A Methodology for Determining the Rehabilitation Needs of Buildings

Beata Nowogońska

Architecture and Environmental Engineering, Faculty of Civil Engineering, University of Zielona Góra, Szafrana 1, 65-516 Zielona Góra, Poland; b.nowogonska@ib.uz.zgora.pl; Tel.: +48-68-3282-290

Received: 4 May 2020; Accepted: 1 June 2020; Published: 2 June 2020

Abstract: The appropriate rehabilitations planning of buildings should be based on the analysis of rehabilitation needs. This article proposes a methodology for Determining the Rehabilitation Needs of Buildings (DRNB). The DRNB method can be used for buildings made with traditional technology. The methodology provides the possibility to prioritize the analyzed objects and their elements as well as to determine the sequence of rehabilitation needs of any buildings and their elements. The method can be used for a single building or several buildings. The obtained results can be compared and order relations between them can be determined, which will allow the planning of repair works. In setting the priorities in the DRNB method, the implementation of the Analytical Hierarchy Process (AHP) was used. The article presents also the application the DRNB method and results of determination of rehabilitation needs for residential buildings that are located in Poland in Zielona Góra. Determining the rehabilitation needs of building components should be the first stage of planning repair works. The DRNB method helps to determine which elements in which buildings need necessary rehabilitation now, which elements of rehabilitation are important now, and which elements can be rehabilitated later—i.e., if the repair works are only useful and are not currently necessary.

Keywords: buildings; buildings elements; rehabilitation needs; rehabilitation planning; degree of technical condition; degradation of buildings

1. Introduction

Neglect of repairs is one of the main reasons for the decrease in the technical value of buildings [1–4]. The main task of building maintenance is rehabilitation planning [5–9]. In order to maintain existing buildings, it is necessary to solve problems related to forecasting rehabilitation needs [10–19]. Decision making is always difficult due to limited financial resources [20–23]. Buildings and their components are damaged to varying degrees. Building elements have different service lives. The estimation of the service life of the construction elements of a building and its materials [24–29] is an essential part of maintenance programs.

Research is needed to identify the most urgent rehabilitation needed. Making decisions connected with the choice of the type, scope and date of repairs on buildings is very problematic for managers. Algorithms supporting decision-making regarding repair works are necessary. Morelli and Lacasse proposed combines two methods: failure mode and effect analysis (FMEA) with the limit states (LS) to assess the durability of the given retrofit action [30]. Different models for maintenance management have been developed; e.g., the Building Envelope Life Cycle Asset Management BELCAM project by Vanier, Lacasse et al. that employs a stochastic decision-support system for roofing service life maintenance management [31,32]. Shen and Spedding presented [33] a model for priority setting in planned maintenance of large building stocks, and successful validation of the model in the UK and Hong Kong has been demonstrated. A different approach is found in work by
Alshubbak, Pellicer, Catala, Teixeira [34], where a model is developed that allows for the identification of the owner’s needs in all phases of the building life cycle. Vanier, Tesfamariam, Sadiq, Lounis presented a number of prioritization techniques that can be used to compare and rank repair projects [35]. Buccor and Sobotka proposed a decision model of the choice of the scope of repairs based on three assessments of a building [36]. Sherwin reviews overall models for maintenance management from the viewpoint of one who believes that improvements can be made by regarding maintenance as a contributor to profits rather than a necessary evil [37]. Jones and Sharp draw attention to the weakness inherent in the current theoretical model underpinning built asset maintenance and to propose a new performance-based model that aligns maintenance expenditure to corporate performance [38].

The correct building maintenance strategy should include a multi-annual maintenance action plan optimized for various criteria that match the owners’ goals for existing restrictions. The developed model is used to compare the economics of various renovation plans in a selected scenario. The model of team Farahani is used to compare the economy of different maintenance and renovation plans in a chosen scenario in order to determine the optimal maintenance interval for a single and a combination of building components [39]. Bento Pereira, Calejo Rodrigues and Fernandes Rocha presented a post-occupancy evaluation (POE) method focused on building maintenance [40]. The three main purposes are: to obtain useful data for optimizing the buildings’ maintenance plans; to search for correlations between the occupants’ characteristics and their expectations toward the building; to study the occupants’ willingness to pay for maintenance procedures.

In order to provide a specific time schedule for a sustainable building maintenance, [41] Daniotti and Lupica Spagnolo developed a specific method for Service Life Prediction based on the correlation between users’ requirements and measured decays of building components’ performance characteristics. Team Daniotti and Lupica Spagnolo outline benefits and challenges in adopting Building Information Modeling BIM based processes for the operation and maintenance of buildings [42]. Madureira, Flores-Colen, de Brito and Pereira presented a methodology to implement a maintenance plan for buildings’ facades [43]. Later obsolescence of buildings can be reduced by taking into account the obsolescence criteria in the construction of new buildings [44].

All the above-mentioned studies are interesting and necessary in practice. This article presents a different approach. The proposed method applies to more buildings in use and takes into account the interdependence of rehabilitation works. Each building consists of components damaged in various degrees.

In the case of a large number of buildings, where each element is damaged to varying degrees, there are problems in planning rehabilitation work. There are many problems:

- Which building needs rehabilitation more and which should be next?
- Which element (e.g., windows, roofing) should be rehabilitated first?
- Is it possible to wait and rehabilitate several building components together?
- Which element of which building needs rehabilitation immediately?
- The proposed a methodology for Determining the Rehabilitation Needs of Buildings (DRNB) should be the answer to these questions.

### 2. Materials and Methods

The methodology for Determining the Rehabilitation Needs of Buildings (DRNB) consists of the following sequence of actions:

1. establishing criteria that take into account factors affecting the rehabilitation needs;
2. determination of importance of decision criteria;
3. selection of analyzed buildings;
4. determination the meters of the criteria;
5. determination of the mathematical equation determining the importance of rehabilitation needs;
6. determination of indicators determining the order of rehabilitation needs of the elements of the buildings analyzed.
The proposed methodology for Determining the Rehabilitation Needs of Buildings (DRNB) was
developed in order to rescue damaged public residential buildings. However, it can also be used for
private buildings.

