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Review

Creating Sustainable Buildings: Structural Design Based on the Criterion of Social Benefits for Building Users

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Abstract: Sustainable building involves reducing negative environmental impacts with a simultaneous increase in life quality. The aim is to optimize building performances while considering all aspects of sustainability: environmental, economic, and social. The building structure determines the building's performances, and it should be designed and evaluated as a subsystem of the building, in line with the objectives of the system–building. This paper investigates structural design based on integrated design objectives within the criterion of social benefits for users throughout the use phase of the building, focusing on protection and safety, aspects of comfort, spatial organization, spatial adaptability, and maintenance. The problem was studied using integrative literature review methodology and system theory. The main findings of the research are a review and critical analysis of the representative literature and the derived conceptual framework for structural design based on the criterion of social benefits for building users, which should support more comprehensive and more efficient decision-making during systemic design and optimization of buildings. The presented integrated literature review indicates the need for the application of a systemic approach to structural design in order to create sustainable buildings.

Keywords: sustainable building; integrated design; structural design; social benefits; socially-based criteria for structural design

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1. Introduction

Sustainable development implies balanced goals of socio-economic development and environmental protection, with a focus on life quality. One of the key strategies for raising the level of sustainability involves reducing negative environmental impacts due to the construction, use, and deconstruction of built capacities, with a simultaneous increase in life quality [1]. Life quality can be interpreted as a relation between an individual and their living environment [2], where the living environment is considered as a complex natural, built, social, cultural, economic, political-administrative, and legal environment, i.e., a unique system of interconnected factors surrounding the human.

This research focuses on the principles of design and evaluation of buildings and their subsystems, considering that design is the underlying problem of human-environment relations and changes in those relations [3], especially bearing in mind that 80% of the influence of the built capacities on the environment is determined in the design phase [4]. "In many ways, the environmental crisis is a design crisis. It is a consequence of how things are made, buildings are constructed, and landscapes are used." [5] (p. 24).

Spatial design based on the principles of sustainable development requires a qualitatively new approach to building design, i.e., integrated design approach based on a systemic analysis of social, economic, and environmental aspects [6]. The reductionistic approach to building design, based on a limited number of criteria and a linear approach, is replaced by a holistic one, while accepting the complexities of architecture and its systems. The aim is to optimize building performances in line with integrated design objectives.

Structural design within the integrated building design approach aims to improve the overall performances of a building as a whole. In this process, the load-bearing structure is created on the basis of a series of parameters concerning the building's sustainability. In that context, the notion of optimal behaviour of building structure, i.e., of its optimal performances, is changing [7]. The building structure cannot be understood and thus evaluated without comprehending its relation to a specific function of architectural space.

Some studies have dealt with the topic of sustainable structural design, but they are predominantly related to environmental and economic issues, neglecting social sustainability [8–15]. When it comes to social sustainability, recognized as a fundamental component of sustainability [16], which concerns the creation of "places that promote wellbeing, by understanding what people need from the places" [17] (p. 16), most research to date is related to issues of creating socially sustainable cities, towns, and communities [17–19], i.e., socially sustainable urban development. Some research deals with the social aspect of sustainability in the construction sector [20–24], but a small number look at the subject in an architectural context [25–28]. Given the above, recognizing the importance of a people-centric sustainable built environment, and the lack of research on the subject, the European Commission highlights one of the key objectives to be achieved before 2030, named "Built for and with the people" [29] (p. 50), which concern, among other issues, "achieving specific outcomes for the users in terms of functionality, comfort, convenience, accessibility, health, wellbeing" [29] (p. 14). This objective is closely related to building design, and thus to structural design.

Despite the recognized importance of social sustainability, to the best of the author's knowledge, there is little research related to structural design in this context, especially those who apply a systemic approach and who comprehensively deal with the topic. Having the above in mind, this paper represents the analysis of structural design in line with integrated design objectives within the criteria of social benefits for users through the use phase of the building. The analysis was conducted through an integrative literature review focusing on structural design based on users' needs to review, critique, and synthetize representative publications on the topic in an integrated way, such that a new conceptual framework and perspective can be generated.

The literature review was guided by the research question: According to which principles should building structures be designed in order to achieve social benefits for building users? To answer this question, the research is focused on comprehending the behaviour of building subsystem-building structure directed towards achieving the goal of a system-building—social quality. The primary research aim is to establish the structural design principles in line with integrated design objectives derived from indicators of ecological quality [30], within the criterion of social benefits for users throughout the use phase of the building. Furthermore, the goal is to express these principles through the criteria for integrated design and assessment of the building structures harmonized with the quantitative and qualitative indicators of social benefits to enable their application in architectural practice. The research relates to the issue of the development of sustainable building solutions, but also to the contribution to the methodology of the basic field of research—architecture.

