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Improving Quality and Sustainability Outcomes in Building Rehabilitation: Concepts, Tools, and a New Assessment Methodology

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Abstract

Pursuing quality and sustainability concerns in construction activities is not new. However, the construction sector continues to face criticism for the outcome of many interventions, and significant progress is still required to realise both objectives. This is particularly pressing in sectors essential for quality of life and wellbeing, such as housing, and in areas frequently neglected in research and practice, such as existing buildings. This paper provides insights into the assessment of quality and sustainability in existing buildings, clarifying these concerns, exploring their interrelationship, emphasising the critical role of the design phase, and synthesising relevant methodologies focused on each objective. Furthermore, a novel methodology is proposed to minimise the risk of poor quality in building rehabilitation processes. Methodologically, the paper includes a review of concepts associated with quality and sustainability in building rehabilitation, a synthesis of existing evaluation tools and methods, and the development of the proposed methodology. The main findings include a definition of construction quality, identification of strong correlations between quality and sustainability, and the recognition that using accessible, flexible, and collaborative tools during the design phase is crucial to achieving both objectives, especially in the context of existing buildings, where practical and operational outcomes remain limited.

Keywords: building rehabilitation; construction quality; housing sustainability; assessment methods

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1. Introduction, Objectives, and Research Methodology

Addressing quality concerns in the construction sector, especially in housing, is not new. Creating healthy and safe environments that acknowledge physical, social, and personal factors has been established as the key to quality of life and wellbeing of citizens [1,2]. Simultaneously, sustainability in the building sector has long been established as a common goal, entailing a set of well-established concerns, namely environmental, social, and economic ones, which must be tackled in all constructions, including existing buildings [3].

Despite these well-established ambitions, there is still a long way to go. Regarding building quality, the overall complexity of construction activities, characterised by long processes involving various stakeholders, frequently results in low-quality outcomes, verified on a global scale [4,5]. This is particularly relevant in more complex interventions, such as rehabilitation actions, where a lack of culture and practice surrounding the importance of adapted and qualified interventions in existing buildings prevails [6,7].

Furthermore, certain aspects impacting sustainability and development linked to quality of life and wellbeing, such as housing [2], remain highly unexplored and unacknowledged [8]. Moreover, the complex relationship between housing and sustainability and the indissociable synergies these concepts encompass have been confined to a few studies.

The need for a cultural shift towards quality and sustainability in the construction sector has been highlighted by several authors [9,10], particularly in the context of existing buildings [11,12]. Expanding the scope of these concerns has become a priority, along with promoting decision-support tools that encourage and evaluate these goals in construction activities, especially those focused on sustainability [13]. Addressing these issues at the right time, i.e., during the often-overlooked design phase, is crucial. This can be achieved through flexible, easy-to-use tools [13,14].

The preceding discussion highlights three key research gaps to which this study aims to contribute. First, there is a lack of conceptual clarity regarding the definition of quality in construction. Second, there has been limited investigation into the relationship between quality and sustainability within the built environment. Third, there is a need for the development of easy-to-use tools that support holistic consideration of both concerns—quality and sustainability—in the context of existing buildings.

Considering these gaps, this paper explores and clarifies the concept of quality in construction, with particular emphasis on the role of the design phase in achieving high-quality outcomes. It further examines the relationship between quality and sustainability through an extensive yet structured review of both concepts and presents a critical discussion of existing assessment methods, key indicators, and major concerns associated with each. A new tool is then proposed to minimise poor-quality outcomes in rehabilitation projects. Developed in the Portuguese context—representative of broader trends in Southern European construction—this methodology adopts a flexible and innovative approach to promoting qualified and sustainable interventions in existing buildings. It enables the prompt assessment of rehabilitation projects by verifying a target set of specific aspects identified as essential for achieving higher quality and sustainability standards. This includes both technical parameters (e.g., thermal or acoustic performance) and strategic concerns (e.g., environmental sustainability, accessibility, and heritage preservation). The application of the tool to two case studies is also briefly discussed, demonstrating its capacity to deliver reliable and stable results.

The research methodology begins with a detailed exploration of two core concepts: quality and sustainability in construction. First, the concept of quality in construction is examined, discussing its importance in ensuring durable, efficient, and cost-effective built environments. Emphasis is placed on the design phase, which is shown to be critical in shaping outcomes, especially in the context of rehabilitation. The relationship between quality and sustainability is then addressed, underscoring their interdependence, particularly in housing. This is followed by a review of existing assessment methods, focusing on their criteria and the ways in which quality and sustainability concerns intersect. Building on this analysis, a new method, MiMaQ, is introduced, and its application to two case studies is discussed, demonstrating its comprehensive outputs and holistic approach to evaluating rehabilitation projects.