The main aim of developing the DRNB method was to rescue damaged existing historic
buildings and buildings located in representative parts of the city. For this reason, the choice of
criteria was limited.

The following criteria were adopted: the degree of technical condition of a building element
(Section 2.1); the type of element in the building structure (Section 2.2); the durability of the element
(Section 2.3); the influence of the technical condition of the element on the damage to other elements
(Section 2.4); the interdependence of the rehabilitation of the element related to the rehabilitation of
another one (Section 2.5); the value of the building due to its location (Section 2.6); the value of the
building heritage (Section 2.7).

It should be noted, however, that these criteria are selected as the main indicators for
commissioning rehabilitation work. Many criteria have been omitted; for example, costs. It is
assumed that historic buildings and those located in representative locations must be renovated. It
has been assumed that the limitations of financial resources will only result in postponement of the
rehabilitation works, but with the order obtained after applying the DRNB method.

The criteria were established on the basis of consultations with persons involved in the
maintenance of residential buildings: building managers, university employees, appraisers,
conservationists, designers and contractors of renovation works. The criteria adopted are presented
in Table 1.

| Criteria | Symbol cᵢ | Criteria Name |
|----------|------------|---------------|
| c₁       |            | the degree of technical condition of the building element |
| c₂       |            | type of element in the building structure |
| c₃       |            | durability of element |
| c₄       |            | impact of the technical condition of the element on damage to other elements |
| c₅       |            | interdependence of the rehabilitation of an element related to the rehabilitation of another |
| c₆       |            | the value of the building due to its location |
| c₇       |            | the heritage value of the building |

Criteria is determined by criteria meters. Matrix of data set Dᵢ is determined by meters mᵢj:

\[ t_{ij} \] meters of the degree of technical condition of an i-th element in the j-th building;
\[ s_{ij} \] meters of type of element in the building structure of an i-th element in a j-th building;
\[ d_{ij} \] meters of the durability of an i-th element in a j-th building;
\[ o_{ij} \] meters of the impact of the technical condition of an i-th element on damage to other elements
in a j-th building;
\[ r_{ij} \] meters of interdependence between of the repair of an i-th element related to the repair of other
elements in a j-th building;
\[ l_{ij} \] meters of the value of a j-th building due to its location;
\[ h_{ij} \] meters of the heritage value of a j-th building;

where
\[ i \] an ordinal number of an element in a building; \( i = 1, 2, 3, \ldots, m; \)
\[ j \] an ordinal number of the building; \( j = 1, 2, 3, \ldots, n. \)

For the criteria to be comparable, the sum of the measures for individual elements in the building
is 1.0 for all criteria.

2.1. Criterion of the Degree of Technical Condition of the Building Element
The criterion of the degree of technical condition of individual elements in buildings is based on the percentage values of wear of elements established during the evaluation of the technical condition of buildings.

The meters of the degree of technical condition wear $t_{ij}$ is given by the formula:

$$t_{ij} = \frac{t^*_{ij}}{100 \text{m}}$$

where:

- $t^*_{ij}$ the degree of technical condition of an i-th element in the j-th building, resulting findings of experts (given in percent);
- $i$ denotes an ordinal number of an element in a building, $i = 1, 2, 3, \ldots, m$;
- $j$ denotes an ordinal number of the building; $j = 1, 2, 3, \ldots, n$;
- $m$ total number of building elements analyzed.

2.2. Criterion of Type of Element in the Building Structure

The criterion type of element in the building structure assumes division of the building into structural elements, cladding, equipment and finishing. Function indicators have been assigned to each group of elements $s^*_{ij}$:

- for structural elements 1.0;
- for shielding elements 0.75;
- for equipment elements 0.50;
- for finishing elements 0.25.

The meters of the structure of the building $s_{ij}$ is determined by the equation:

$$s_{ij} = \frac{s^*_{ij}}{\sum_{i=1}^{m} s^*_{ij}}$$

where:

- $s^*_{ij}$ indicator of structure for i-th element in the j-th building.

Numerical values meters for criterion structure $s_{ij}$ are given in Table 2.

Table 2. Numerical values meters for criterion structure $s_{ij}$.

| Number | Element Symbol e_1 | Element Name          | Indicator of Structure $s^*_{ij}$ | Meters of Structure $s_{ij}$ |
|--------|--------------------|-----------------------|-----------------------------------|------------------------------|
| 1      | e_1                | walls                 | 0.25                              | 0.028                        |
| 2      | e_2                | ceilings              | 0.75                              | 0.083                        |
| 3      | e_3                | stairs                | 0.75                              | 0.083                        |
| 4      | e_4                | roof construction     | 0.50                              | 0.056                        |
| 5      | e_5                | roof covering         | 0.50                              | 0.056                        |
| 6      | e_6                | gutters and drainpipes| 0.50                              | 0.056                        |
| 7      | e_7                | floors                | 0.25                              | 0.028                        |
| 8      | e_8                | windows               | 0.25                              | 0.028                        |
| 9      | e_9                | doors                 | 0.25                              | 0.028                        |
| 10     | e_10               | water installations   | 0.75                              | 0.083                        |
| 11     | e_11               | sewage installations  | 0.75                              | 0.083                        |
| 12     | e_12               | heating installations | 0.50                              | 0.056                        |
| 13     | e_13               | internal plasters     | 0.50                              | 0.056                        |
| 14     | e_14               | external plasters     | 0.50                              | 0.056                        |
|        | total              |                       | 9.00                              | 1.00                         |

2.3. Criterion of Durability
Durability criterion includes the diverse processes of technical wear and tear of the building elements due to their different durability periods. The durability meter \( d_{ij} \) is determined by the Equation (3).

\[
d_{ij} = \frac{d_{ij}^*}{\sum_{i=1}^{m} d_{ij}^*}
\]

where:
- \( d_{ij}^* \) indicator of durability periods of the \( i \)-th element in the \( j \)-th building;
- \( m \) the number of all building elements analyzed.

The indicator of durability is determined by Equation (4).

\[
d_{ij}^* = \frac{\sum_{i=1}^{m} D_{ij}}{D_{ij}}
\]

where:
- \( D_{ij} \)—average life of \( i \)-th element.