2. Materials and Methods

This integrated literature review identifies design strategies and derives and presents a conceptual framework for systemic design and optimization of building structures aimed at improving building performances in line with the integrated design objectives within the criterion of social benefits for building users. An integrative literature review is a distinctive form of research that "reviews, critiques, and synthesizes representative literature on a topic in an integrated way such that new frameworks and perspective on the topic can be generated" [31] (p. 356). This type of literature review was chosen because research focuses the emerging topic, which requires a more creative collection of data, as the goal is not to cover all published works on the topic but rather to combine insights from different fields [32]. Another benefit of using this methodology is that it facilitates learning more about the phenomenon and understanding changes in trends of a focused problem, especially when research emerges in different fields [31].

The data analysis part of an integrative literature review is not particularly developed according to a specific standard [33]. However, the general aim is to critically analyse the literature and the main ideas and relationships of an issue [32]. The existing literature on sustainable building and structural design, focusing on social benefits for building users, was searched. The following keywords were used to search the literature: sustainable building, integrated design, structural design, wellbeing, safety and security, thermal comfort, air comfort, acoustic comfort, visual comfort, spatial organization, functional adaptability, and building maintenance. The literature search was conducted in two main databases: Web of Science and Google Scholar. A total of 131 references relevant to the problem was included in the study. Publication formats are journals, conference proceedings, books, chapters in the books, reports, and standards.

The conceptual structuring of the topic was based on system theory as a guiding theory [34], in order to organize the review in a coherent conceptual way [31], and to critically analyse selected data to comprehend the behaviour of a building structure as a subsystem that contributes to the quality of a system—the building as a whole. Moreover, it is a methodological approach that enables scientific shaping of the problem of the whole system, which is a building in the case of this research.

The principles within the applied systemic approach are:

- mutual connection and dependence of a building's subsystem;
- behaviour of subsystem-building structure relating to achieving the goal of system-building—social quality;
- observation of the subsystem-building structure within the process of the functioning of the system-building;
- belonging of the system-building itself, as a subsystem, to a higher-level system;
- system-building's interaction with the environment.

In order to build, refine, and organize the body of knowledge, i.e., to explore and reveal the theoretical basis of the said methodological concept of structural design that focuses on how to create buildings as complex systems which successfully perform their function over their life cycle [35], the systems thinking principles are applied. In recent decades, systems thinking, as an investigative methodology related to the conceptualization of functional systems, is replacing the previously dominant approach of reductionism [36]. This way of thinking is aimed at understanding systems, predicting their behaviours, and devising their modifications in order to produce desired effects [37]. It enables a deeper understanding of phenomena through seeing interrelationships rather than things [38]. In systems thinking, functional systems are not only technological systems but are also complex systems of people and technology. They are interdependent on other systems and subsystems, spanning sociological, cultural, political, and economic domains [39]. Systems thinking is also the art of simplifying complexity [40] through considering parts of a system problem while not losing sight of the whole [41].

Figure 1 shows a visual model of systems thinking as a global research methodology applied in this research, along with the research methods in individual research steps:

In order to discover the issues and to search for trends, i.e., to answer the question "What has been happening with the structural design in the context of social sustainability?" a literature review and a critical analysis of bibliographic sources as research methods were applied. These methods were applied to reveal the relevance of the research and establish the research gaps related to structural design in the context of social sustainability. During the search for key causes, i.e., methodological or interpretational constraints that impede progress in the field, the focus question that stimulated future research was developed "According to which principles should building structures be designed in order to achieve social benefits for building users?" The above question arose from the question "Why is the reductionist and prescriptive approach to structural design no longer satisfactory?"

This question has directed research towards the identification of new goals of structural design, for which critical analysis of bibliographic sources and systems analysis as research methods were applied. These methods were also applied to answer the question "How structural design can be improved in the context of social sustainability?" This involved searching deeper into the problem and developing deeper questions. Searching deeper involved managing complexity through considering parts of a system problem while not losing sight of the whole. In that context, in this research, bounded concerns were considered, related to structural design in the context of safety and security, aspects of comfort, spatial organization, spatial adaptability, and maintenance, ensuring that one of the selected issues is the concern of the system-building as a whole. Identification of design strategies and derivation of structural design criteria, based on the understanding of the goal of the system-building—social quality, implied systems analysis and systems synthesis as research methods.