2. The Concept of Quality

The term "quality" is defined in ISO 9000:2015 as "the degree to which a set of inherent characteristics of an object fulfils requirements" [15] (2015). The extinct British Standard BS 4778-1:1987 defined it as "the totality of features and characteristics of a product or service that bear upon its ability to satisfy stated or implied needs" [16].

In construction, quality is associated with meeting objectives regarding project and regulatory standards, local demands, and client requirements [17]. This term is also part of a triad of concerns that are subjacent to each project and ultimately determine its success: time, cost, and quality [18]. The ideal outcome optimises these concerns by achieving maximum quality through minimal cost and time [19]. Some authors even define quality in construction as the achievement of deliverables according to the project's specifications within a specific amount of time and budget [5]. However, accomplishing this balance and reaching the optimal fallout is far from simple since the construction sector is complex, dynamic, nonlinear, and frequently disorganised [5], involving interconnected and long processes of planning and executing [20].

The shift from manufacturing to construction processes has increased this complexity, given the extended time required to complete construction projects, the resources needed, and the necessity of meeting legal standards [10,21]. Consequently, construction projects often attract criticism and are frequently perceived as low-quality—whether in terms of design, construction processes, or the final product [10,22]. This lack of quality in the building sector is a globally recognised issue [4].

Strategies have emerged to address these challenges, including quality management and its concerns. However, implementing these strategies in real-world construction scenarios has proven difficult, primarily due to conservative stakeholders, the involvement of multiple participants, the transitory nature of projects, and the need to comply with regulatory standards [21]. Furthermore, most construction projects are characterised by individual specifications, demands, and constraints, which typically translate into one-of-a-kind processes hampering the adoption of standardised approaches [20]. This is particularly relevant in certain construction activities, such as building rehabilitation, given the specificity of balancing construction works with the qualities and deficiencies of existing buildings [12].

Despite a growing number of methodologies aimed at addressing specific quality management issues, recent research underscores the need for a shift in quality culture within the construction sector. Such a shift requires, among other factors, innovation and the ability to learn from mistakes [10]. Within this changing paradigm, the construction sector should move from focusing on defect-free outcomes to error prevention, emphasising in-process and pre-control measures rather than post-control [10]. New approaches advocate learning from errors, reducing project rework, and fostering innovation [9].

Regardless of the approach followed, investing in quality is always advisable given the direct relation between the investment and its benefits, even though research has shown that excess quality costs do not carry additional advantages [20]. Thus, tackling quality concerns in construction activities in a feasible way and creating quality-oriented strategies may pave the way to address this broad concern [5].

Also, recent research points to broader approaches to quality in buildings that greatly surpass the context of new construction. Sinha et al. [23] suggest that quality standards should integrate features of traditional techniques with the perspective of economy and rationality of modern practice. Also, the global objective of decarbonising building stock justifies the need to invest in retrofit and rehabilitation actions in the construction sector [24], ensuring quality in these interventions and, thus, their deliverables. In Portugal, the poor condition of the existing building stock [25], limited awareness of rehabilitation actions, and lack of accessible, easy-to-use methodologies to guide projects are the primary reasons for the low quality observed in many of these interventions [26]. This situation underscores the need for change not only in Portugal but also in other countries in similar circumstances.

3. The Role of Design

Besides acknowledging the importance of quality in construction activities, it is crucial to identify, analyse, and tackle situations where quality is not verified. Also, observing when and why they appear is necessary to understand these circumstances fully and propose solutions.

Concerns associated with building quality often arise only when anomalies occur, the justification for which is usually the alleged existence of execution mistakes [14]. The importance of the remaining phases, namely design, and how they affect poor building quality, is usually forgotten [26]. Recent research shows that rework costs in construction projects are 78% related to design changes, deriving from unresolved issues in this phase and, thus, before execution starts [9].

Problems of faulty building designs are intricate and deep-rooted [14]. Minato et al. [27] recognised how design is influenced by factors operating on different levels and stakeholders, involving individual designers, corporations, and the construction industry on both local and global levels. In 1994, Lam et al. [28] had already discerned how most failures began at the design stage, mainly due to disregarding specific requirements and developing deficient technical specifications [14,28]. Khan et al. [21] concluded that quality issues in the design phase arose primarily due to prioritising low cost, delays in integrating consultants and contractors, miscommunication among team members, and unrealistic predictions of clients. Hamzah et al. [14] also call attention to the general lack of awareness of designers regarding the impact of their tasks.