Numerical values meters for criterion of durability \( d_{ij} \) are given in Table 3.

**Table 3. Numeric values of durability meters \( d_{ij} \).**

| Number | Element Name              | Time of Durability \( D_{ij} \) | Indicator of Durability \( d_{ij}^* \) | Meters of Durability \( d_{ij} \) |
|--------|---------------------------|----------------------------------|----------------------------------------|----------------------------------|
| 1      | walls (brick)             | 140                              | 5.804                                  | 0.023                            |
| 2      | ceilings (wooden)         | 70                               | 11.607                                 | 0.046                            |
| 3      | stairs (wooden)           | 35                               | 23.214                                 | 0.093                            |
| 4      | roof construction         | 80                               | 10.156                                 | 0.041                            |
| 5      | roof covering             | 70                               | 11.607                                 | 0.046                            |
| 6      | gutters and drainpipes    | 17.5                             | 46.429                                 | 0.186                            |
| 7      | floors                    | 50                               | 16.250                                 | 0.065                            |
| 8      | windows                   | 50                               | 16.250                                 | 0.065                            |
| 9      | doors                     | 90                               | 9.028                                  | 0.036                            |
| 10     | water installations       | 37.5                             | 21.667                                 | 0.087                            |
| 11     | sewage installations      | 37.5                             | 21.667                                 | 0.087                            |
| 12     | heating installations     | 35                               | 23.214                                 | 0.093                            |
| 13     | internal plasters         | 55                               | 14.773                                 | 0.059                            |
| 14     | external plasters         | 45                               | 18.056                                 | 0.072                            |
| total  |                           | 812.50                           | 249.72                                 | 1.00                             |

The shorter the element’s lifetime, the sooner the element should be rehabilitation due to the progressing technical wear process. Therefore, the element’s durability coefficient was determined to be inversely proportional to its durability.

### 2.4. Criterion of Impact of the Technical Condition of the Element on Damage to Other Elements

The effect of destruction of element on the condition of other elements was determined on the bases of the impact of the damaged element on the destruction of other elements in the building. The meter \( o_{ij} \) is determined by the Equation (5).

\[
o_{ij} = \frac{o_{ij}^*}{\sum_{i=1}^{m} o_{ij}^*}
\]

where:
- \( o_{ij}^* \) indicator of impact of wear condition of the \( i \)-th element in the \( j \)-th building on other elements;
- \( m \) the number of all building elements analyzed.
Indicator of impact \( o_{ij}^* \) of wear condition of the i-th element in the j-th building on other elements is determined:

\[
o_{ij}^* = \sum_{iz=1}^{izm} g_{ij}
\]

where:

- \( g_{ij} \) indicator of importance of the i-th element in the j-th object (determined on the basis of the importance of the elements given in the literature according to [45]);
- \( iz \) the number of elements that are damaged due to the un-renovated i-element;
- \( izm \) the number of all elements that are damaged due to the un-renovated i-element.

Numerical values of indicators of importance of elements \( g_{ij} \) are given in Table 4.

### Table 4. Indicators of importance of elements \( g_{ij} \).

| Number | Element Symbol \( e_i \) | Element Name | Importance Element According [45] | Indicator of Importance Element \( g_{ij} \) |
|--------|--------------------------|--------------|-----------------------------------|---------------------------------|
| 1      | \( e_1 \)                | walls        | 3.0                               | 0.294                           |
| 2      | \( e_2 \)                | ceilings     | 1.0                               | 0.098                           |
| 3      | \( e_3 \)                | stairs       | 1.2                               | 0.118                           |
| 4      | \( e_4 \)                | roof construction | 1.0                          | 0.098                           |
| 5      | \( e_5 \)                | roof covering | 0.9                               | 0.088                           |
| 6      | \( e_6 \)                | gutters and drainpipes | 0.3                          | 0.029                           |
| 7      | \( e_7 \)                | floors       | 0.2                               | 0.020                           |
| 8      | \( e_8 \)                | windows      | 0.7                               | 0.069                           |
| 9      | \( e_9 \)                | doors        | 0.5                               | 0.049                           |
| 10     | \( e_{10} \)             | water installations | 0.3                          | 0.029                           |
| 11     | \( e_{11} \)             | sewage installations | 0.3                          | 0.029                           |
| 12     | \( e_{12} \)             | heating installations | 0.3                          | 0.029                           |
| 13     | \( e_{13} \)             | internal plasters | 0.2                           | 0.020                           |
| 14     | \( e_{14} \)             | external plasters | 0.3                           | 0.029                           |
|        | total                    |              | 10.2                              | 1.00                            |

The meters of the impact of damage to the same elements in different buildings were assumed to be equal (e.g., the effect of the destruction of worn roofing on other elements is the same in all buildings) for all buildings regardless of design solutions, number of floors, type of heating, etc.

The meters of the impact of the damage of the other elements \( o_{ij} \) for individual building elements calculated according to formula (5) are included in Table 5.

### Table 5. Meters of the impact of the damage \( o_{ij} \).

| Number | Damaged Element | Elements Affected by Damage | Indicator of the Impact of the Damage \( o_{ij}^* \) (according to formula 6) | Meters of the Impact of the Damage \( o_{ij} \) (according to formula 5) |
|--------|-----------------|-----------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| 1      | walls           | \( e_1, e_5, e_{13} \)     | 0.166                                                                           | 0.082                                                                           |
| 2      | ceilings        | \( e_7, e_8, e_{10}, e_{11}, e_{12}, e_{13} \) | 0.176                                                                           | 0.087                                                                           |
| 3      | stairs          | \( e_7, e_{13} \)          | 0.039                                                                           | 0.019                                                                           |
| 4      | roof construction | \( e_2, e_6, e_7, e_{13} \) | 0.304                                                                           | 0.149                                                                           |
| 5      | roof covering   | \( e_2, e_6, e_7, e_{13} \) | 0.353                                                                           | 0.173                                                                           |
| 6      | gutters and drainpipes | \( e_{14} \) | 0.029                                                                           | 0.014                                                                           |
| 7      | floors          | \( e_2 \)                  | 0.098                                                                           | 0.048                                                                           |
| 8      | windows         | \( e_7, e_{13} \)          | 0.039                                                                           | 0.019                                                                           |
| 9      | doors           | \( e_7, e_{13} \)          | 0.039                                                                           | 0.019                                                                           |
| 10     | water installations | \( e_1, e_{12}, e_{13} \) | 0.137                                                                           | 0.067                                                                           |
| 11     | sewage installations | \( e_1, e_{12}, e_{13} \) | 0.137                                                                           | 0.067                                                                           |
| 12     | heating installations | \( e_1, e_{12}, e_{13} \) | 0.137                                                                           | 0.067                                                                           |
| 13     | internal plasters | \( e_7 \) | 0.020                                                                           | 0.010                                                                           |
Meters of the impact of the damage were calculated according to an example for roof covering:

\[ o_5^* = g_2 + g_3 + g_4 + g_7 + g_{13} = 0.353 \]  \hspace{1cm} (7)

\[ o_5 = \frac{0.353}{2.038} = 0.173 \]  \hspace{1cm} (8)

2.5. Criterion of Interdependence of the Rehabilitation of an Element Related to the Rehabilitation of Another

The meters of the interdependence of the rehabilitation of the i-th element \( r_{ij} \) is given by the formula:

\[ r_{ij} = \frac{r_{ij}^*}{\sum_{i=1}^{m}(1 - r_{ij}^*)} \]  \hspace{1cm} (9)

where:

- \( r_{ij}^* \) — indicator of impact of interdependence of the rehabilitation of the i-th element by formula (10):

\[ r_{ij}^* = \sum_{i=1}^{ir} g_{ij} \]  \hspace{1cm} (10)

where:

- \( g_{ij} \) — indicator of importance of the i-th element in the j-th object;
- \( ir \) — the number of elements that to be repaired before rehabilitation of the i-th element;
- \( irm \) — the number of all elements that need to be repaired before rehabilitation of the i-th element.

Numerical values meters for criterion of interdependence of the rehabilitation \( r_{ij} \) are given in Table 6.

| No. | Element Building of Rehabilitation | Interdependent Elements | Indicator of the Interdependence of the Rehabilitation \( r_{ij}^* \) | 1-\( r_{ij}^* \) | Meters of Interdependence of the Rehabilitation \( r_{ij} \) |
|-----|-----------------------------------|-------------------------|--------------------------|----------------|--------------------------|
| 1   | walls                             | -                       | 0.000                    | 1.000          | 0.108                    |
| 2   | ceilings                          | -                       | 0.000                    | 1.000          | 0.108                    |
| 3   | stairs                            | e1                      | 0.294                    | 0.706          | 0.076                    |
| 4   | roof construction                 | -                       | 0.000                    | 1.000          | 0.108                    |
| 5   | roof covering                     | e4                      | 0.098                    | 0.902          | 0.097                    |
| 6   | gutters and drainpipes            | e1, e5, e9, e14         | 0.510                    | 0.490          | 0.053                    |
| 7   | floors                            | e1, e2, e3, e5, e6, e7, e11, e13 | 0.735                    | 0.265          | 0.029                    |
| 8   | windows                           | e1                      | 0.294                    | 0.706          | 0.076                    |
| 9   | doors                             | e1, e2                  | 0.392                    | 0.608          | 0.065                    |
| 10  | water installations               | e1, e2                  | 0.392                    | 0.608          | 0.065                    |
| 11  | sewage installations              | e1, e2                  | 0.392                    | 0.608          | 0.065                    |
| 12  | heating installations             | e1, e2                  | 0.392                    | 0.608          | 0.065                    |
| 13  | internal plasters                 | e1, e2, e3, e5, e6, e8, e11, e12 | 0.716                    | 0.284          | 0.031                    |
| 14  | external plasters                 | e1, e5, e8, e9          | 0.500                    | 0.500          | 0.054                    |
|     | total                             |                         | 4.715                    | 9.285          | 1.00                      |

Meters of the interdependence of the rehabilitation were calculated according to an example for roof covering:

\[ r_{5}^* = g_4 = 0.098 \]  \hspace{1cm} (11)

\[ r_5 = \frac{1 - 0.098}{9.285} = 0.097 \]  \hspace{1cm} (12)
2.6. Criterion of Locality

Some buildings need to be renovated first because of their location because they are located, for example, near the city center or on a transit route. In the method, the location meter for the entire building $l_i$ can be equal to 0.00 or 1.00. For individual building elements, the location meter $l_{ij}$ is given by the formula:

$$l_{ij} = \frac{l_i}{m}$$

where:

- $l_i$ location indicator for the entire facility (i.e., the $j$-th building);
- $m$ the number of all building elements analyzed.

2.7. Criterion of the Heritage Value of the Building

Many of the buildings have a heritage value. The heritage value meter $h_i$ for the whole object is assumed to be equal to 1.00 or 0.00 depending on whether the building has values related to the time of creation, type of use or history, legend, etc. For individual building elements the heritage value meter $h_{ij}$ is given by the formula:

$$h_{ij} = \frac{h_i}{m}$$

where:

- $h_i$ the heritage indicator for the entire facility (i.e., the $j$-th building);
- $m$ the number of all building elements analyzed.

2.8. Importance of Criteria

The importance of decision criteria was determined by using the Analytical Hierarchy Process AHP. The data was obtained on the basis of consultations with persons related to the rehabilitation of residential buildings: building managers, university research workers, appraisers, monument conservators, employees of design offices and executive rehabilitation companies. The results obtained are presented in Table 7.

| $c_1$ | $c_2$ | $c_3$ | $c_4$ | $c_5$ | $c_6$ | $c_7$ | Total | Relative Importance of Criteria | Importance of Criteria |
|------|------|------|------|------|------|------|------|-------------------------------|-----------------------|
| 1.00 | 5.00 | 3.00 | 5.00 | 0.14 | 9.00 | 7.00 | 30.14 | 0.300                         | 0.30                  |
| 0.20 | 1.00 | 7.00 | 5.00 | 3.00 | 3.00 | 1.00 | 20.20 | 0.201                         | 0.20                  |
| 0.33 | 0.14 | 1.00 | 1.00 | 0.14 | 1.00 | 7.00 | 14.61 | 0.145                         | 0.15                  |
| 0.20 | 0.20 | 7.00 | 1.00 | 0.33 | 1.00 | 1.00 | 10.73 | 0.106                         | 0.10                  |
| 0.33 | 0.14 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 14.33 | 0.142                         | 0.15                  |
| 0.10 | 0.33 | 0.20 | 1.00 | 1.00 | 1.00 | 1.00 | 4.63  | 0.046                         | 0.05                  |
| 0.33 | 1.00 | 0.33 | 1.00 | 1.00 | 1.00 | 1.00 | 5.66  | 0.056                         | 0.05                  |

The results have been checked. Consistency ratio CR is less than 1.0, equal to 0.094.