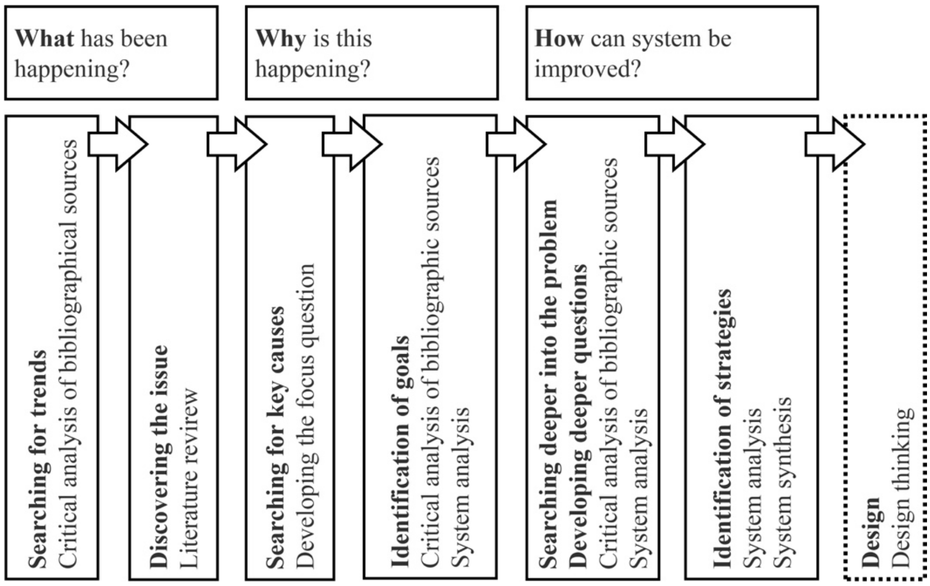

Figure 1. Visual model of system thinking applied in this research.

3. Results

3.1. Criterion of Social Benefits for Buildings Users

The concept of sustainable development involves a social dimension. Yet, for two decades, environmental and economic issues have taken precedence. The approach which neglected social sustainability failed to generate meaningful change [42]. Today, the humane dimension of sustainability is recognized as fundamental [16]. However, the main problem with social sustainability is that there is little consensus as to what it is or how it could be applied [43], especially because of its qualitative nature [44]. When it comes to the social sustainability of the built environment, the key objective concerns "achieving specific outcomes for the users in terms of functionality, comfort, convenience, accessibility, health, wellbeing" [29] (p. 14). The aim is to create "places that promote wellbeing, by understanding what people need from the places" [17] (p. 16). Wellbeing implies ecological quality based on a balanced relationship between people and their environment, i.e., ecological balance. Within this research, the ecological quality of the building, that is taken as the system boundary, is defined as "the extent to which building performances meet the needs and expectations of its users, related to social and economic benefits achieved with simultaneous protection and improvement of the environment throughout the life-cycle of the building" [30] (p. 22). The goal is to create buildings as functional systems. i.e., to create architectural spaces that contribute to users' life quality and satisfaction by preserving their health and encouraging a sense of security, comfort, and harmony with the environment. This goal is becoming increasingly important, bearing in mind that buildings' economic value is also based on user's needs and the ability of building to enable their satisfaction. Economic value is actually the judgment that people make about the importance of the building for maintaining their life and wellbeing [45]. Clients are interested in buildings that can meet their needs to a greater extent, i.e., improve the quality of their activities while reducing the operating and maintenance costs [46]. The above indicates the basic role of buildings, which today, in management theory, are primarily seen as "enablers" that can facilitate processes but also contribute to the opposite [47]. Research shows that architectural spaces, thanks to their qualities, can enhance employee productivity, improve the learning process, or contribute to the faster healing of patients [48–50].

Bearing in mind the above, building social quality assessment must not be reduced to the evaluation of quantitative performances [51]. The need for qualification, not just quantification of the social performances of buildings as functional systems, is also recognized in building sustainability assessment systems that deal with added value [52]. The BREEAM (Building Research Establishment Environmental Assessment Method) sustainability assessment method (Watford, UK) includes an indicator which focuses on the impact of a building on the wellbeing of its occupants. The DGNB (German Sustainable Building Council) method (Stuttgart, Germany) considers qualitative sociocultural and functional criteria related to a building's utility value. In this context, based on the analysis of the European standard for assessment of the social performance of buildings [53], the main academic studies dealing with building performance evaluation [52], and European sustainability assessment systems that address social sustainability in a more encompassing way, BREEEAM and DGNB indicators related to social benefits for users throughout the use phase of the building are proposed [30]. Furthermore, this literature review includes representative references that confirm the relevance of these indicators in the context of their relationship with the social aspects of sustainability, that is, their importance for users' health and wellbeing. As such, these indicators are the basis for architectural design quality assessment by assessing the level of quantitative and qualitative performances, but they are also the basis for defining integrated design objectives [30]. In this paper, bearing in mind its thematic framework, the indicators that are primarily analysed concern the load-bearing structure as a subsystem of the building. Based on the above, the review and the critical analysis of the representative literature are conducted focusing on the following aspects: protection and safety, comfort, effective spatial organization, spatial adaptability, and maintenance efficiency.

