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**Research paper**

# The assessment of the social performance of residential buildings

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**Abstract:** The article presents method of assessment of one of the three basic aspects of sustainable construction concerning social utility properties of residential buildings. The study was based on the recommendations of standards [1] and [2], on the basis of which the area of features characterizing the social aspect of buildings was determined. Additionally, the presented method includes criteria which are necessary for the assessment of this aspect, and which are not included in the normative guidelines. The presented method fits in with the current trend of sustainable construction. This method enables and facilitates the comparison of social utility properties in different residential buildings. It is also allows for the classification of buildings according to the degree to which they meet their social utility properties; that can be a practical tool to support the decision on the future of the building (i.e., the sequence of necessary refurbishments) or the decision to buy or sell the property by indicating its strengths and weaknesses. By developing a way to assess a comprehensive set of criteria, the proposed method allows you to quickly and easily assess the social quality of residential buildings. In addition, the proposed measures for individual criteria can easily be adapted to requirements in other countries. The proposed "star" classification can also be used as a universal scale for assessing the social quality index of buildings.

**Keywords:** residential buildings, building's sustainability, method of assessment, mathematical model, the social quality index

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# 1. Introduction

Construction is one of the most important areas of economic and social life. To a large extent, this economic sector is used natural resources and influences the environment both during construction production, which results in construction services and buildings, as well as during their exploitation. Implementation of the principles of sustainable development in the building sector consists in particular in reducing the consumption of energy and natural resources, as well as in reducing the production of waste and pollution from the transport of building materials [3], [4], [5]. The indirect objective is to protect the health of the inhabitants which is a social benefit. Such emphasis on sustainable construction (SC) aspects does not take into account the equivalence of three basic objectives of the SC (i.e., environmental, economic and social aspects - Fig. 1). However, given that people, in most climate zones, spend around 80% of their lives at homes, the social aspect (health and comfort of users) becomes particularly important.

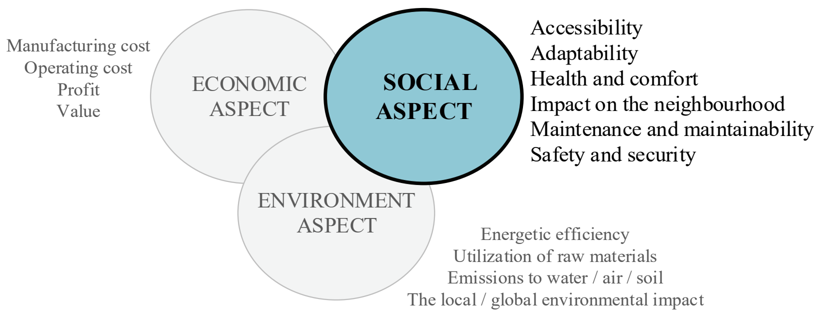



Fig. 1. Three main aspects of sustainable construction

The development of modern construction should be characterized by the introduction of innovative technologies and modern solutions that will combine beneficial economic effects with care for the health and comfort of users. Among the three main aspects of the SC listed, the social aspect is the least studied and elaborated. There are only a few studies and analyses in the literature regarding the particular properties it concerns. In general, the analyses that concerning this issue are limited to covering only a part of the features of social aspect. There is no study presenting it in its entirety, especially in relation to the postulates of sustainable construction. In the international standards concerning the social aspect [1] and [2] there are guidelines for the development and implementation of rules; however, there are no given methods of assessment of levels, classes or standards for the classification of buildings.

Furthermore, the analysis of the activities of organizations who manage building resources shows that funds allocated for refurbishment and modernization are often spent accidentally, have an "image" character and do not take into account the social needs (third pillar) of sustainable construction. The refurbishment policy pursued so far shows that it is worth working on a tool that also takes into account the needs of users, which can contribute to a better planning of refurbishment and modernization works and improving the financial policy related to the operation of residential buildings. The lack of a comprehensive approach to this issue and the lack of a proposal for a method of social assessment of buildings was the reason for undertaking research in this field and developing a method of assessment of social utility properties of residential buildings.
The presented method allows for multi-criteria assessment, which takes into account different nature of the features (i.e., determined, random or fuzzy) describing the social aspect of sustainable construction. On the other hand, the software of decision-making model is a useful decision support system for both users and residential building managers.

## 2. Overview of knowledge

The issue concerning the social aspect presented in the following work covers a broad spectrum of knowledge ([2], [6], [7], [8], etc.). Topics related to the maintenance and evaluation of buildings require extensive expert knowledge in many fields related to construction, environmental engineering, economics, management sciences, sociology, etc.. The systematization of knowledge necessary for the analysis of the discussed subject matter is divided into three main issues – presented in the Fig. 2.

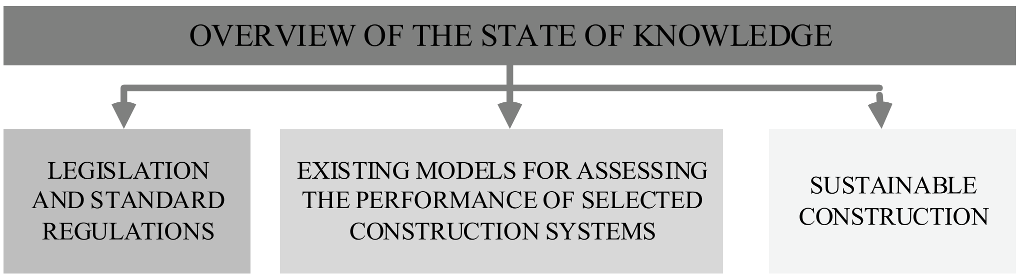



Fig. 2. Overview of the knowledge

The legislation and standards are contained regulations concerning the maintenance of buildings. Among the most important ones, which were the source of information for the author and helped to systematize the set of criteria, were: *Construction Law, Regulation of the Minister of Infrastructure of 12 April 2002 on the technical conditions that should be met by buildings and their location, and series of standards: ISO 15686, EN 15643 and EN 16309: 2014.*

The spectrum of problems that fall within the scope of the assessment of the degree of wear and tear of a building is so wide that it seems an inexhaustible source of analysis. The literature review ([9], [10], [11], [12], [13], [14], [15], etc.) revealed multiple topics concerning the assessment of the technical condition of construction objects. Many authors [16], [17], [18], [19], [20], [21], etc., were also involved in the development of models supporting the evaluation of buildings, which considered e.g., functional state or moral state, but never in a complex manner. The authors of those studies combine, among other things, functional wear and tear with technical wear and tear, by estimating the value of a building on the basis of the degree to which its functions are adapted to current market requirements.