2.9. Mathematical Model of Method for Determining the Rehabilitation Needs of Buildings DRBN

Decision criteria for rehabilitation needs $c_1$, $c_2$, ..., $c_7$ determined by meters of decision criteria of $t_{ij}$, $s_{ij}$, $d_{ij}$, $o_{ij}$, $r_{ij}$, $l_{ij}$, $h_{ij}$ and the importance of these criteria $w_1$, $w_2$, ..., $w_7$ are the output for determining the matrix of indicators of the order of rehabilitation needs $k_{ij}$.

The sequence of importance of rehabilitation needs of building elements can be determined by prioritizing the order indicators $k_{ij}$. Order indicators for $n$ elements in the $j$-th object can be obtained by solving the matrix equation.
\[ K_j = B_j W_p \]  

(15)

\[ [k_{ij}]_{m \times 1} = [b_{ip}]_{m \times u} \times [w_p]_{u \times 1} \]  

(16)

where:
- \( K_j \) \( [k_{ij}]_{m \times 1} \) matrix of indicators determining the need of rehabilitation of elements in the \( j \)-th building.
- \( B_j \) \( [b_{ip}]_{m \times u} \) matrix of criteria measures for elements in the \( j \)-th building;
- \( W_p \) \( [w_p]_{u \times 1} \) matrix of importance of criteria;
- \( i \) — denotes an ordinal number of an element in a building, \( i = 1, 2, 3, \ldots, m \);
- \( j \) — denotes an ordinal number of the building; \( j = 1, 2, 3, \ldots, n \);
- \( p \) — denotes an ordinal number of the criteria; \( p = 1, 2, 3, \ldots, u \).

The matrix of criteria measures \( B_j \) (for the \( j \)-th building) is a rectangular finite matrix with dimensions \( m \times u \).

\[
B_j = \begin{bmatrix}
 t_{ij} & s_{ij} & d_{ij} & o_{ij} & r_{ij} & l_{ij} & h_{ij} \\
 t_{ij} & s_{ij} & d_{ij} & o_{ij} & r_{ij} & l_{ij} & h_{ij} \\
 t_{ij} & s_{ij} & d_{ij} & o_{ij} & r_{ij} & l_{ij} & h_{ij} \\
 \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
 t_{uj} & s_{uj} & d_{uj} & o_{uj} & r_{uj} & l_{uj} & h_{uj}
\end{bmatrix}
\]

(17)

The \( W_p \) matrix with \( u \)-importance criteria:

\[
W_p = \begin{bmatrix}
 w_t \\
w_s \\
w_d \\
w_o \\
w_r \\
w_l \\
w_h
\end{bmatrix}
\]

(18)

The result of Equation (14) is the matrix \( K_i \). Matrix \( K_i \) contains indicators determine the order of needs for rehabilitation of \( m \)-elements in the \( j \)-th building.

\[
K_i = \begin{bmatrix}
 k_{1,j} \\
k_{2,j} \\
k_{3,j} \\
\vdots \\
k_{m,j}
\end{bmatrix}
\]

(19)

The task is to solve the matrix Equation (14). By multiplying the numerical meters of the criteria by the importance of these criteria, we obtain the numerical values assigned to each examined element in a given building that was included in the study. The numerical values resulting from research are indicators of the order of rehabilitation needs — \( k_{ij} \). The higher the index, the more it is necessary to renovate the \( i \)-th element in the \( j \)-th object. The indicator is not, however, any physical rehabilitation value of the elements, it is only used to rank the building elements due to the proposed order of rehabilitation needs.

The result for a large number of buildings is a set of matrixes corresponding to the number of buildings. Specific words of the matrix give the possibility of ordering the analyzed objects and their elements in any number of buildings, as well as determining the relation of the order of any two objects and their elements to each other.

The proposed method can be used in planning rehabilitation works. Analyzing the results of the method of using indicators, one can give the order of rehabilitation of individual elements in a
damaged building. The method does not help in the determination of the date of the repair of any of the examined object or its elements, as the term depends on the funds that the buildings administrators may spend on the repair and also on the costs of the overhauls of particular building elements.

2.10. Scale Range of Indicators of Need Rehabilitation

In order to analyze the size of the rehabilitation needs of any examined building, i.e., determining whether the rehabilitation order index is high or low, two extreme theoretical (fictitious) models of buildings were adopted. The worst and best possible conditions were adopted and the largest and smallest result of the scale of rehabilitation indexes was obtained.

For the building where rehabilitation is the least necessary, the most favorable values for the building were adopted:
- \( t_i = 0.0 \) (degree of wear of all elements in the building is 0%);
- \( l_i = 0.0 \) (rehabilitation is not necessary due to the location);
- \( h_i = 0.0 \) (the building without any cultural values).

The measures of the impact of damage on other components \( o_i \), measure of structure \( s_i \), measure of the durability \( t_i \), measure of interdependence of the rehabilitation \( r_i \) and importance of criteria are permanent.