3.2. Critical Analysis of Structural Design Based on the Criterion of Social Benefits for Buildings Users

3.2.1. Safety and Security during Extreme Events

The building should have the capacity to resist projected current and future loadings. Additionally, it should have the ability to maintain its function in the case of natural or man-made extreme events [54]. The aim is to provide objective safety and security for users by reducing the degree of damage in case of foreseen and unforeseen events.

In general, a building structure must be designed to resist the loads to which it may be exposed to during the life cycle of the building. Minimum requirements for loads resulting from winds, snow, earthquakes, and explosions specified in codes must be met. However, a reserve in the estimated loads should exist in the case of environmental loads, given that, due to climate change, some loads, such as wind, snow, and temperature, have become unpredictable [55]. Given that a methodology that simultaneously considers prescribed and abnormal loads is still not developed enough, it is necessary to ensure the robustness of the structure, which reduces the possibility of disproportionate collapse due to initial damage in case of unforeseen events [54,56,57]. The robustness of the structure is primarily based on ductility, continuity, and redundancy [58]. It should be kept in mind that most structural failures result from defects of connections between structural elements. These connections should be strong as the parts that are connected, thus ensuring robustness against unforeseen actions [59].

The specific safety aspect relates to the earthquake resistance of buildings. Analyses show that most existing buildings in Europe are highly vulnerable to earthquakes [60]. The seismic risk keeps increasing given that basic principles of earthquake-resistant design are often not followed in the case of new buildings [61]. Next to the size of the building, the shape of the building is a fundamental parameter that controls its behaviour in the event of an earthquake [62]. Symmetrical and compact forms are favourable to reduce the torsion of a building, i.e., to avoid unpredictable stress concentrations, which can cause local collapse and modification of dynamic behaviour. Additionally, it is necessary to provide more direct load paths within the structure, as well as more even stress distribution. The previous implies the avoidance of structural irregularities in the vertical and horizontal direction, i.e., variations in the structural system, strength, stiffness, and mass. The above is particularly significant because it has been shown that structural irregularities affect a building's performance during an earthquake. They can lead to a reduction in collapse safety and to greater damage [63]. Additionally, one specific problem is that analysis methods often cannot accurately predict the mechanical behaviour of an irregular structure, leading to inadequate design [64]. In addition to the above, the essential characteristics of seismically resistant structures are ductility, deformability, and damageability, which allow the structure to deform without collapse, sustaining damage [65].

The building structure should be made of elements that meet the prescribed fire resistance, i.e., preserve load-bearing capacity, stability, integrity (without cracks, to prevent gas penetration), and thermal insulation properties (in the case of surface structural elements) during a certain required time. These criteria may be required individually or in combination [66]. An approach based on the testing and analysis of the fire resistance of individual structural elements gives results good enough for standard and simple structures. However, this approach can give an inaccurate picture of the fire resistance of the whole structure, especially in the case of non-standard and complex assemblies [67]. Given that the static system largely conditions mechanical resistance of the structure in the event of a fire, one of the key passive fire safety measures is to ensure the redundancy of the structure [68].

Undesirable displacements of building structure can be a consequence of the shrinking and swelling of materials due to changes in relative humidity and temperature in the environment, and also as a consequence of material creep. In the case of mid-rise wood-frame construction, given that it is difficult to predict this displacement accurately, it is suggested that a good margin of safety should be added in the design to avoid potential adverse consequences [69], i.e., to prevent unwanted geometric effects.

3.2.2. Thermal Comfort

Thermal comfort refers to satisfaction with the thermal environment. The importance of thermal comfort is indicated by studies that show that the thermal environment has a significant impact on the health and productivity of building users [70]. Given that each person experiences thermal conditions differently, the aim is to provide average, optimal thermal comfort conditions in accordance with the function of architectural space. Thermal comfort indicators related to building structure are air temperature, mean radiant temperature, and relative air humidity.