The functionality of a building structure treated as the adjustment of its technical and functional parameters to its design or actual purpose (i.e., whether in the face of changes in regulations, standard requirements, etc., the object can continue to perform its current function) is presented in M. Prystupa works.

The evaluation of buildings with regard to technical, functional, social and economic aspects is presented in A. Ostańska's work [22]. The author focuses on the development of programs for revitalization of housing estates taking into account the needs of residents and energy efficiency of buildings. Based on the assessment of technical condition and surveys conducted among users, the author proposes in her works an algorithm for preparing revitalization programs for prefabricated housing complexes.

In turn, determining the utility value of the building by defining the value of four characteristics [(exploitation requirements): technical, energy, visual and functional] was presented in a dissertation by Robert Bucoń. In his work, the author presented a decision-making model that aims to support the decision-maker in deciding on choosing the actions and the scope of the refurbishment of buildings. The obtained value allows to estimate the market value of a building, which may support the process of selling or renting it.

There are also many studies in the literature, where proposals for methods of assessment of buildings in the aspect of sustainable development were presented (e.g., certificates: [23], [24], [25], [26], [27], [28] and [29]). However, in most of them, the focus is on one of the three main aspects characterizing the SC – the environment.

Therefore, the issue presented in this article focuses on the social aspect, which is equally important in the assessment of sustainability in accordance with the principles of sustainable development (SD) ; when considering residential buildings, it seems to be the most important aspect.

Given the nature of the social aspect the standards and policies that have been developed and implemented in the area of sustainable construction have been analysed. It has been shown that the standards mostly contain only a list of basic site evaluation criteria and general guidelines for their evaluation. In the case of economic and environmental aspects, ways of measuring individual factors (criteria) are also given, but they are missing on the social aspect [2]. Furthermore, the standard is also lacked of factors related to the immediate environment of the building that have a significant impact on the quality of life of its occupants. These factors have been included in the assessment method presented.

The literature review has shown that in order to maintain a coherent SC approach, it is necessary to develop a tool for a comprehensive assessment of each of the pillars of sustainability. Since methods for assessing both environmental and economic aspects have already been developed, there is a need to build a functional tool for a comprehensive sustainability assessment of the last, and equally important characteristic: the social aspect.

## 3. Methodology of research

In the field of construction and related sciences, issues of varying degrees of complexity (single and multi-criteria) can be encountered. Most often, the nature of the considered decision problem determines its multi-criteria character. In most issues, there are several options to be considered, each of them should be examined in terms of multiple factors that characterize it. The issue presented in this article, also due to the numerous group of criteria important in the process of assessment of the social aspect of sustainable construction, belongs to the methods of multi-criteria analysis.

The applied methodology aims to develop a tool to assist the user, owner or manager of the building in making decisions related to the management of the housing substance by taking into account the social needs of the residents. The methodology presented consists of the stages which are described below:

1. Defining the issue of the assessment of the social performance of a building through:

– identification of issues related to the operation of residential buildings, i.e., legal regulations, standards and the assessment models developed until now; the concept of a reference building,
– acquaintance with the state of knowledge in the field of sustainable construction covering regulations, standards and existing methods of assessment and certification,
– getting to know the specifics of multi-criteria analysis called *Multiple-criteria decision analysis* (MCDA) and expert-mathematical methods.

2. Development of a model based on the analysis of the social condition of a building or its part (selected residential units) and the characteristics of components of a building, using the system approach:
   a. Define the structure of the model:
      – identification and formalization of the model of the presented issue,
      – development of a model structure based on the theory of systems (evaluation tree).
   b. Formulating a Preliminary Set of Criteria (PSC) and processing it into a Final Set of Criteria (FSC) through:
      – literature research including critical analysis of regulations, standards, design and execution documentation, compliance schedule books,
      – graph theory – application of an ordering algorithm to reduce PSC,
      – a direct user survey,
      – expert interviews,
      – statistical analysis,
      – reliability indicators of the conducted tests.
   c. Developing a method of evaluating the criteria taken into account in the model, using techniques and tools such as:
      – literature research, including critical analysis of regulations, standards, design and execution documentation,
      – direct user survey,
      – questionnaire surveys among experts,
      – expert interviews and consultations,
      – logic fuzzy,
      – statistical analysis.
   d. Determining the weights of the criteria to be taken into account in the social assessment of the building through:

  - direct user surveys,
  - questionnaire surveys among experts,
  - expert interviews,
  - statistical analysis of the results of surveys used to determine the validity of the criteria taken into account in the evaluation.
3. Carrying out building assessment using multi-criteria analysis and determining the social quality index by:
   - referring to a reference building,
   - the choice of the method of aggregating the assessment – the use of a summative adjusted indicator,
   - calculation of the social quality index (proposal for the classification of residential buildings),
   - application of the method on selected examples.
4. Development of a computer application with the use of IT tools:
   - *Typescript – Angular* language, which is an extension of *JavaScript* language,
   - *Firebase* – a tool for managing an application.
5. Analysis and interpretation of the results:
   - a summary of the objectives and the thesis of the work,
   - final conclusions,
   - the definition of the directions for further research.

The proposed methodology allows for the identification of practical and measurable prosocial solutions in the field of proper use and maintenance of existing residential buildings. It should be noted that the assessment can be carried out by the owner and manager as well as by the users of the building. It also allows for a detailed social assessment of the analyzed building and its comparison with the previously determined evaluation of the reference building[2]. The obtained difference allows to determine the indicator showing how big the discrepancies between a given object and the value obtained for a reference building are. The indicator take into account the current technical and construction regulations, modern logistic solutions of cities and housing estates, new construction technologies, etc.

[2] More information on the reference building is provided in Chapter 4.2.