For this data, the \( K_{\text{min}} \) matrix was obtained, which contains the smallest possible indicator of rehabilitation needs that can be obtained by subsequent elements in the building:

\[
K_{\text{min}} = \begin{bmatrix}
0.050 \\
0.054 \\
0.049 \\
0.059 \\
0.056 \\
0.048 \\
0.024 \\
0.040 \\
0.034 \\
0.041 \\
0.041 \\
0.042 \\
0.020 \\
0.042
\end{bmatrix}
\]

For the building where rehabilitation is the most necessary, the most unfavorable values for the building were adopted:
- \( t_i = 1.0 \) (degree of wear of all elements in the building is 100%);
- \( l_i = 1.0 \) (the building is located in the city center);
- \( h_i = 1.0 \) (the building is in the register of monuments).

A matrix of rehabilitation needs was obtained for the building thus adopted:
Individual matrix words are assigned to building elements. The largest possible indicator of the order of needs is for the roof structure.

After determining the extreme values that rehabilitation order indicators can achieve, you can relate the indicator of any element in any building to these two values. You can check the place of the numerical range determined according to the number denoting the order of a particular element in a given object.

3. Results and Discussion

In accordance with the proposed principles of the methodology for Determining the Rehabilitation Needs of Buildings (DRNB), an analysis of rehabilitation needs was carried out for 50 residential buildings in Zielona Góra (a city in Poland, population 140,000). All tested buildings are made in traditional technology. The buildings are characterized by similar material and construction solutions. The buildings are 3-storey, the walls are made of solid brick, with wooden ceilings and stairs, a wooden truss framing, roof covering with ceramic tiles. The buildings were built in the years 1850–1915 as town houses. Some of the buildings are in the register of the State Monument Protection Service. The manager of all the analyzed buildings is the Department of Public Utilities and Housing in Zielona Góra.

Periodic technical condition assessment [46] was carried out by experts for all buildings. During the assessment, percentage wear of the technical condition of individual building elements was determined (Table 8). The method DRBN uses these results. For the buildings studied, a cultural value index of 1.0 was adopted for buildings constructed before 1900 (for 68% of buildings), and 0.0 was adopted for the remaining buildings. A location indicator of 1.0 was used for buildings located in the city center (for 20% of facilities), and 0.0 was used for the remaining buildings.

\[
\begin{bmatrix}
0.079 \\
0.083 \\
0.078 \\
0.088 \\
0.084 \\
0.077 \\
0.053 \\
0.068 \\
0.062 \\
0.069 \\
0.069 \\
0.070 \\
0.048 \\
0.071
\end{bmatrix}
\]

Table 8. Average technical wear and tear for the components of the buildings tested.

| No | Element Building       | Average Value | Minimum | Maximum | Standard Deviation |
|----|------------------------|---------------|---------|---------|--------------------|
| 1  | walls                  | 46.1          | 30      | 70      | 11.4               |
| 2  | ceilings               | 46.3          | 30      | 80      | 12.7               |
| 3  | stairs                 | 45.2          | 25      | 90      | 14.4               |
| 4  | roof construction      | 44.6          | 25      | 85      | 15.6               |
| 5  | roof covering          | 48.0          | 0       | 75      | 16.9               |
| 6  | gutters and drainpipes | 53.7          | 30      | 80      | 14.2               |
| 7  | floors                 | 46.1          | 30      | 85      | 12.1               |
| 8  | windows                | 61.8          | 30      | 90      | 13.2               |
| 9  | doors                  | 49.8          | 20      | 80      | 11.0               |
| 10 | water installations    | 34.1          | 20      | 100     | 12.5               |
| 11 | sewage installations   | 35.1          | 20      | 100     | 12.5               |
Appropriate calculations were carried out. The results are the numbers specifying the rehabilitation needs of the 14 elements in each of 50 buildings. The results are shown in Figure 1. The results obtained are indicators of rehabilitation needs. The indicators have been arranged from the highest to the lowest value. The order indicates the rehabilitation needs of the elements in the buildings under study. In this order, rehabilitation of all building group components should be carried out.

Assuming the division of building elements into order groups, it is possible to assess the size of rehabilitation needs. It is proposed to adopt 4 order groups of elements:

- elements for which rehabilitation is absolutely necessary, with sequence values greater than 0.068,
- elements for which rehabilitation is important, with values of order indicators from 0.051 to 0.068,
- elements for which rehabilitation is useful, with values of order indicators from 0.031 to 0.05,
- elements for which rehabilitation is not needed now, with sequence index values less than 0.031.

The first two groups include buildings elements which technical wear is greater than 50%. Additionally, rehabilitation is absolutely recommended for them due to the cultural and historical values of the buildings themselves or their location.

The “rehabilitation is useful” group contains elements with the degree of wear lower than 50%, but due to their location and cultural conditions, their (or their elements) rehabilitation must be performed earlier than the repair for the elements of the fourth group.

Assuming the division of the buildings into the four groups, it is possible to assess the size of the rehabilitation needs for the analyzed group of buildings.

Results are presented in Figure 2.

| No. | Element building              | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  |
|-----|------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1   | walls                        | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 2   | ceilings                     | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 3   | stairs                       | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 4   | roof construction            | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 5   | roof covering                | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 6   | gutters and drain pipes      | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 7   | floors                       | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 8   | windows                      | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 9   | doors                        | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 10  | water installations          | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 11  | sewage installations         | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 12  | heating installations        | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 13  | internal plasters            | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 14  | external plasters            | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|

Legend
- 0.067 - indicators with values lower than 0.067 and higher than 0.036
- 0.031 - indicators with values lower than 0.071 and higher than 0.067
- 0.057 - indicators with values greater than 0.071
The analysis included 14 elements in 50 buildings, 700 in total. The results in Figure 1 indicate that as much as 92% of building components are eligible for rehabilitation. Rehabilitation is absolutely necessary for 12% of elements, rehabilitation is important for 52% elements, rehabilitation is useful for 28% and only for 8% of elements (usually internal plasters), rehabilitation is not needed now.

The methods presented in the literature are helpful in planning rehabilitation works. They rely primarily on the assessment of the choice of the type of material in rehabilitation, assessment of costs over time or planning preventive rehabilitation of buildings. All methods are needed. The method for Determining the Rehabilitation Needs of Buildings (DRNB) presented in the article is based on the assessment of rehabilitation needs. The needs of rehabilitation may result from the poor technical condition of the building element, ending material durability, needs of rehabilitation due to the location or protection of cultural heritage.