Adequate building structure solution can contribute to thermal comfort while reducing energy consumption for heating and cooling. In this sense, building structure solutions should be conditioned by climatic factors. The aim is to minimize temperature fluctuations in interior spaces. Therefore, it is necessary to provide adequate thermal resistance of the structure while minimizing thermal bridges [71]. Additionally, it is necessary to achieve sufficient airtightness of assembly, i.e., reduction of air leaking [72]. When it comes to air leakage, non-monolithic structural assemblies are more sensitive, especially those made of materials that are sensitive to the effects of wetting and drying in terms of dimensional stability. Thermal comfort can be enhanced by the appropriately applied thermal mass of exposed structural elements [73]. In temperate climate areas, during the summer day, exposed structural elements cooled during the night (naturally or forcedly) can have a lower temperature to the interior air temperature and can contribute to the cooling effect [74]. On the other hand, during the winter day, the heated structure can have a higher temperature than the interior air temperature and thus contribute to the effect of heating, i.e., feeling of comfort. The thermal properties of materials from which building structure is made affect the mean radiant temperature, which is an important element of thermal comfort [75]. The sense of comfort in the interior spaces is also affected by the ratio of air temperature and air humidity. The applied structural materials will influence interior air humidity, i.e., their hygroscopic properties [76]. Steel structures do not participate in the regulation of interior air humidity. On the other hand, wood and concrete can absorb moisture from the air and dissipate it, thus contributing to air humidity regulation proportionally to the degree of absorption [77]. It should be kept in mind that equally significant wetting and drying process of the structure can be disrupted in the case of highly insulated buildings, thereby increasing the risk of the occurrence of condensation and the damage caused by wetting [78].

3.2.3. Air Comfort

Air comfort refers to conditions that provide the required amount of clean air, i.e., indoor air quality, which is without risk to the health of the building users. The air quality affects the health of users and their ability to perform activities [79]. The aim is to provide the required amount of fresh air to minimize chemical air pollutants and radiation and the presence of microbes, particles, and microfibers. Additionally, the aim is to minimize the presence of unpleasant odours.

The indoor air quality will be affected by the possibility of changing the air through the building envelope. If structural materials in the façade zone are air permeable, higher air quality will be achieved [80]. Additionally, in this way, the possibility of excessive wetting of walls and mould occurrence will be reduced. The risk of mould occurrence, which is a serious concern for indoor air quality, is higher in thermal bridge zones [81]. Additionally, sensitive places are structural element joints that slacken due to the effects of various loads, which allows the penetration of moisture and the development of mould [82]. Particularly sensitive are modern assemblies with an increased amount of insulation that dry more slowly, in whom the risk of condensation and mould growth is increased [83]. The building structure has been indicated as one of the major reasons for the elevated volatile organic compound (VOC) concentration in buildings [84], with possible negative health effects. These emissions can predominantly be related to thermal insulation materials within the building structure, stay in place formwork for concrete structures, wood-based structural elements, pigments and coatings for concrete, and wood and steel preservatives. Therefore, when it comes to indoor air quality, the application of low-emission materials and products is advised [85]. In the context of the above, besides the required performance characteristics, construction material selection should consider the possible presence of dangerous substances [53,86] relevant to indoor air quality.

3.2.4. Acoustic Comfort

The acoustic environment in the interior space results from the sound coming from different sources. Sound sources can be related to the exterior environment, installed building systems, and user's speech and activities. The aim is to reduce or eliminate unwanted sounds, i.e., noise, and achieve the appropriate level and quality of wanted sounds, minimize negative effects on user's health, and increase the feeling of comfort [87,88].

It is necessary to control the noise on the transmission paths by using acoustically efficient materials and assemblies that enable better sound control, i.e., adequate insulation from the airborne and impact sound. The main acoustic condition for partitions refers to the minimum values of their insulation properties that must be achieved in individual positions in the building, according to users' activities that dictate the conditions that should be satisfied [53,89,90]. The value of sound reduction indices and impact sound insulation level depend on the physical properties of partitions: the surface mass and complexity of its internal structure [91]. Instead of increasing the surface mass, sound insulation improvement can be effectively achieved by forming discontinuities in the partition internal structure. This can be achieved by forming sandwich structures consisting of two or more layers of solid material between which there is a layer of air or porous absorption material [92]. When it comes to insulation from impact sound, contemporary floor structures usually imply additional layers of floor or ceiling to ensure adequate acoustic performances [93,94]. However, when it comes to prefabricated systems, especially those made of elements of small surface mass, the degree of sound insulation between two rooms cannot be determined only based on the insulating properties of individual partitions. In such systems, flanking transmission, or indirect transmission of airborne and impact sound, which refers to the transmission of sound vibrations mainly through the connections of structural elements, can be dominant [95]. When it comes to the quality of wanted sounds, i.e., sound quality in accordance with a space's function, it is necessary to apply materials with adequate acoustic performances, within assemblies with adequate shape and arrangement of spatial elements, given that emitted sound is altered by architectural space due to sound reflection, absorption, and diffusion phenomena occurring over its surfaces [96].