# 4. Description of the decision-making model

## 4.1. A building object as a system structure and system components

In order to analyze (establish) the social assessment of residential buildings for further consideration the construction object was treated as a system. The definition of this concept depends on the area (scientific discipline), interests and language of formalization used. In this study, definitions of the system have been adopted according to Mario Bunge. A residential building will be perceived as a dynamic system, consisting of a set of different construction products, components and/or construction structures (the so-called: composition of system "C" and its surroundings "E"), deliberately selected to meet the specific requirements of the owners and users. These elements constitute a deliberately oriented one unit; they have certain properties and are in specific relationships between themselves (the so-called: relationship structure "S"). Treating a building as a system in further analyses has certain "effects". Such assumption allows to present the studied phenomena and processes in the form of mathematical models, and then carry out the analysis with the use of available mathematical apparatus.

It is assumed that the buildings under assessment must fulfil the basic requirements for the ultimate and serviceability limit states, so that they do not pose a direct threat during their use. These requirements are fulfilled by a preliminary **technical and functional assessment** of the building called here a **functional equivalent (EF).** The EF expresses the operational requirements, which evaluation method is presented, among others in standards [1] and [2] . Among the assessed factors, there are basic requirements contained in the Regulation [29]. Each of the assessed features included in the functional equivalent is based on the analysis of the operation process of the construction object, which is based on Compliance Schedule Book (CSB). A functional equivalent is the representation of the required technical characteristics and functionality of a building.

The social assessment of the building in relation to the so-called reference object can only be carried out if all the requirements of the functional equivalent are met (thanks to which we have information that the building does not pose a threat and the load-bearing capacity limit states are not exceeded). Therefore, the main elements of functional equivalent should be described. These elements should be described together with their intended purpose and relevant detailed technical requirements. Thanks to the preliminary determination of the requirements contained in the equivalent, it is possible to conduct a rational assessment of social properties of the analyzed facility. The social aspect will be assessed from the user's point of view by meeting current standards and ensuring the comfort of the residents of the facility.

## 4.2. Identification of the reference building

The reference building is a hypothetical building designed in accordance with applicable standards and common practice and shares the same technological, structural and performance parameters as the building under assessment. The reference building is used for comparative calculations with the analyzed object.

The reference object will be a simplified form, in which the parameters necessary to carry out the calculation procedures to compare it to the tested building are included. The created reference object has all the main parameters of the analyzed object, which gives a picture of how a model object with specified parameters should looks like. What is important here is that the reference building is not an "ideal" building with only the highest grades. In practice, an ideal building should be the object under assessment, which would be the best example of realization in accordance with all requirements (not necessarily resulting from regulations). The reference building, on the other hand, is to serve as a reference point that represents all the requirements of current legislation and regulations.

## 4.3. Model construction stages

In the presented study, it was assumed that the selected features characterizing the building constitute **the assessment criteria**. Using appropriate mathematical methods, a set of social evaluation criteria for buildings was distinguished. In addition, due to a large number of criteria, they have been **grouped into subcategories and categories**. The presented grouping of the set of criteria was performed in accordance with the division structure proposed in the standard [2]. Finally, 6 main categories were adopted, each of which was detailed by subcategories characterized by evaluation criteria.

On the basis of the description of the criteria, indicators for their evaluation were adopted. Indicators for which no legal regulations and user requirements existed so far were determined on the basis of expert surveys, surveys or fuzzy logic (Fig. 3).