Poor-quality issues arising from the design phase are inconsistent with several characteristics of this stage, such as the potential to influence project outcomes (as can be seen in Figure 1), technical qualifications of those involved, and the opportunity to compare alternative solutions for various project aspects [26]. Additionally, quality in the design phase has been shown to enhance performance, sustainability, functionality, durability, cost-effectiveness, and competitive advantage in the market [17]. On the other hand, nonconformance during the design phase can increase the risk of failures, high costs, construction reworks, post-construction anomalies, claims, and warranty issues [17]. This is particularly relevant in certain construction activities, such as rehabilitation actions, which require a specialised approach with qualified and multidisciplinary professionals that is not yet disseminated.

In the construction sector, digital technologies emerged as tools to minimise the lack of quality in the design phase, curtailing reworks and faults. However, even though technologies such as BIM have advantages such as supporting decision-making processes or enabling technical verifications, their use in fully mitigating poor-quality situations in construction activities is considered controversial by some authors, especially given the inability to stimulate qualified human actions [9]. Moreover, research often focuses on analysing the application of a single tool to specific quality problems, underscoring the lack of multidisciplinary approaches to address this issue [10]. Additionally, the use of technology and the allocation of more qualified resources tend to correlate with the project's budget, suggesting that larger, more costly projects may adopt strategies such as quality control or project management tools to address quality concerns [21]. In contrast, smaller, routine projects are often left without supportive tools for quality assurance.

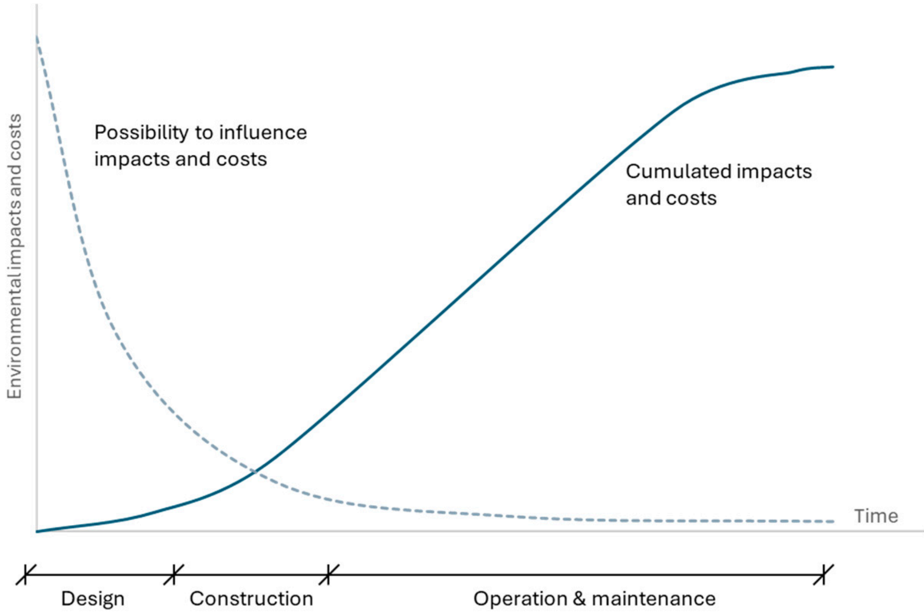

Figure 1. Influence of the design phase on future impacts and costs in construction (adapted from [29]).

Acting towards qualified and sustainable rehabilitation actions in housing requires new perspectives to face this context. Firstly, defying the concept of design quality, considering social, economic, environmental, technical, and functional perspectives, is of utmost importance to tackle multiple dimensions that any intervention entails [23]. Furthermore, it is critical to discuss quality and its implications with stakeholders, namely, engineers, architects, legal authorities, and policymakers [23,30]. Also, developing methods and tools that support decision-making without representing an excessive workload, allowing the assessment of solutions through collaborative outputs [9,13,31], may pave the way for an effective contribution towards a complex scenario.

4. Assessing Housing Quality and Sustainability

4.1. Discussion of Concepts

Addressing quality in the specific context of residential buildings is crucial, given housing's impact on individuals' quality of life [2], the significant amount of time people spend at home [32,33], and its status as one of the most substantial investments in life [34]. Additionally, global challenges, such as pandemics, underscore the importance of stable and high-quality housing for public health and personal wellbeing. Pollack et al. [35] explored the connection between strong housing policies, disease transmission, and social inequalities during the COVID-19 pandemic. Similarly, Newton et al. [36] highlighted how poor-quality precarious housing contributed to mental health issues among private renters during the pandemic, calling out the need for public housing policies to address the matter.

Even though research on housing quality has been carried out since the mid-20th century [37], a consensual definition of this term is still to be found, indicating an intricate concept neither static nor simple [23,38]. There are numerous examples of semantic variations in addressing the issue, such as using different terms (like "adequate" by UN-Habitat) [39] or more complex expressions (such as "perceived housing quality") [40]. The discussion surrounding this concept can, however, be perceived as positive since the review of concepts such as this and the dimensions it entails, raising awareness of its complexity, contributes to promoting social cohesion and fighting inequalities [23].