3.2.5. Visual Comfort

Light is essential for perceiving space, shapes, colours, and textures, and understanding the arrangement of spatial elements. The role of light in architectural spaces is related to three domains: health, safety, and the experience of space [97,98]. Visual comfort involves the following: the required amount of natural light, with simultaneous control of direct sunlight; sufficient surface illumination level, according to specific visual tasks and spatial uniformity of illumination; glare control; and lighting performances in accordance with the space's function.

The type of load-bearing structure affects the possibility of forming openings, that is, conceptualizing their position, size, and shape, which are related to daylighting [99] and overall lighting quality. Additionally, applied materials within the exposed building structure, which are characterized by a specific structure, colour, and texture, and thus by a certain degree of reflection, as well as shape and arrangement of exposed structural elements, contribute to the quality of lighting, affecting the light distribution, intensity, and colour [100,101].

3.2.6. Electromagnetic Radiation Protection

Long-term exposure to electromagnetic fields, especially fields with a frequency of 50–60 Hz, has harmful effects on the user's health [102]. Therefore, it is necessary to limit the exposure, i.e., the electric and magnetic field strength [103], especially in spaces where long-term and chronic exposure of users is expected. The aim is to minimize electromagnetic pollution by identifying sources and applying measures to limit their impacts.

Metal elements in building structure can shield a building against electromagnetic fields, but they can also increase the strength of electromagnetic fields in indoor spaces due to reflections and superposition of electromagnetic waves [77]. Furthermore, research indicates that highly reinforced concrete walls and floors can amplify the effects of electromagnetic radiation [104]. In the context of the above, it is necessary to understand the electromagnetic properties of building materials, i.e., transmission and reflection, in order to apply measures to effectively reduce electromagnetic field strength in indoor spaces [105].

3.2.7. Effective Spatial Organization

An important qualitative aspect related to the social benefits for building users, which concerns the added value, refers to the realization of the effective spatial organization of user's activities. Therefore, it is necessary to ensure spatial functionality [106,107], that is, undisturbed realization of planned activities, which implies meeting space standards and creating adequate relations and communication between individual spatial zones. In arranging these relations, it should be kept in mind that spatial organization is actually the organization of people's relations [108].

Structural form largely conditions the spatial organization of user's activities, that is, the functionality of architectural space. If the physical spaces, defined by structural form, do not coincide with the social ones, defined by the user's activities, the building will not be perceived as correct [109]. In that context, the aim is to achieve effective structural form for a given social space of the building. It is an approach to structural design based on careful harmonization of structural form with people and their needs [110].

3.2.8. Functional Adaptability

The user's needs that a building or its parts should meet change over time [111]. In that sense, an important precondition for extending the useful life of a building and maintaining its value is its capacity to accommodate change [112].

The applied building materials and constructive system solutions have a strong impact on a building's adaptability and, consequently, its resilience [113]. The realization of new activities is largely conditioned by building structure solutions. In order to enable changes in space function with a low level of resource consumption, it is necessary to form larger spans (from minimum 7.5 to 12 m) and higher floor-to-ceiling heights (minimum 2.7 m) [114–116]. A structural floor system should accommodate several mechanical and electrical service distribution schemes based on different space functions [117]. The structural concept should enable the easy subsequent formation of openings in interior bearing partitions and the façade zone. Additionally, the possibility of the simple realization of connections of new structural elements with the existing ones should be provided. There should be a reserve in the load-bearing capacity of building structures [118], primarily in the value of the live load, according to expected new functions, but also in relation to estimated building upgrades [112,118]. It is necessary to enable easy separation of elements that have a significantly different technical and economic lifespan. In that context, the connections of elements made with screws are more favourable than glued, welded, or casting in situ [119]. The physical separability of key building layers are as follows: building structure (average lifespan of over 50 years), installation systems (average lifespan approximately 15 years), and light internal partitions (average lifespan approximately 6 years), and these should be achieved with simultaneous integration on the functional level [120].

3.2.9. Building Maintenance Efficiency

Building maintenance refers to a series of activities aimed at ensuring the efficient functioning of a building and maintaining its value [121]. The aim is to provide maintenance efficiency during expected service life, which implies maximum effects with a minimum investment of human, material, and financial resources [122].