The method DRBN may also be used in planning complex repairs for all quarters of a town. The result of such an applied method will be one matrix of sequence for all the buildings, which can be obtained after determining the weighted average wear for all the buildings.

4. Conclusions

The method DRNB presented in the article is based on the assessment of rehabilitation needs. The needs of repairs may result from the poor technical condition of the building element, ending material durability, needs of rehabilitation due to the location or protection of cultural heritage. The most important advantages of the method are:

1. The proposed methodology for Determining the Rehabilitation Needs of Buildings DRNB for an arbitrary group of buildings allows us to arrange the examined objects in terms of the need for their rehabilitation and to determine the order between any two buildings.
2. This method can be used for rehabilitation work schedules for a single building and for a larger group of buildings, e.g., quarter of a town.
3. Financial resources are always too small. Choosing a building element or building from among many is always an important problem. The proposed method will help in making decisions.
4. Rehabilitation works carried out using the DRNB method will stop building degradation.

The method DRNB helps to determine which elements in which buildings need necessary rehabilitation now and for which elements rehabilitation is important now and which elements can
be rehabilitated later—i.e., the repair works are only useful and are not currently needed. The results for buildings in Zielona Góra indicate that as much as 92% of building components are eligible for rehabilitation. Rehabilitation is absolutely necessary for 12% of elements, rehabilitation is important for 52% elements, rehabilitation is useful for 28% and only for 8% of elements (usually internal plasters), rehabilitation is not needed now.

The conclusions resulting from the conducted analysis are the basis for further research of methods studying the costs of rehabilitating buildings.