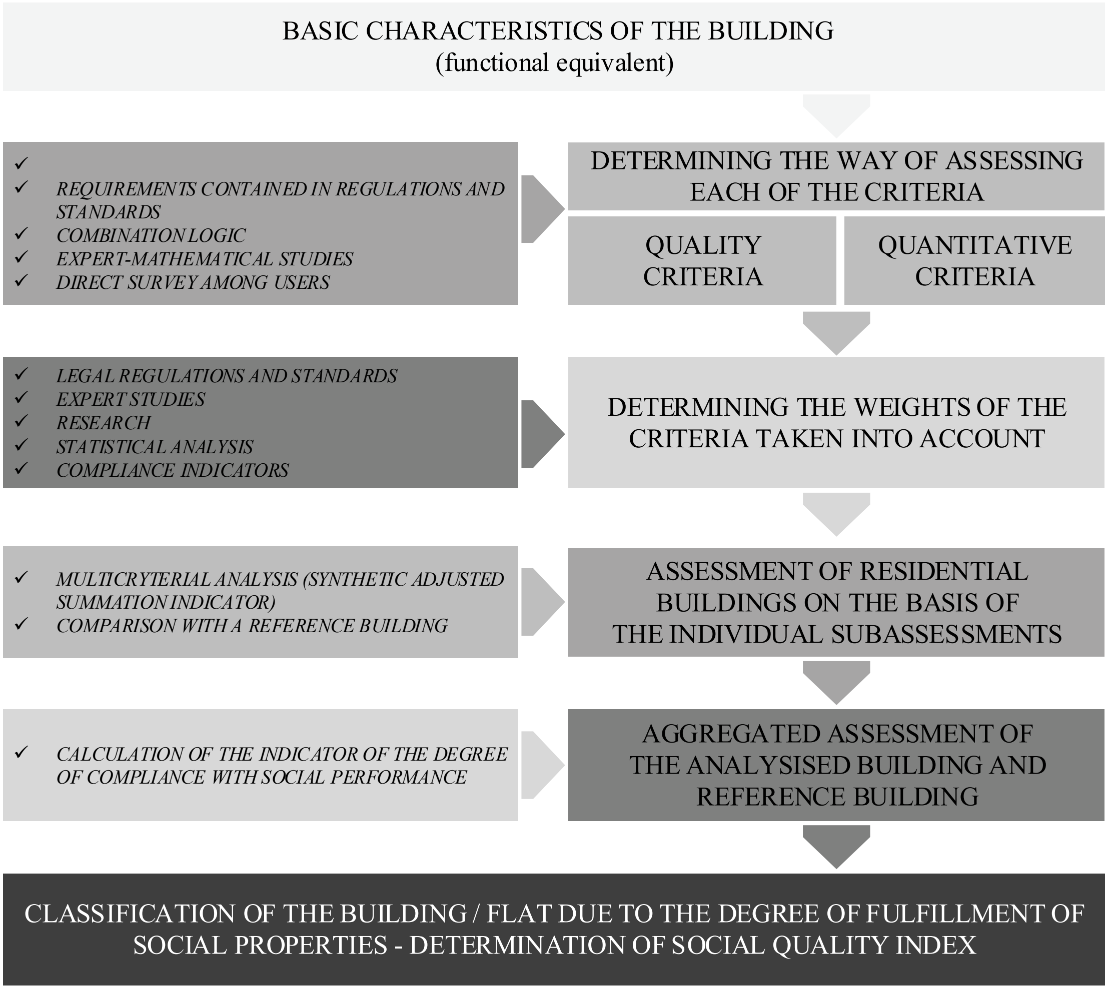



Fig. 3 Stages of model construction and applied research methods

It is assumed that if the required characteristic is determined by legislation and/or user requirements, this assessment is determined by the highest known requirements. This means that if the requirements of the decision-makers were higher than the applicable legislation, the assessment took into account the degree of compliance with the users' requirements. Conversely, where the social assessment was based on national, local or regional legislation or principles, the features and characteristics were described in such a way that the fulfilment or improvement of those principles could be demonstrated.

Finally, only the basic, most important elements related to the categories of criteria $K_i$ $(i = 1,2,\dots,m)$ describing a given system (object) were included in the model. The assessment of social performance shall be carried out by assessing each of them. In order to more accurately define the scope of the category $K_i$ $(i = 1,2,\dots,m)$, the subcategories $K_{ij}$ $(j = 1,2,\dots,n_i,\ i = 1,2,\dots,m)$ are specified. Each of the subcategory is evaluated by the criteria $K_{ijk}$ $\left(k = 1,2,\dots,n_{ij}, j = 1,2,\dots,n_i,\ i = 1,2,\dots,m\right)$.

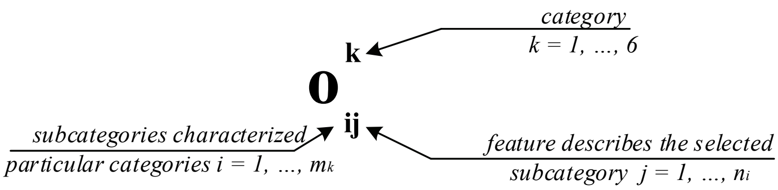
The social assessment is determined by a vector of grades for the included categories:

(4.1) $$O = [O^1, O^2, \dots, O^i] \quad dla\ i = 1,2,\dots,m;$$

In order to formally describe each of the $\boldsymbol{O^i}$ assessments of the $K_i$ category state matrix with $n_i$ components (subcategories) evaluated by $n_{ij}$ criteria, the following assessment matrix has been introduced:

(4.2) $$O^i = [o^i_{j,1}, o^i_{j,2}, \dots, o^i_{j,k}] \quad dla\ i = 1,2,\dots,m;\ j = 1,2,\dots,n_i;\ k = 1,2,\dots,n_{ij},$$

where:




while the values of $o^i_{j,n_{ij}}$ for the last ones $n'_{ij}$ will be zeroes,
where:

(4.3) $$n_{ij} \text{ values of the index } k,\ n'_{ij} = \max_{1 \le j \le n_i} n_{ij};$$

(4.4) $$n_i \text{ values of the index } j,\ n'_i = \max_{1 \le i \le m} n_i;$$

The evaluation values of the criteria were determined on the basis of the experts' knowledge. To evaluate the considered feature (criterion), depending on the existing state of affairs, a discrete scale was finally adopted, consisting of $1 \div p$ levels for $p = 5$. The adopted scale made it possible to take into account the influence of factors that are difficult to measure.

The problem of unequal importance of the criteria, subcategories and categories was eliminated by applying the so-called weightings correcting the values according to the preferences expressed by the expert [31]:

(4.5) $$\lambda_{ijk} \in [0,1]\ where \sum_{i=1}^{m} \lambda_{ijk} = 1 \ \ dla\ j = 1,2,\dots,n_i, k = 1,2,\dots,n_{ij}$$

The model assumes the scale of weights: from 0.1 to 1.0 (0.1 – not important, ..., 1.0 – very important).

# 5. Determination and aggregation a set of assessment criteria

## 5.1. Set of criteria

Developing a comprehensive database of criteria for assessing the social aspect is one of the most difficult and at the same time the most extensive parts, therefore, the characteristics and method of assessing the criteria proposed by the author has been presented in a separate study.

The diversity of the range of characteristics under assessment required knowledge and research in many fields, conducting research among users and experts, and detailed analysis. The database of criteria has been determined in two stages. The first step was to define the Preliminary Set of Criteria (PSC), in which all the characteristics that could be taken into account in the assessment of the social aspect of residential buildings were gathered. Then, the reduction of the resulting set of criteria to the so-called Final Set of Criteria (FSC) was performed using appropriate mathematical tools based on graph theory, allowing to eliminate the criteria for convergent building characteristics. Next, each of the criteria belonging to the FSC was characterized and the method of its evaluation was proposed. In order to obtain a solution, weightings for particular criteria were also determined by means of questionnaire and expert surveys. The final grouped set of evaluation criteria is presented in the Table 1.

Table 1 Structure of the criteria database for social evaluation of residential buildings

| | | | | | |
|---|---|---|---|---|---|
| $K_1$ | Accessibility | $K_{11}$ | Accessibility to building facilities including people with additional needs | $K_{111}$ | Approach to the building |
| | | | | $K_{112}$ | Entrance to and movement inside the building |
| | | $K_{12}$ | Access to building services | $K_{121}$ | Provision and operability of sanitary facilities |
| | | | | $K_{122}$ | Provision and ease of operation of switches and control systems |
| | | | | $K_{123}$ | Accessibility for people with additional needs of electronically or mechanically operated systems |
| | | | | $K_{124}$ | Provision of communication systems in the building (e.g. telephones, information systems, etc.) |
| | | $K_{13}$ | Composition of the urban layout of the surroundings | $K_{131}$ | Access to basic services |
| | | | | $K_{132}$ | Accessibility (location) of public utilities |
| | | | | $K_{133}$ | Proximity to green and recreational areas |
| | | | | $K_{134}$ | Building intensity and ventilation hygiene |