Building maintenance efficiency is related to the maintainability of its structure [53], which is conditioned by achieved reliability, durability, and accessibility for its maintenance, defined in the design phase [123]. The building structure should have a satisfactory level of reliability during the service life [124], during which it should suffer no or minimal damage, especially because structural repairs can be technically demanding and economically unsustainable [125]. The building structure should be designed for optimal durability, with regular maintenance, which corresponds to the average estimated service life for the intended function [126]. The building structure service life will depend on the degree of exposure to various environmental influences, quality of applied materials, applied protection measures, global conception and details, quality of construction work, and maintenance quality [123]. It is necessary to understand the physical and chemical properties of applied structural materials and the mechanisms of their deterioration (mechanical, climatic, chemical, biological) in the context of local environmental conditions [124]. In addition to adequate material selection and quality [122,127] and adequate protection measures, adequate details will provide greater protection of components from degradation factors [128]. The details should be designed to eliminate water accumulation on structural elements, which may occur because of rainwater penetration, condensation due to air leakage, condensation due to diffusion of water vapour, and installation leaks. It is necessary to minimize these effects primarily through the possibility of drying. In the context of the above, the use of partially hygroscopic materials which are not sensitive to moisture is favourable, in assemblies that allow drying [78]. It is necessary to provide easy access to all parts of the building structure, so that maintenance can be carried out [122]. It is necessary to provide easy repairs and easy replacement of damaged elements.

3.3. Conceptual Framework for Structural Design Based on the Criterion of Social Benefits for Building Users

After review and critical analysis of the representative literature, conducted with the aim of responding to the research question: "According to which principles should building structures be designed in order to achieve social benefits for building users?", a conceptual framework for structural design is derived. Based on the criteria of social benefits for building users, key quantitative and qualitative structural design criteria are synthesized and presented in a structured and systematic way. In order to manage complexity, bounded concerns were considered, ensuring that one selected issue is the concern of the system-building as a whole. Table 1 shows key socially-based structural design criteria in relation to the criteria of social benefits for building users: safety and security during extreme events, thermal, air, acoustic, and visual comfort, electromagnetic radiation protection, effective spatial organization, functional adaptability, and building maintenance efficiency.

Keeping in mind changes in the design paradigm, broadening the theoretical basis, and increasing in complexity, the given conceptual framework should enable more comprehensive and more efficient decision-making during systemic design and optimization of buildings within the interdisciplinary team that is working on the development of user-centric sustainable building concepts.

Table 1. Conceptual framework for structural design based on the criterion of social benefits for building users.

Criteria of Social Benefits for Building Users—Indicators [1,2,16–30,42–53]	**Socially-Based Criteria for Design and Assessment of Building Structures**
Safety and Security During Extreme Events [54]	[55–69]
- capacity of a building to resist projected loadings - ability of a building to maintain its function in the case of extreme events	• reserves in estimated loads • robustness of building structure—ductility, continuity, redundancy • reduction of building torsion—symmetrical and compact forms • more even stress distribution • more direct load paths • avoidance of structural irregularities in the vertical and horizontal direction, i.e., variations in the structural system, strength, and stiffness • mass reduction and uniform mass distribution • deformability and damageability of building structure—failure announcement • adequate design of connections between structural elements • application of structural elements that meet the prescribed fire resistance and thermal insulation properties • adequate measures to reduce the effects of shrinkage, swelling, and creep of structural materials

Table 1. *Cont.*

Criteria of Social Benefits for Building Users—Indicators [1,2,16–30,42–53]	**Socially-Based Criteria for Design and Assessment of Building Structures**
Thermal Comfort [70]	[71–78]
- air temperature - mean radiant temperature - relative air humidity	• adequate thermal resistance of building structure • minimization of thermal bridges—low framing factor • sufficient airtightness of assembly—adequate connection details and dimensional stability of structural materials • adequate thermal mass of building structure • adequate colours of exposed structural elements • adequate radiant temperature of surface structural elements • adequate hygroscopic properties of structural materials—the possibility of regulating the humidity of interior spaces, i.e., wetting and drying of the building structure
Air Comfort [79]	[80–86]
- quantity of fresh air - amount of chemical air pollutants - radiation level - presence of microbes - amount of particles and micro fibres - presence of unpleasant odour materials	• air permeable surface structural elements in the façade zone • elimination of occurrence of excessive moisture in façade zone and thus occurrence of mould ○ air permeable surface structural elements ○ details that minimize thermal bridging ○ adequate connections of structural elements • minimization of the presence of structural materials that release chemical air pollutants, radiation, particles, microfibers, and unpleasant odour
Acoustic Comfort [87,88]	[89–96]
- background/ambient noise level from external sources, installed - systems, human speech and activity (sound pressure level in space) - acoustic performances in accordance with space's function	• adequate sound reduction index of structural elements • adequate impact sound insulation level of structural elements • low structural flanking transmission, i.e., low indirect transmission of airborne and impact sound ○ adequate materialization of structural elements ○ adequate connection details • adequate acoustic performances of structural materials and assemblies ○ adequate materialization of structural elements ○ adequate shapes and disposition of structural elements
Visual Comfort [97,98]	[99–101]
- percentage of area under daylight - control of direct sunlight - illumination level - uniformity of illumination - glare control, direct or reflective - lighting performances in accordance with space's function	• possibility of forming openings—adequate sizes, shapes, and positions of openings within the building structure • adequate shape of structural elements • adequate structure, colour, and texture of materials of exposed • building structure
Electromagnetic Radiation Protection [102]	[103–105]
- electromagnetic field strength	• adequate electromagnetic properties of structural materials