While it is well established that housing quality extends far beyond the physical attributes of the environment, research varies on the additional factors contributing to inhabitants' quality of life. Jacobs [41] refers to how qualified housing is related to healthy environments, identifying five broad categories of conditions: physical, chemical, biological, building and equipment, and social. Le et al. [42] proposed an approach addressing concerns such as location, proximity to facilities, architecture and building design, public spaces, microclimate, and equipment. Sinha et al. [23] identified categories including personal satisfaction, dwelling design features, location, society, economy, and institutional characteristics.

Diverse approaches illustrate how the quality of living environments should be perceived on a broader scale, including social, economic, personal, and environmental aspects [1]. This range of concerns suggests how sustainability is indissociable from housing quality, given how it implies social, ecological, and economic concerns.

Nonetheless, research varies in acknowledging how one concept is part of the other or vice versa. On the one hand, some authors refer to housing quality as an element of housing sustainability: Maliene et al. [34], for example, characterise sustainable housing as qualified, economical, ecological, comfortable, and available (Figure 2). On the other hand, some authors indicate sustainability as a sector of housing quality. Chohan et al. [43] defined quality indicators for housing design, which included aspects of architectural design, structure and construction, maintenance, site and layout, building services, user comfort, and sustainability, having concluded the latter to be a dominant aspect of quality from the users' point of view.

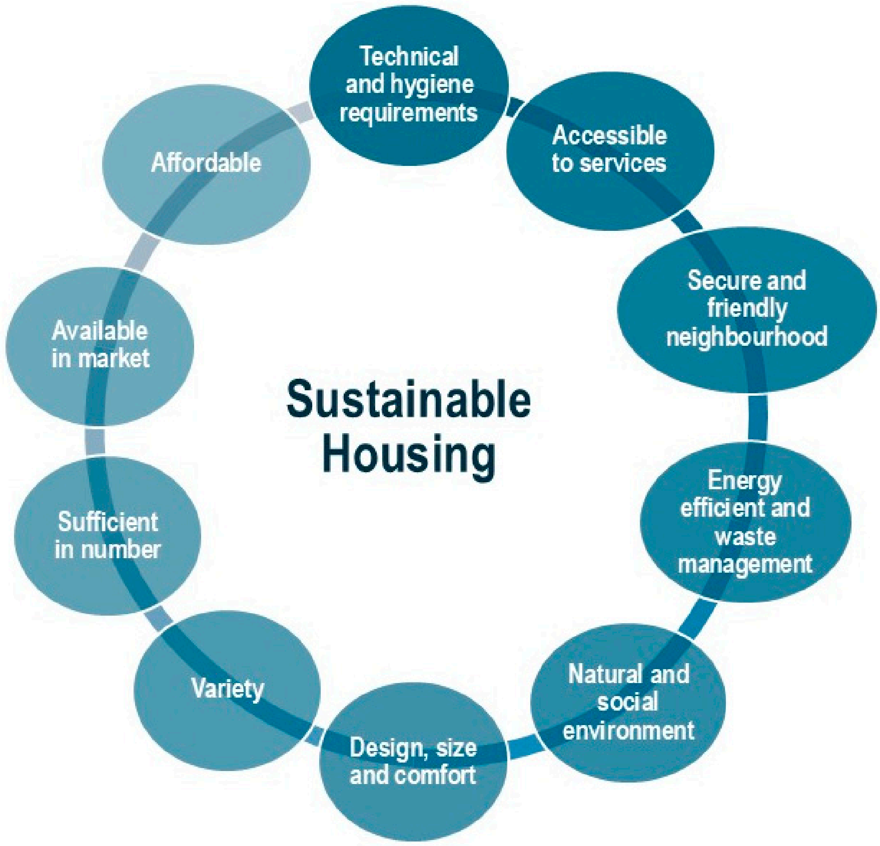

Figure 2. Examples of diverse criteria that may contribute to sustainable housing (adapted from [34]).

Housing plays a fundamental role in sustainable development due to its influence on quality of life, pointing out its crucial role as a sectoral policy. Despite this, and until recently, housing policies in Europe had received little attention. However, newly published documents have begun to acknowledge their relevance, marking a shift in the discourse, such as the European Affordable Housing Plan [44], currently in public consultation, or the Political Guidelines for the next European Commission 2024–2029 [45].

Also, attention is still not frequently drawn to the importance of building rehabilitation actions towards citizens' quality of life regarding housing and its contribution to healthier and more sustainable environments. However, building rehabilitation contributes en route to the three main dimensions of sustainable development since it promotes environmental and economic savings while contributing to social development, integration, and cohesion [46]. The lack of general insight by local authorities and consumers regarding housing quality concerns and regulations is also a meaningful scenario in these interventions [47]. Thus, assuring the quality of these interventions, especially in residential buildings, remains a pertinent challenge to tackle in both research and practical contexts.

