the brick depth;
Vertical masonry slit of 42 cm long and 1 mm wide.
Crumbling of masonry joints, not fixed;
Wall humidity, fixed in 0.5% of the total wall area;
Fixed in the wall of free-moving bricks, 2 pcs. bricks, amounting to 0.03% of the total wall area.</td></tr>
<tr><td>Case 5</td><td>
</td><td>Masonry breakage of 100% of the brick depth;
Vertical masonry slit of 9 cm long and 1 mm wide.
Crumbling of masonry joints of 12 cm horizontally, 9 cm vertically, and the total
of 21 cm;
Wall humidity of 15.01% of the total wall area is fixed;
Fixed in the wall of free-moving bricks, 1 pc. bricks, 0.43% of the total wall area.</td></tr>
</table>

Table 2. Damage size calculations

Cases	Depth of masonry breaking (%)	Crack width (mm)	Crack length (cm)	Wet wall area (m^2)	Of free-moving bricks in wall area (%)
Case 1	24.16	2	9	0	0
Case 2	6.66	1	70	0	0
Case 3	58.33	2	63	3.8	0
Case 4	26.66	1	42	0.5	0.03
Case 5	100.00	1	9	15.01	0.43

Table 3. Source data matrix

Cases	Depth of masonry breaking (%)	Crack with (mm)	Crack length (cm)	Wet wall area (m^2)	Of free-moving bricks in wall area (%)
	X_1	X_2	X_3	X_4	X_5
Optimisation direction	Min	Min	Min	Min	Min
Case 1	24.16	2	9	0	0
Case 2	6.66	1	70	0	0
Case 3	58.33	2	63	3.8	0
Case 4	26.66	1	42	0.5	0.03
Case 5	100	1	9	15.01	0.43

Table 4. Priority repair work queue

No.	Case	Priority repair work order
1	Case 1	4
2	Case 2	2
3	Case 3	1
4	Case 4	3
5	Case 5	5

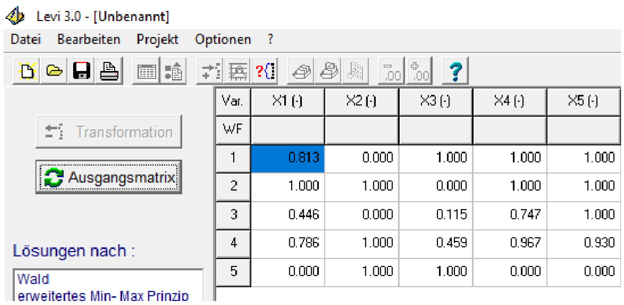


Figure 5. Normalised matrix

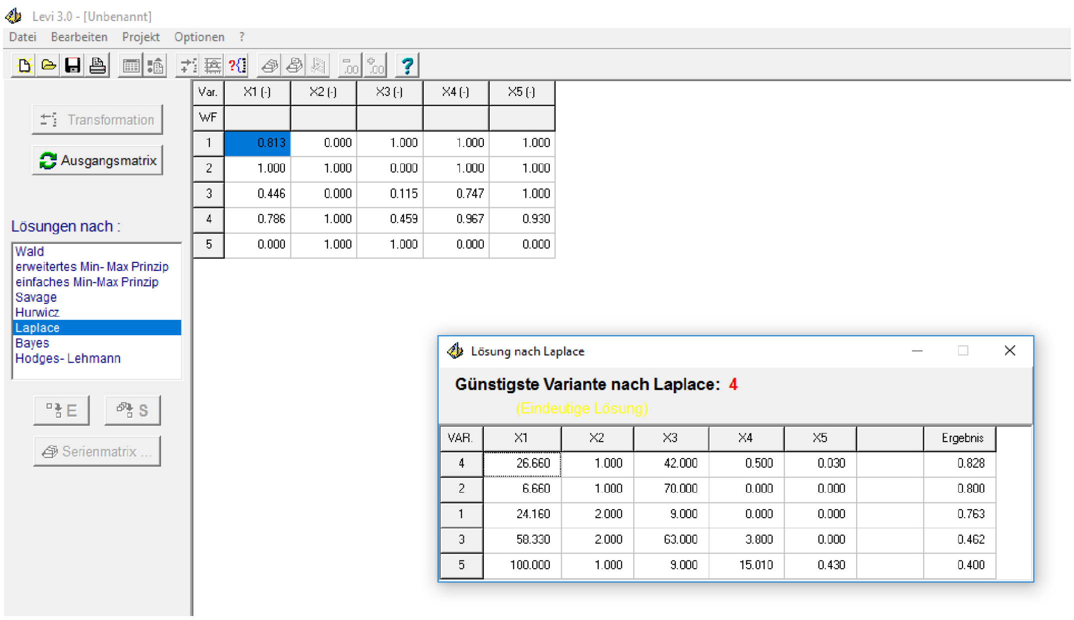


Figure 6. Results were obtained according to the Laplace's rule

Conclusions

Laplace's rule was used to select the evaluation methodology. Defect damage magnitudes were calculated, and key criteria were determined. Once the size of the damage was determined, the size of the defect in the environment of the building was also determined. LEVI 3.0 software was used to determine the defect repair sequence. The software was used to create a normalised matrix according to the assigned optimisation direction, which was set to minimise everywhere. The matrix normalisation was performed linearly. Following these steps, the decision was subject to the Laplace rule, the results of which showed the most expeditious course of repair. Based on the calculation results, the article's authors recommend construction companies perform the work in the following sequence: Case 3, ≺ Case 2, ≺ Case 4, ≺ Case 1, ≺ Case 5. Once the obtained results are analysed, it is assumed that the calculations can be used to solve a practical task. Case 3 appears the worst: it is characterised by multiple damages in a large area of the wall, such as masonry collapse or cracks. The priority line recommends the order for the removal of masonry defects.

Such a defect assessment algorithm has advantages to be used by repair contractors and people or companies performing building maintenance. First, the model allows planning the course of repair works properly. When carrying out repair work in a building with recurring defects that mainly occur at the building site, proper workflow and its planning are essential. Errors in job planning can lead to downtime for contractors, resulting in significant losses. The second advantage is the maintenance control of the building. According to the algorithm, it is possible to determine critical defects with sufficient precision to be repaired in the order of priority. It is not uncommon for defects to appear erroneous, so the application of the algorithm gives control over this process. The third advantage is that the algorithm evaluates the defect criteria in the environment of all the defects under study. In other words, the analysed defects may be multiple, and the focus does not have to be on one type of defect only. This advantage allows building maintenance contractors to assess building defects in the entire building. The developed algorithm is flexible; therefore, it can be applied to identify specific defects and determine the repair process of structures by identifying multiple and various defects.

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