Table 1. *Cont.*

Criteria of Social Benefits for Building Users—Indicators [1,2,16–30,42–53]	**Socially-Based Criteria for Design and Assessment of Building Structures**
Effective Spatial Organization [106,107]	[108–110]
- degree of realization of space standards - relations and communications between individual spatial zones	• effective structural form for a given social spaces of the building
Functional Adaptability [111,112]	[113–120]
- possibility of realization of various activities - possibility of different spatial arrangement and furnishing - adaptability of building systems - possibility of intervention in relation to solution of the building's envelope	• disposition of structural elements which enables change of space's function • structural concept that enables the easy subsequent formation of openings • reserve in the load-bearing capacity of the building structure • easy separation of key layers of the building—building structure, installations, and light internal partitions
Building Maintenance Efficiency [121,122]	[123–128]
- accessibility for maintenance - maintenance frequency - scope of maintenance work - maintenance method—type of work and work organization	• reliability and optimal durability of the building structure ○ known mechanisms of structural materials deterioration ○ adequate material quality and protection measures ○ adequate global structural concept and details ○ adequate method of construction and maintenance • accessibility for maintenance • low maintenance frequency • possibility of easy repair • possibility of easy replacement of damaged elements

4. Discussion and Conclusions

Sustainable building involves reducing negative environmental impact with a simultaneous increase in life quality [1]. In order to achieve these goals, a user-centric approach in building design should be applied [29]. It is a qualitatively new holistic approach to building design [6], i.e., an integrated design approach which gradually replaces the reductionistic one based on a limited number of criteria and a linear principle. The aim of an integrated design approach is to optimize building performances in accordance with integrated design objectives [30,51–53]. Within this approach, the structural design aims to improve the overall performances of a building as a whole. In this process, the building structure is created on the basis of a series of new interrelated parameters concerning the building's social sustainability.

A review of the literature showed that, despite the recognized importance of social sustainability, there is only a small amount of research related to structural design in this context, especially those that apply a systemic approach and deal with the topic comprehensively. Given the above, this research dealt with identifying strategies for structural design based on the criterion of social benefits for building users. The subject analysis of representative literature was performed in accordance with the research question: "According to which principles should building structures be designed in order to achieve social benefits for building users?" The identified strategies were the basis for deriving the conceptual framework for structural design to support the decision-making process related to systemic, integrated design and optimization of building structures. The following aspects of the social quality of buildings were analysed: safety and security, thermal comfort, air comfort, acoustic comfort, visual comfort, electromagnetic radiation protection, spatial organization, functional adaptability, and building maintenance. Within each aspect, a set of performance indicators were given. For every aspect and performance indicator, a critical analysis of representative literature was conducted. Based on the perceived problems, applied solutions, and examples of good practice, a set of criteria for the integrated design and evaluation of building structures, harmonized with quantitative and qualitative indicators of social benefits for building users, is synthetized and presented in a structured and systematic way.

The presented integrated literature review indicates the need for the application of a systemic approach, based on comprehending the possible forms of connections and dependencies of subsystems of the building, building structure, and structural materials, as well as from comprehending the behaviour of these subsystems directed towards achieving the goal of a system-building. It is a user-oriented performance-based approach to structural design that, in its practical operationalization, should provide design and assessment of buildings of various quantitative and qualitative properties, with a higher common property—social quality. This approach to structural design is based on the principle of contextuality, where each solution derives from its inherent set of parameters. Multiple influencing factors condition the building structure solution. In addition to integrated design objectives, which can be considered global, the outcomes will be affected by the conditions of the local environment and users' needs in a given time context [129]. It is a systemic approach to building design that requires systemic thinking and the continuous interaction of all participants in the design process, which implies interdisciplinarity and transdisciplinarity in order to explore complex interdependencies of multiple aspects from which, in a nonlinear, iterative process, ideas and concepts that enhance wellbeing emerge [130].

Bearing in mind the complex nature of a given form of structural design, based on multiple analyses of many aspects of social sustainability, further research related to the development of strategies for implementing this design concept in engineering practice is needed. In addition to improving the educational process and educational content [37,131], which should include systems thinking within an integrated systemic approach to building design, implementing the concept of user-oriented design in engineering practice implies further development of a legal framework and standards related to social sustainability. This is also emphasized by the European Commission, which insists on the development of a certification framework for healthiness and wellbeing of the built environment, "so that user-centric approaches become a reality" [29] (p. 14).

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