4.2. Housing Quality and Sustainability Assessment Tools

Research focusing on quality assessment in buildings is not new. In the late 1940s, Solow [48] stressed the need for large-scale rehabilitation actions in urban environments and quantified housing quality, evaluating physical and environmental aspects of the built environment. Even though it is consensual that this concept surpasses tangible concerns, factors assessed when evaluating housing quality and sustainability have significant variations, as mentioned earlier.

Given the importance of considering these two ultimate goals in housing environments, an analysis was conducted regarding methodologies that intend to assess, guide, or evaluate quality or sustainability in the field of existing buildings. Table 1 synthesises information associated with nine tools, guides, or methodologies that contribute to assessing either of these concerns, indicating the type of assessment, scope of analysis, and indicators. In this study, a systematic review methodology was employed to identify and analyse existing quality and sustainability assessment tools used in the construction industry. The review process began with a comprehensive search for validated tools using the following keywords: "sustainability assessment", "quality assessment", or "construction assessment". Inclusion criteria required that these methodologies and tools provide detailed methodological descriptions of the assessment and focus specifically on applications within the construction sector. Data extraction concentrated on tool characteristics, including scope, indicators, focus, and geographic context. The extracted information was then categorised and organised thematically, as shown in Table 1, which details the total number of criteria for each tool and provides a basic description of the indicators. Also, two research works developed in Portugal [49,50] were considered and included in Table 1 due to their innovative role in proposing assessment methodologies on quality and sustainability applicable to the national context.

Table 1. Quality and sustainability assessment methods.

Name; Country/Authorship	Assessment (Quality/Sustainability)	Scope	(Total Number of Groups of Criteria) Description of Criteria
Design Quality Indicator (DQI); United Kingdom	Q	All construction	(3) 1. Functionality (a. Use; b. Access; c. Space); 2. Build quality (d. Performance; e. Engineering; f. Construction); 3. Impact (g. Character and innovation; h. Form and materials; i. Staff and patient environment; j. Urban and social integration).

Table 1. *Cont.*

Name; Country/Authorship	Assessment (Quality/Sustainability)	Scope	(Total Number of Groups of Criteria) Description of Criteria
NF Habitat; France	Q	All construction	(3) 1. Quality of life (a. Security; b. Air quality; c. Water quality; d. Functionality; e. Hygrothermal comfort; f. Acoustic quality; g. Visual comfort; h. Olfactory comfort); 2. Respect for the environment (a. Energy performance; b. Reduction in water consumption; c. Soil use; d. Material resources; e. Waste; f. Pollution); 3. Economic performance (a. Housing durability; b. Control of consumption and charges).
Método de avaliação da qualidade arquitetónica habitacional (MAQAH); Portugal	Q	All housing	(5) 1. Comfort in the environment; 2. Safety; 3. Functional and spatial adequacy; 4. Articulation; 5. Customisation.
Système d'Évaluation de Logements (SEL); Switzerland	Q	All housing	(3) 1. Site (6 criteria); 2. Surrounding environment (8 criteria); 3. Housing unit (11 criteria).
Building Environmental Assessment Method (BEAM); Hong Kong	S	All construction	(7) 1. Site aspects; 2. Management; 3. Materials and waste aspects; 4. Energy use; 5. Water use; 6. Indoor Environmental quality; 7. Innovations and additions.
WELL Building Standard; United States	S	All construction	(10) 1. Air, 2. Water; 3. Nourishment; 4. Light; 5. Movement; 6. Thermal comfort; 7. Sound; 8. Materials; 9. Mind; 10. Community.
VERDE (*Metodología para la evaluación y certificación ambiental de edifícios*); Spain	S	All construction	(6) 1. Lot and location; 2. Energy and atmosphere; 3. Natural resources; 4. Indoor environment; 5. Social aspects; 6. Building quality.
Level(s); European Commission	S	All construction	(6) 1. Greenhouse gas emissions along a buildings' life cycle; 2. Resource efficient and circular material life cycles; 3. Efficient use of water resources; 4. Healthy and comfortable spaces; 5. Adaption and resilience to climate change; 6. Optimised life cycle cost and value.
Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB); Germany	S	All construction	(6) 1. Environmental quality; 2. Economic quality; 3. Sociocultural and functional quality; 4. Technical quality; 5. Process quality; 6. Site quality.