| | | | | | |
|---|---|---|---|---|---|
| $K_2$ | Aadaptability | $K_{21}$ | Building's ability to accommodate the change of user requirements | $K_{211}$ | Optimization of internal load-bearing-elements (e.g. easy of demolition/ demountability of internal building elements), |
| | | | | $K_{212}$ | Possibility to assemble equipment for the transport of people, including people with additional needs (e.g. lifts), |
| | | $K_{22}$ | Building's ability to accommodate technical changes | $K_{221}$ | Accessibility and demountability of pipes and cables |
| | | | | $K_{222}$ | Provision of space for additional pipes and cables for technical changes |
| | | $K_{23}$ | Building's ability to accommodate the change of use | $K_{231}$ | Provide fire safety |
| | | | | $K_{232}$ | Redundancy in load-bearing capacity |
| | | | | $K_{233}$ | Ensuring hygienic-sanitary conditions and environmental protection |
| $K_3$ | Health and comfort | $K_{31}$ | Thermal characteristics | $K_{311}$ | Room/building temperature control possible |
| | | | | $K_{312}$ | Possibility of controlling the humidity of the air |
| | | | | $K_{313}$ | Ventilation can be controlled |
| | | | | $K_{314}$ | Air-conditioning controllability |
| | | $K_{32}$ | Characteristics of indoor air quality | $K_{321}$ | Concentration of harmful substances used in construction and finishing materials |
| | | | | $K_{322}$ | Concentration of CO2, harmful oxides and dusts |
| | | | | $K_{323}$ | Risk of mould and fungus growth |
| | | $K_{33}$ | Acoustic characteristics | $K_{331}$ | Acoustic insulation from indoor sounds, e.g. ventilation, sanitary installations, footsteps, etc. |
| | | | | $K_{332}$ | Acoustic insulation against external sounds, e.g. from neighbouring buildings; against air sounds, e.g. cars, airplanes, wind turbines |
| | | $K_{34}$ | Characteristics of visual comfort | $K_{341}$ | Daylight contribution |
| | | | | $K_{342}$ | Occurrence of the phenomenon of glare and visual connection with the "outside world" |
| | | | | $K_{343}$ | Quality of artificial lighting and controllability of light intensity |
| | | $K_{35}$ | Spatial characteristics | $K_{351}$ | Number and floor area of all rooms per person |
| | | | | $K_{352}$ | Number and floor area toilets, bathrooms and kitchen per person |
| | | | | $K_{353}$ | Floor to ceiling height |
| | | | | $K_{354}$ | Number and dimensions (length, width, height) of connecting space (halls, landings, stairs, corridors) |
| | | | | $K_{355}$ | Auxiliary premises and shared spaces |
| | | | | $K_{356}$ | Number and area of balconies, terraces or gardens |
| $K_4$ | Mpacts on neighbourood | $K_{41}$ | Noise | $K_{411}$ | Emitted sound pressure level |
| | | | | $K_{411}$ | Sound insulation |
| | | $K_{42}$ | Emissions to outdoors | $K_{421}$ | Dust and smoke |
| | | | | $K_{422}$ | Odour |
| | | | | $K_{423}$ | Release of hazardous substances into groundwater and/or surface |
| | | $K_{43}$ | Glare/ overshadowing | $K_{431}$ | Day and/or nigth glare / Overshadowing |
| $K_5$ | Maintenance and maintainability | $K_{51}$ | Maintenance operations | $K_{511}$ | Frequency and duration of regular maintance |
| | | | | $K_{512}$ | Safety of users during work |
| | | | | $K_{513}$ | Maintainability |
| | | $K_{52}$ | Renovation and refurbishment works | $K_{521}$ | Frequency/need to carry out repair and refurbishment works |
| | | | | $K_{522}$ | Possibility to use the building while performing renovation and refurbishment |

| | | | | | |
|---|---|---|---|---|---|
| $K_6$ | Safety and security | $K_{61}$ | Resistance to climate change | $K_{611}$ | Rain and flood resistance |
| | | | | $K_{612}$ | Wind resistance |
| | | | | $K_{613}$ | Resistance to weight and heavy snowfall |
| | | $K_{62}$ | Safety and security angainst accidental actions | $K_{621}$ | Earthquake (tąpnięcia) |
| | | | | $K_{622}$ | Explosions |
| | | | | $K_{623}$ | Fire resistance |
| | | | | $K_{624}$ | Resistance to dynamic external actions |
| | | $K_{63}$ | Safety and security angainst intruders and vandalism | $K_{631}$ | Lighting of access roads |
| | | | | $K_{632}$ | Safe storage of waste |
| | | | | $K_{633}$ | Provision of physical barriers |
| | | | | $K_{634}$ | Alarm and surveillance systems |
| | | $K_{64}$ | Security against interruptions of utility supply | $K_{641}$ | Presence of back-up equipment for heating and electricity |
| | | | | $K_{642}$ | Free and safe movement inside of the building and building evacuation in case of interruption of electricity |

## 5.2. Defining the structure of the system and its model

In the proposed method, the building is assessed on the basis of criteria grouped into subcategories which are assigned to six main categories – listed in Table 1. The social assessment is proposed to be expressed by means of **an indicator of the social quality** of the analyzed object. A set of partial building assessments expressed in numbers is called its social utility characteristics or social assessment.

A discrete, stepped, five-point evaluation of features was adopted: where 5 – is the highest and 1 – the lowest. Using qualified assessments $O^i,\ for\ i = 1, \dots, m$ is obtained a block matrix of social aspect assessment $\boldsymbol{O}$ and a block matrix of weights $\boldsymbol{\Lambda}$ assigned to it:

$$\boldsymbol{O} = [O^1, O^2, \dots, O^m] \tag{5.1}$$

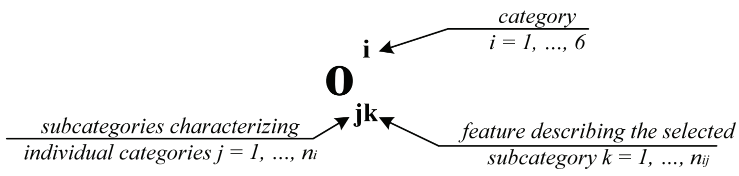
$$\boldsymbol{\Lambda} = [L^1, L^2, \dots, L^m] \tag{5.2}$$