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

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

**References**

1. Lacasse, M.A. Advances in Service Life Prediction—An Overview of Durability and Methods of Service Life Prediction for Non-Structural Building Components; *Proceedings of the Annual Australasian Corrosion Association Conference*, Wellington Convention Centre, Wellington, NZ, November 16-19, 2008; pp. 1-13
2. Silva, A.; de Brito, J.; Gaspar, P.L. Methodologies for Service Life Prediction of Buildings; Springer International Publishing: Switzerland, 2016; Volume VII, p. 432, doi:10.1007/978-3-319-33290-1.
3. Zavadskas, E.; Antuchevičienė, J.; Kapliński, O. Multi-criteria decision making in civil engineering: Part I—a state-of-the-art survey. *Eng. Struct. Technol.* 2016, 7, 103–113.
4. Nowogórskas, B. The Method of Predicting the Extent of Changes in the Performance Characteristics of Residential Buildings. *Arch. Civ. Eng.* 2019, 65, 81–89, doi:10.2478/ace-2019-0020.
5. Paulo, P.; Branco, F.; Brito, J.; Silva, A. Buildings Life—The use of genetic algorithms for maintenance plan optimization. *J. Clean. Prod.* 2016, 121, 84–98.
6. Matulionis, R.C.; Freitag, J.C. Preventive Maintenance of Buildings; Published by Wiley & Sons, Incorporated, John, U.S.A. 1990.
7. Ortega, L.; Serrano, B.; Fran, J.M. Proposed method of estimating the service life of building envelopes. *Rev. De La Construcción* 2015, 14, 60–68.
8. Christen, M.; Schroeder, J.; Wallbaum, H. Evaluation of strategic building maintenance and refurbishment budgeting method Schroeder. *Int. J. Strateg. Prop. Manag.* 2014, 18, 393–406.
9. Leśniak, A.; Wieczorek, W.; Górka, M. Selection of the Variant of the Aluminium-Glass Facade Implementation Using the AHP Method. In *Advances in Intelligent Systems and Computing*; Springer International Publishing: Switzerland, 2020; doi:10.1007/978-3-030-37919-3_53.
10. Ibadov, N. The alternative net model with the fuzzy decision node for the construction projects planning. *Arch. Civ. Eng.* 2018, 64, 3–20.
11. Drozd, W.; Kowalik, M. Comparison of technical condition of multi-family residential buildings of various ages. *Arch. Civ. Eng.* 2020, 66, 55–67, doi:10.24425/ace.2020.131774.
12. Nowogórskas, B. Proposal for determining the scale of renovation needs of residential buildings. *Civ. Environ. Eng. Rep.* 2016, 22, 137–144.
13. Prieto, A.J.; Vásquez, V.; Silva, A.; Horn, A.; Alejandre, F.J.; Macías-Bernal, J.M. Protection value and functional service life of heritage timber buildings. *Build. Res. Inf.* 2019, 47, 567–584.
14. Drozd, W.; Leśniak, A. Ecological Wall Systems as an Element of Sustainable Development—Cost Issues. *Sustainability* 2018, 10, 2234, doi:10.3390/su10072234.
15. Nowogórskas, B. Performance characteristics of buildings in the assessment of revitalization needs. *Civ. Environ. Eng. Rep.* 2019, 29, 119–127.
16. Biolek, V.; Hanáč, T. LCC Estimation Model: A Construction Material Perspective. *Buildings* 2019, 9, 182. doi:10.3390/buildings9080182.
17. Radziszewska-Zielińska, E.; Śadowski, G. Proposal of the Use of a Fuzzy Stochastic Network for the Preliminary Evaluation of the Feasibility of the Process of the Adaptation of a Historical Building to a Particular Form of Use. In *IOP Conference Series: Materials Science and Engineering*; Materials Science and Engineering; IOP Publishing Ltd: Volume 245/7, p. 072029.
18. Colen, I.F.; de Brito, J.; Freitas, V. Discussion of Criteria for Prioritization of Predictive Maintenance of Building Façades: Survey of 30 Experts. *J. Perform. Constr. Facil.* 2010, 24, doi:10.1061/(ASCE)CF.1943-5509.0000104.
19. Paulo, P.; Branco, F.; Brito, J. Buildings Life: A building management system. Struct. Infrastruct. Eng. 2014, 10, 388–397, doi:10.1080/15732479.2012.756919.
20. Moretti, N.; Re Ceconi, F. A Cross-Domain Decision Support System to Optimize Building Maintenance. Buildings 2019, 9, 161. doi:10.3390/buildings9070161.
21. Nowogorska, B.; Korentz, J. Value of Technical Wear and Costs of Restoring Performance Characteristics to Residential Buildings. Buildings 2020, 10, 9.
22. Frangopol, D.M.; Lin, K.-Y.; Estes, A.C. Life-cycle cost design of deteriorating structures. J. Struct. Eng. Asce 1997, 123, 1390–1401. doi:10.1061/(ASCE)0733-9445(1997)123:10(1390).
23. Wieczorek, D.; Plebankiewicz, E.; Zima, K. Model estimation of the whole life cost of a building with respect to risk factors. Technol. Econ. Dev. Econ. 2019, 25, 20–38, doi:10.3846/tede.2019.7455.
24. Rivera-Gómez, H.; Montaño-Arangó, O.; Corona-Armenta, J.R.; Garnica-González, J.; Hernández-Gress, E.S.; Barragán-Vite, I. Production and Maintenance Planning for a Deteriorating System with Operation-Dependent Defectives. Appl. Sci. 2018, 165, 8.
25. Hola, A.; Sadowski, Ł. A method of the neural identification of the moisture content in brick walls of historic buildings on the basis of non-destructive tests. Autom. Constr. 2019, 106, 102850, doi:10.1016/j.autcon.2019.102850.
26. Mrówczyńska, M.; Gibowski, S. Indicating Vertical Deviation of Historical Buildings Using Geodetic Methods—Case Study of Brick and Wood Tower in Nowe Miasteczko. Civ. Environ. Eng. Rep. 2016, 22, 127–136. doi:10.1515/ceer-2016-0041.
27. Monczynski, B.; Ksit, B.; Szymczak-Graczyk, A. Assessment of The Effectiveness of Secondary Horizontal Insulation Against Rising Damp Performed by Chemical Injection. IOP Conf. Ser. Mater. Sci. Eng. 2019, 471, 52063. doi:10.1088/1757-899X/471/5/052063.
28. Radziszewska-Zielina, E.; Kania, E.; Śadowski, G. Problems of the Selection of Construction Technology for Structures of Urban Agglomerations. Arch. Civil Eng. 2018, 64, 55–71.
29. Rudbeck, K. Methods for designing building envelope components prepared for repair and maintenance. In Department of Buildings and Energy; Technical University of Denmark: Lyngby-Taarbæk, 1999; R-035.
30. Morelli, M.; Lacasse, M.A. A systematic methodology for design of retrofit actions with longevity. J. Build. Phys. 2019, 42, 585–604.
31. Lounis, Z.; Vanier, D.J.; Lacasse, M.A.; Kyle, B.R. Decision-Support System for Service Life Asset Management: The BELCAM Project. Durability of Building Materials and Components; National Research Council Canada: Ottawa, ON, Canada, 1999, 4, 2338–2347.
32. Vanier, D.J.; Lacasse, M.A. BELCAM project: Service life, durability, and asset management research. In Proceedings of the 7th Conference on Durability of Building Materials and Components, Stockholm, Sweden, 19–23 May 1996; Volume 2, pp. 848–856.
33. Shen, Q.; Spedding, A. Priority setting in planned maintenance—Practical issues in using the multiattribute approach. Build. Res. Inf. 1998, 26, 169–180, doi:10.1080/096132198369940.
34. Alshubbak, A.; Pellicer, E.; Catala, J.; Teixeira, J. A Model for identifying owner’s needs in the building life cycle. J. Civ. Eng. Manag. 2015, 21, 1046–1060.
35. Vanier, D.; Tesfamariam, S.; Sadiq, R.; Lounis, Z. Decision models to prioritize maintenance and renewal alternatives. In Proceedings of the Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Montréal, QC, Canada, 14–16 June 2006; pp. 2594–2603.
36. Bucoří, R.; Sobotka, A. Decision-making model for choosing residential building repair variants. J. Civ. Eng. Manag. 2015, 21, 893–901, doi: 10.3846/13923730.2014.895411.
37. Sherwin, D. A review of overall models for maintenance management. J. Qual. Maint. Eng. 2000, 6, 138–164.
38. Jones, K.; Sharp, M. A new performance-based process model for built asset maintenance. Facilities 2007, 25, 525–535. doi:10.1108/02632770710822616.
39. Farahani, A.; Wallbaum, H.; Olof Dalenbäck, J. Optimized maintenance and renovation scheduling in multifamily buildings—A systematic approach based on condition state and life cycle cost of building components. Constr. Manag. Econ. 2019, 37, 139–155.
40. Bento Pereira, N.; Calejo Rodrigues, R.; Fernandes Rocha, P. Post-Occupancy Evaluation Data Support for Planning and Management of Building Maintenance Plans. Buildings 2016, 6, 45.
41. Daniotti, B.; Lupica Spagnolo, S. Service Life Prediction Tools for Buildings’ Design and Management. In Proceedings of the 11DBMC International Conference on Durability of Building Materials and Components, Istanbul, Turkey, 11–14 May 2008; doi:10.13140/RG.2.1.4311.6002.
42. Daniotti, B.; Pavan, A.; Lupica Spagnolo, S.; Caffi, V.; Pasini, D.; Mirarchi, C. Benefits and Challenges Using BIM for Operation and Maintenance. In *BIM-Based Collaborative Building Process Management*; Springer Tracts in Civil Engineering; Springer: Berlin/Heidelberg, Germany, 2020; pp. 103–142.
43. Madureira, S.; Flores-Colen, I.; de Brito, J.; Pereira, C. Maintenance planning of facades in current buildings. *Constr. Build. Mater.* 2017, 147, 790–802. doi:10.1016/j.conbuildmat.2017.04.195.
44. Chen, Ch.; Juan, Y.; Hsu, Y. Developing a systematic approach to evaluate and predict building service life *J. Civ. Eng. Manag.* 2017, 23, 890–901.
45. Arendarski, J. *Durability and Reliability of Residential Buildings*; Arkady: Warszawa, Poland, 1978. (In Polish)
46. Periodic inspection protocol 2018. Department of Municipal and Housing Administration in Zielona Góra, 2018, Zielona Góra. (In Polish).

© 2020 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).