Table 1. *Cont.*

Name; Country/Authorship	Assessment (Quality/Sustainability)	Scope	(Total Number of Groups of Criteria) Description of Criteria
Building Research Establishment Environmental Assessment Method (BREEAM) Domestic refurbishment and fit-out; United Kingdom	S	Existing housing	(8) 1. Management; 2. Health and wellbeing; 3. Energy; 4. Water; 5. Materials 6. Waste; 7. Pollution; 8. Innovation.
Leadership in Energy and Environmental Design v5 (LEED); United States	S	All construction	(9) 1. Integrative process, 2. Planning and assessments; 3. Location and transportation; 4. Sustainable sites; 5. Water efficiency; 6. Energy and atmosphere; 7. Materials and resources; 8. Indoor environmental quality; 9. Project priorities.
Modelo de avaliação da sustentabilidade nos processos de reabilitação (MARS); Portugal	S	Existing buildings	(9) 1. Site; 2. Transportation; 3. Water; 4. Energy; 5. Materials; 6. Exterior environment; 7. Interior environment; 8. Use; 9. Culture, economy, society.

Regarding the quality assessment methods, their scope of application varies significantly. While there are methods that can be applied to all types of buildings and construction, such as DQI [51] and NF Habitat [52], certain methods apply to specific typologies of building occupation, such as housing—refer to SEL [53] or MAQAH [49].

Criteria used in each assessment method are based on various underlying logics. Some methods, such as NF Habitat, have a strong technical focus, evaluating aspects related to internal and external finishes, infrastructure, or building components. Others, such as SEL, use indicators grouped by physical context and follow a top-down approach, assessing aspects of spaces such as site, street, building, or dwelling. Additionally, methods like MAQAH or DQI include criteria that assess specific aspects related to architecture, comfort, functionality, and access.

The scope logic for the sustainability assessment methods is similar to that described above, with broader methods applicable to all buildings, such as DGNB [54], BEAM [55], or VERDE [56], and others specialising in existing buildings, like MARS [50]. Certain sustainability assessment methods, such as BREEAM [57] or LEED [58], have specific tools adapted to existing buildings, such as BREEAM refurbishment and fit-out, which can then be applied to domestic or non-domestic use.

When considering the assessed criteria, although the widely accepted definition of sustainability includes environmental, economic, and social aspects, only DGNB and Level(s) [59] address all three of these concerns. MARS, WELL [60], and VERDE focus primarily on environmental and social indicators, while BEAM and BREEAM are dedicated mainly to the assessment of environmental performance.

Finally, it is important to note that methods such as NF Habitat, which is presented as a quality assessment methodology, rely on criteria that span the three dimensions of sustainability. This suggests the existence of methods that embody the previously stated indissociable relationship between quality and sustainability in the built environment.

An analysis of the general concerns addressed by methodologies listed in Table 1 was conducted. The quality and/or sustainability indicators described in Table 1 were examined and categorised into the following areas of concern: technical and functional performance, heritage preservation, environment, economy, and society. Table 2 presents the results of that analysis, showing which concerns each methodology addresses.

Table 2. Concerns addressed by the quality and sustainability assessment methods.

Methodology	Scope	Assessment (Quality/Sustainability)	Concerns Addressed				
			Technical and Functional Performance	Heritage	Environment	Economy	Society
DQI	All buildings	Q	✓				✓
NF Habitat	All buildings	Q	✓		✓	✓	
MAQAH	Housing	Q	✓				✓
SEL	Housing	Q	✓				
BEAM	All buildings	S	✓		✓		
WELL	All buildings	S	✓		✓		✓
VERDE	All buildings	S	✓		✓	✓	✓
Level(s)	All buildings	S	✓		✓	✓	✓
BREEAM Dom. Ref.	Existing housing	S	✓		✓		
DGNB	All buildings	S	✓		✓	✓	✓
LEED	All buildings	S	✓		✓		✓
MARS	Existing buildings	S	✓	✓	✓	✓	✓

The information synthesised in Table 2 leads to the conclusion that all analysed methods, whether focused on quality or sustainability assessment, include a component related to technical and functional performance. For quality assessment, this aligns with the basic definition of quality in the built environment, which emphasises physical attributes. Regarding other factors surpassing these, both DQI and MAQAH consider social criteria, and NF Habitat also includes economic and environmental concerns.

Environmental concerns are covered in all sustainability assessment methods, which is consistent with the traditional pillars of sustainability. BEAM is the only methodology that specifically targets environmental performance without addressing social and/or economic concerns. Nonetheless, about half of the quality assessment tools analysed cover social and economic factors, although only a few include economic indicators.

Finally, despite all methods being applicable to existing buildings, heritage concerns are only addressed in MARS, which defines a sustainability assessment system for rehabilitation in historic areas. This focus aligns with previous research advocating for assessment methods and tools that guide interventions while balancing contemporary alterations with the preservation of existing building characteristics that embody historical and cultural value [61,62]. Nonetheless, the fact that only one methodology includes criteria dedicated to this matter stresses how the preservation of architectural, cultural, and heritage values is still generally overlooked as a main component of quality and sustainability in existing buildings.