Using qualified assessments $o_{jk}$, where $j = 1, \dots, n_i$ ; $k = 1, \dots, n_{ij}$ is obtained an assessment matrix for each of the categories $\boldsymbol{O^i}$ taken into consideration and a weighting matrix $\boldsymbol{\Lambda}^i$ assigned to it:

$$\boldsymbol{O}^i = \begin{bmatrix} o^i_{1,1} & \cdots & o^i_{1,n_{ij}} \\ \vdots & \ddots & \vdots \\ o^i_{n_i,1} & \cdots & o^i_{n_i,n_{ij}} \end{bmatrix} \tag{5.3}$$

$$\boldsymbol{\Lambda}^i = \begin{bmatrix} \lambda^i_{1,1} & \cdots & \lambda^i_{1,n_{ij}} \\ \vdots & \ddots & \vdots \\ \lambda^i_{n_i,1} & \cdots & \lambda^i_{n_i,n_{ij}} \end{bmatrix} \tag{5.4}$$

where:




In order to obtain a single-number rating indicator in the multi-criteria analysis process, one of the aggregation procedures can be used. To implement the purpose of the analysis, the method of synthetic indicators was applied, and more precisely the adjusted sum index.

The optimization process consists in finding the value (evaluation, quality) of the analyzed building due to the social aspect of sustainable construction and comparing it with the parallel assessment for the reference building. The obtained value of social assessment of the examined building with simultaneous assessment of the reference building allows to identify the weakest points of the analyzed object from the user's point of view, which will allow to make the right decisions in the future regarding the improvement of comfort of its use.

## 5.3. Survey research to determine the weighting of the assessment criteria

The weight assigned to particular characteristics was determined based on data obtained from direct surveys among users of apartments in two voivodships and surveys among construction experts.

The scope of the research included:

1. In a user survey:
   a. preparation of forms to conduct surveys,
   b. conducting direct surveys among apartment users,
   c. checking the variability of the coefficient of variation of the obtained survey results, which resulted in the rejection of outliers' results,
   d. the processing of the results obtained by using statistical measures

2. In the survey conducted among experts:
   a. selection of an appropriate expert group,
   b. preparation of forms to conduct surveys,
   c. conducting surveys among experts,
   d. checking the conformity of the judiciary's (expert) opinions,
   e. processing of the results obtained using statistical measures.

In the model, it was decided to leave constant values of weights of the evaluated features. This decision was dictated by the fact that different buildings could be compared later and by the introduction of the star classification for residential buildings, discussed in the next chapter.

## 6. Indicator of the social quality of the building

In the presented method, the calculation of the aggregation assessment is carried out in parallel for two objects:

- for the building under consideration, the assessment at time $t$ (6.1)

$$\boldsymbol{O_D}(t) = \sum_{i=1}^{6} \boldsymbol{O}_C^i \cdot \boldsymbol{L}_C^i \tag{6.1}$$

- and analogously for the reference object (6.2).

$$\boldsymbol{O_R}(t) = \sum_{i=1}^{6} \boldsymbol{O}_C^{iR} \cdot \boldsymbol{L}_C^i \tag{6.2}$$

Then, both scalar quantities are compared with each other by calculating the difference $\Delta_{\boldsymbol{R+D}}(t)$ between the social usable value of the reference building and the social usable (real) value of the building in the examined time $t$. The difference, and then the quotient of the difference of the social evaluation of the examined object to the social usable value of the reference object is:

$$\Delta_{\boldsymbol{R+D}}(t) = \boldsymbol{O_R}(t) - \boldsymbol{O_D}(t) \tag{6.3}$$

$$\delta = \frac{\Delta_{\boldsymbol{R+D}}(t)}{\boldsymbol{O_R}(t)} \cdot 100\% \tag{6.4}$$

where:

$\boldsymbol{O_R}(t)$ – the social utility value of the reference building in time $t$,

$\boldsymbol{O_D}(t)$ – social usable value of the analyzed building in time $t$.

The discrepancy between the assessment of the residential facility under consideration and the reference facility is finally expressed in percentage scale. The discrepancy presented in formula (6.4) shows the degree of social adaptability of the analyzed object (the degree to which the object meets the social properties listed in the previous chapters) – called in the paper **the social quality index**.

The result is interpreted by meeting the limits of degrees of the social utility properties of the analyzed building. In the work, the boundaries were interpreted in the form of hotel stars (indicative of the standard and facilities), which allows the classification of residential buildings due to their social standard – Table 2. The author believes that such a way of assessment could in the future support the process of estimating the value of real estate during its sale or rent.

Table 2 Proposed classification of the building/apartment on the basis of its social characteristics

| Building rating (number of stars) | The degree of fulfillment of social properties $\delta = \frac{\Delta_{\boldsymbol{R+D}}(t)}{\boldsymbol{O_R}(t)} \cdot 100\%$ |
|---|---|
| 5 | [1] $\Delta_{\boldsymbol{R+D}}(t) < 0$ |
| 4 | $0{,}0\% \leq \delta < 20\%$ |
| 3 | $20\% \leq \delta < 40\%$ |
| 2 | $40\% \leq \delta < 60\%$ |
| 1 | $\delta \geq 60\%$ |

[1] is expressed by the formula $\Delta_{\boldsymbol{R+D}}(t) = \boldsymbol{O_R}(t) - \boldsymbol{O_D}(t)$

Additionally, a low level of social properties (1 or 2 stars) may also be an indication for renovation or refurbishment in order to increase the value of the property. A detailed social assessment (Fig. 4) allows to easily indicate the least-rated features of a building and take appropriate steps to eliminate them.

In order to simplify the assessment, a computer application called **SocBuilding** has been developed. The application is available on the Internet server – https://socbud-8b0b6.firebaseapp.com/dashboard, which allows the user to comfortably use it without the need to install any software.