In this context, further research has highlighted the importance of methods that assess the quality and sustainability of interventions. The following characteristics were found to be particularly relevant when developing tools for this purpose:

- Early-stage decision: Rohde et al. [13] state that decision-support tools focused on early-stage processes are user-friendly and practical, promote communication between project stakeholders, facilitate solutions comparison, and enable effective, informative actions rather than merely evaluative ones. Additionally, Clark et al. [40] stress the importance of tools that offer technical insight and support the selection of appropriate actions, especially in regeneration work.

- Collaborative and adapted outputs: Love et al. [9] highlight the need for a cultural shift in error management in the construction sector, advocating for practices that reduce rework and enhance performance and productivity. This approach involves using collaborative delivery systems, improving communication, and developing outputs that build resilience in managing rework and change.
- Simplified and flexible tools: Marrero et al. [31] discuss how construction professionals and designers navigate complex decision-making processes, emphasising that assessment-support tools should not add to their workload and should use familiar language. Thuvander et al. [12] also stress the need for simplified tools, especially for evaluating intangible values. Given the diversity of concerns quality entails and the lack of a global definition, Sinha et al. [23] highlight the need for quality assessment systems to provide adaptable and flexible criteria.

This suggest that "*more knowledge and supporting tools are needed in order to make systematic, synthesised decisions in renovation projects that will enable us to balance various desires, needs, and values with respect to a number of important aspects such as energy, environmental, technical, and economic performance as well as social, cultural, and architectural aspects*" [12].

In light of these factors identified in the literature as critical for assessing and guiding interventions in existing buildings—particularly the need for early-stage, flexible tools with collaborative outputs—and considering the limitations of current methodologies for quality and sustainability assessment in this field, MiMaQ emerges as a tool well-suited to these requirements. By addressing aspects related to technical performance, sustainability, heritage preservation, economy, and society through a prompt assessment of rehabilitation actions, MiMaQ provides a comprehensive approach to evaluating quality. The following section describes this innovative methodology, outlining its objectives and the assessment framework it entails.

5. MIMAQ: Method for Minimising the Risk of Poor Quality in Rehabilitation Projects

5.1. General Description and Goals

The method MiMaQ ("*method for minimising the risk of rehabilitation projects with poor quality indicators*") was developed with the main goal of minimising poor quality in rehabilitation projects. This method was part of a study [63] to minimise the risk of poor quality in rehabilitation interventions.

MiMaQ promptly assesses the project by verifying a set of specific aspects related to technical features considered critical in contributing to the quality of rehabilitation projects and thus, if covered, can suggest that there is a lower risk of poor quality in the result of the intervention [63]. Each project is subjected to a limited number of questions, since the method intends to be a prompt tool. These questions are related to key aspects of rehabilitation projects that are considered to contribute towards their quality, which are distributed within 25 themes. These themes, detailed in the following section, are either related to technical performance areas or more conceptual fields, such as environmental sustainability, economy, or heritage preservation. By subjecting projects to a limited number of questions, this tool aims to provide prompt results on the compliance of projects with specific aspects, indicating situations where further analysis may be necessary to minimise the risk of poor quality in upcoming interventions.

Despite the inherent tension between the promptness of this analysis and its effectiveness in assuring reliable outcomes, this tool has been proven solid, returning coherent results after comprehensive testing runs [26]. Plus, it has proved very flexible to different contexts and goals [64].

5.2. Methodological Framework

The assessment is based on responding to a set of 50 questions related to the rehabilitation project. The number of questions was determined not only to ensure coverage of a diverse range of key topics while maintaining the objective of developing a prompt and efficient tool, but also with the understanding that MiMaQ is not intended to be a quantitative, extensive assessment method. Rather, it serves as a didactic tool to raise awareness of aspects that may be lacking or require revision in rehabilitation projects. This tool was developed in Microsoft Excel, using Macros coded in Visual Basic for Applications (VBA) where necessary, particularly for the algorithms underlying question assignment. The tool is accessible via an individual file, which is currently not publicly available. To generate questions that are tailored to the specific project, a preliminary form must be completed with information about both the existing building and the proposed intervention [6]. The responses to this form result in a curated subset of relevant questions, specifically selected for the project under evaluation.

This form is organised according to several fields, whether related to general data, such as the construction period or building height, or with specific characteristics of the various construction elements, such as the roof or window framing. There are also fields related to pathologies of the pre-existing building [26]. As an example, if the existing structure is made of wood but the project plans to replace it, fully or partially, by a reinforced concrete structure, the options "Wooden structure" and "Reinforced concrete structure" must be selected in the "Structure" field, since the system will look up for questions to suggest based on these keywords [26].