## 7. Example of application of the social assessment method

In the process of verification of the developed method, a comprehensive social assessment of a selected residential building was carried out. A multi-family residential building located in one of Cracow's housing estates has been assessed. The building was constructed in mixed technology: ceilings between storeys, basement walls and pillars on each floor are monolithic, the interior brick walls are made of silicate blocks, external walls are three-layer. Building dimensions: $53{,}10 \times 15{,}45 \times 10{,}60\ m^3$. The housing estate was erected in the years from 2006 to 2008 and altogether consists of nineteen residential blocks (4 types of projects), including 8 buildings according to the same project, one of which is the object under study. The building is triple-staircase, three-storey and basement. It has 24 apartments of various sizes (mostly 3 – rooms), most of the apartments have a balcony, terrace or garden. In the basement storey there are 13 parking spaces for cars and the same number of storage areas. The building is supplied with heat from its own boiler room located in the basement, fired with natural gas from the municipal network. The estate is located on the outskirts of Cracow, is fenced and has an internal road infrastructure and parking spaces for cars on its premises. The estate also includes a playground, walking paths and a private kindergarten. At a distance of about 700 meters from the borders of the estate there is the southern beltway of Krakow – the section between the Zakopiański and Skawiński junctions.

In order to assess the social performance of the building, a site visit was carried out and the necessary information about the building and its surroundings was collected from the residents. The data obtained was assessed according to appropriately selected evaluation scales and assigned corresponding values. Taking into account the importance of individual criteria, subcategories and categories, ratings indicators for each subcategory and category were calculated. The final stage of the full aggregation of assessments was the determination of the adjusted sum index ($\boldsymbol{O_D}$) for the values of the assessment vector obtained in the previous calculations.

$$O_D = 3{,}744 \cdot 0{,}155 + 3{,}632 \cdot 0{,}194 + 3{,}368 \cdot 0{,}215 + 3{,}599 \cdot 0{,}136 + 3{,}898 \cdot 0{,}136 + 3{,}526 \cdot 0{,}163 = 3{,}604$$

This result should be compared to the evaluation of a reference object whose calculations gave an $O_R$ value of 4,2. The obtained scalar values were inserted into the formulae (6.3)–(6.4) obtaining the following result:

$$\Delta_{\boldsymbol{R+D}}(t) = 4{,}20\,0 - 3{,}604 = 0{,}596$$

$$\delta = \frac{0{,}596}{4{,}200} \cdot 100\% = 14{,}2\%$$

The result obtained corresponds to grade 4 (see Table 2).

Using the developed computer program (Fig. 4), the results of the evaluation of the residential building, in which the grade $O_c = 3{,}604$ was obtained, are presented, in comparison to the reference building with the grade: $O_R = 4{,}2$ gives a social quality index value of $\delta = 14{,}2\%$. This result classifies the building as grade 4 in the classification shown in Table 2. In program windows, the results of partial evaluations for all categories (Fig. 4) and subcategories are also visible, which clearly informs the user about the degree to which the requirements contained in them have been met.

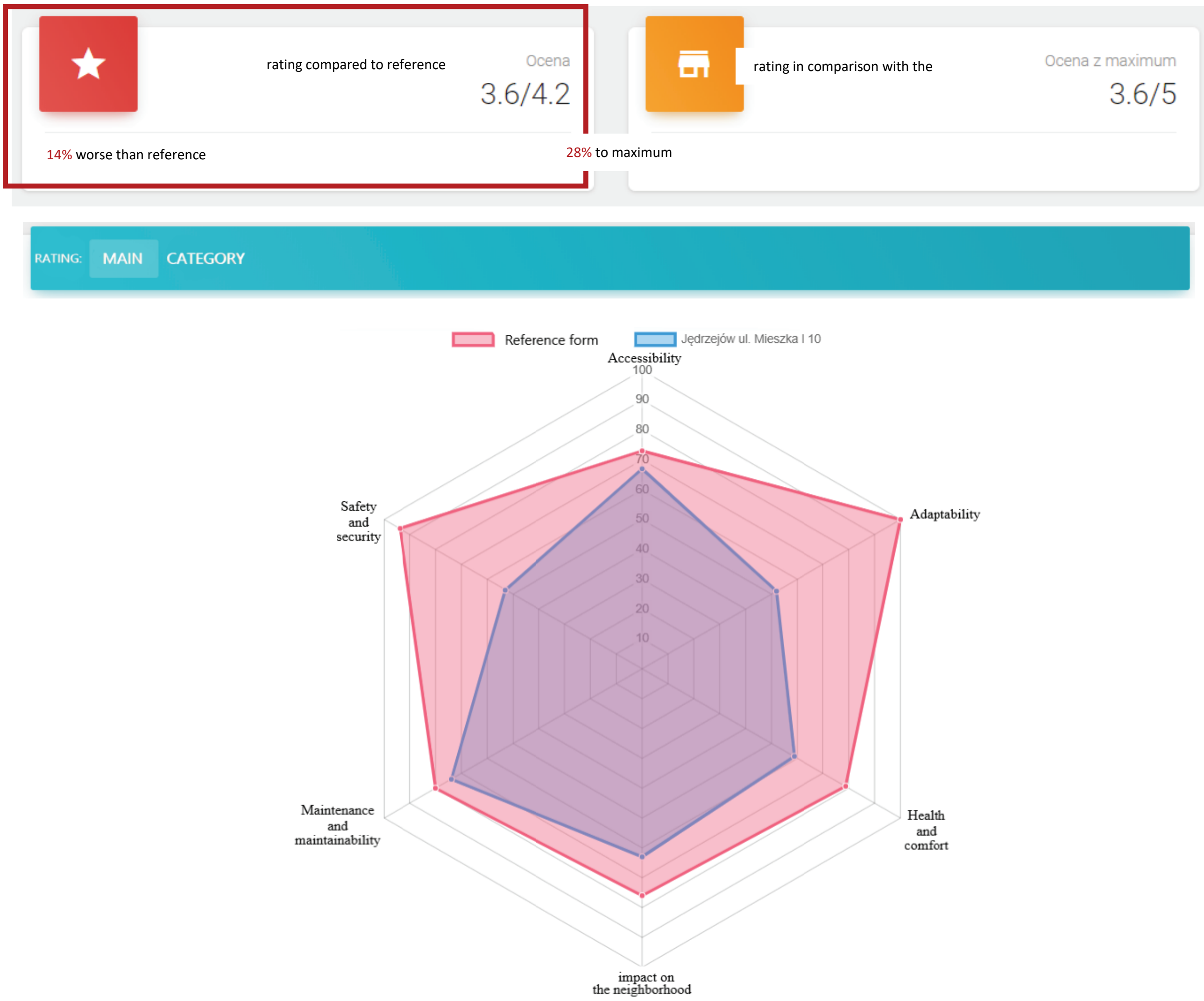



Fig. 4 Example evaluation results sheet for the SocBuilding application

## 8. Summary

The presented method is an aid in the assessment of the property and indicates the manager / owner about the need and scope of refurbishment of the building and functional solutions inside, especially regarding the needs of the residents.

The progressive difference between the degree of fulfilment of the social utility properties of a building and the legal, standard and user requirements during the operation of the facility is a permanent and natural process. Lack of theoretical models allowing to determine the utility value of the social aspect and a forecast of the behavior of the object in the future causes that the condition of buildings is assessed primarily on the basis of visual sensations, as well as conclusions from periodic technical inspections. In addition, due to the lack of an in-depth analysis of the social utility properties of a building, actions that do not improve the comfort of its use are often taken.

The proposed method for assessing the social performance of residential buildings was aimed at systematizing the knowledge related to the characteristics of this aspect. The scope of the evaluation method is very wide and depending on the purpose, it can be used as:

A. Help in the decision-making process:

- a comparison of the social functionalities of the different design options,
- a comparison of the social functionality of the planned refurbishment, reconstruction and/or construction of new buildings,
- the identification of the potential for improvement in social effectiveness,
- to be part of an assessment of *the sustainability* of buildings using LCA methods.

B. Documentation of the results of social functionality in building assessment in::

- certification,
- a statement about a social functionality,
- marketing,
- supporting the development of a sustainable development policy.

In particular, the proposed method has a practical application in the following activities in the management of building real estate::

- supporting the decision making process in the further exploitation of the object,
- assisting the manager (owner) in deciding whether a facility is eligible for renovation, refurbishment or demolition,
- the proper use of funds from the renovation funds for property managers,
- to determine the order and scope of the renovation of individual buildings,
- assisting in the process of determining the market value of the building,
- using the created application as a tool to support the work of real estate offices during the valuation of buildings,
- classification of objects (5-star scale) due to the degree of fulfillment of social utility properties, which in the future may be one of the criteria for choosing the purchase of a flat.

It is also possible to develop the presented method by e.g.:

- analysis of many objects and creation of a database based on them, which will serve to construct a self-learning model. A model based on e.g. neural networks may be another way of obtaining a comprehensive social rating,
- extending the model's capabilities by using BIM[3] to create multiple design options, which will allow to introduce functions that will enable more detailed planning of the directions of renovation and refurbishment of used residential buildings,

[3] BIM – Building Information Modeling.

– using BIM to model 'ideal' building variants for the social aspect of sustainable construction,
– developing assessment models for the two remaining aspects of sustainable construction (environmental and economic) in order to formulate a comprehensive assessment of *the sustainability* of residential buildings.

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## Ocena socjalnych właściwości użytkowych budynków mieszkalnych

**Słowa kluczowe:** budynki mieszkalne, zrównoważoność budynku, metoda oceny, model matematyczny, wskaźnik jakości socjalnej

### Streszczenie:

W artykule przedstawiono metodę oceny jednego z trzech podstawowych aspektów budownictwa zrównoważonego dotyczącą socjalnych właściwości użytkowych budynków mieszkalnych. Opracowanie powstało w oparciu o zalecenia norm (PN-EN 15643-3 2012) i (PN-EN 16309+A1: 2014 2014), na których podstawie określono obszar cech charakteryzujących aspekt socjalny w budynkach. Dodatkowo uwzględniono kryteria, które są niezbędne przy ocenie tego aspektu, jednak nie zostały one zawarte w wytycznych normowych.

Przeprowadzone zostały badania za pomocą następujących metod: bezpośrednie badania ankietowe użytkowników mieszkań i ekspertów w zakresie budownictwa, badania in situ, przegląd i analiza przepisów prawnych i wytycznych normowych oraz literatury związanej z utrzymaniem i oceną obiektów. Wyznaczone, w wyniku przeprowadzonych badań, cechy pozwalające na przeprowadzenie oceny socjalnej budynków pogrupowano w sześć kategorii głównych tj. dostępność, adaptacyjność, zdrowie i komfort, wpływ na sąsiedztwo, utrzymanie i konserwacja oraz bezpieczeństwo i ochrona. W oparciu o przeprowadzone badania wyznaczono również charakter i sposób oceny poszczególnych wartości cech, które następnie przyjęto, jako kryteria w analizie wielokryterialnej oceny socjalnej budynków.

Określenie miar poszczególnych składników oceny wymagało złożonych ustaleń bazowych, które w międzynarodowych normach określono jedynie w sposób ogólny. Koniecznym było opracowanie wskaźników wyrażających przyjęte kryteria oceny dla poszczególnych kategorii. Ustalono sposoby kodowania miar cech wyrażanych w postaci jakościowej do postaci ilościowej. Dla kryteriów wyrażonych w wartościach mianowanych, podano sposób ich przetworzenia do wartości niemianowanych. Pozwoliło to na ujednolicenie skali ocen cząstkowych. Na koniec ustalono sposoby agregacji ocen. Efektem finalnym był również opracowany program komputerowy dostępny na stronie internetowej pozwalający na sprawne przeprowadzenie oceny.

Prezentowana metoda wpisuje się w aktualny trend budownictwa zrównoważonego. Metoda ta umożliwia i ułatwia porównanie socjalnych właściwości użytkowych w różnych budynkach mieszkalnych. Pozwala również na klasyfikację budynków ze względu na stopień spełnienia przez nie socjalnych właściwości użytkowych, co może stanowić praktyczne narzędzie wspomagające decyzję dotyczącą dalszych losów budynku (tj. kolejności niezbędnych remontów) lub decyzję o zakupie bądź sprzedaży nieruchomości poprzez wskazanie jej słabych i mocnych stron.

Dzięki opracowaniu sposobu oceny kompleksowego zestawu kryteriów proponowana metoda pozwala w łatwy i szybki sposób ocenić jakość socjalną budynków mieszkalnych. Ponadto proponowane miary poszczególnych ocen mogą być w łatwy sposób adaptowane do prawnych wymogów obowiązujących w innych krajach. Proponowana „gwiazdkowa" klasyfikacja może również posłużyć jako uniwersalna skala do oceny wskaźnika jakości socjalnej budynków.

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