After completing the preliminary form, the system provides a tailored set of 50 questions, each to be answered as "yes", "no", or "non-applicable". These questions are selected from a broader database of approximately 650 questions, categorised into 25 thematic areas (T01 to T25), which address key construction elements and technical domains relevant to rehabilitation.

These 25 themes and their associated questions form the foundation of the assessment methodology. They were developed through an extensive review of technical manuals, regulatory documents, assessment tools, and academic research focused on good practices in the rehabilitation of existing buildings in the international and Iberian contexts. The process began with a critical analysis of existing frameworks and standards to ensure the methodology is grounded in established knowledge, while remaining open to innovation. This included the identification of areas of concern in regulations in force, key aspects, and construction elements that are frequently the object of interventions, and groups of indicators or criteria covered by other assessment tools in the areas of sustainability and quality in construction and, specifically, in the field of existing buildings. This review allowed the identification of a broad range of technical performance areas criteria (e.g., acoustic performance, structural integrity) and broader conceptual concerns (e.g., sustainability, or heritage value), thereby ensuring that the resulting methodology reflects the complexity and multidimensional nature of rehabilitation projects. The work also identified limitations in traditional assessment approaches, enabling the development of a more holistic and integrated tool.

A key strength of the development process was the collaboration with a multidisciplinary team of Portuguese experts and researchers in the field of building rehabilitation, sustainability, architecture, and construction, each of whom contributed domain-specific insights, proposed assessment questions, and provided iterative feedback. Their input ensured that the final framework is both comprehensive and adaptable across diverse project types and contexts, ensuring the tool's relevance, accuracy, and practical applicability. The final methodology integrates both qualitative and quantitative evaluation criteria, enabling nuanced assessments that go beyond binary or oversimplified scoring. The result is a robust tool that not only evaluates technical and strategic project performance but also supports informed decision-making and continuous improvement.

Each theme does not have a fixed number of associated questions, and individual questions may relate to multiple themes. Given the variation in thematic depth and complexity, a cap has been introduced on the number of questions each theme can contribute to the final 50-question assessment set.

The questions relate to clear and objective construction aspects considered to be good practices in the field of rehabilitation interventions, which were proposed by groups of technical experts specialised in each topic that developed the study and extensive literature reviews [63]. An affirmative response to a question may address more than one specific concern, as some questions are linked to a broader set of issues that extend beyond the primary focus of the question itself [26]. Also, it is important to notice how themes composing MiMaQ usually contribute to more than one of the five major concerns present in other assessment methods identified in Table 2, thus entailing a holistic approach to quality and sustainability assessment in the field of rehabilitation actions. Table 3 indicates themes composing MiMaQ, the maximum number of questions per theme to be included in assessments, and the relation between themes and dimensions of qualified and sustainable rehabilitation actions.

Even though this structure is not mandatory, the questions that compose the assessment are usually composed of three elements: an assumption, which is used to narrow down the scope of the question; the question itself; and an example. The question below is illustrative of this structure: "If there are fungus and mould stains in ceiling corners, are there any measures to correct thermal bridges (e.g., thermal insulation, reinforcement of ventilation and heating)?" Table 4 illustrates the content of five sample questions composing MiMaQ, as well as the themes they belong to.

The fields included in the characterisation form described in the previous subsection match the assumptions of the questions. Thus, the system can automatically identify a list of questions that are directly related to the characteristics of the project being assessed. There are also questions that don't require an assumption and therefore are applicable to all projects.

Moreover, each question has a level of priority of 1, 2, or 3 (1 being the highest level), which depends on its relevance within the topic it belongs to and compared with the remaining questions on that same topic. The user can define the maximum number of questions with a priority lower than the maximum (level 1) that they want the system to present in the final assessment.

Table 3. Themes, maximum number of questions per assessment, and relation with dimensions of qualified and sustainable rehabilitation actions.

	Roofs T01	Walls T02	Floors T03	Openings T04	Coatings T05	Connections T06	Technical installations T07	Foundations T08	Structure T09	Seismic vulnerability T10	Hygrothermal performance T11	Acoustics T12	Fire T13	Ventilation T14	Natural lighting T15	Accessibility T16	Context and pre-existence T17	Intrinsic value T18	Heritage preservation T19	Sustainability T20	System compatibility T21	Construction feasibility T22	Durability and maintenance T23	Cost control T24	Process or ganisation T25
Maximum No. of questions per assessment	10	10	5	7	10	7	5	5	10	5	7	7	7	5	3	3	5	3	3	3	3	3	3	2	2
Technical and functional performance	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆					◆	◆	◆		◆
Heritage preservation																	◆	◆	◆				◆		
Environment											❖			❖	❖		❖	❖	❖	◆			◆		
Economy						⧫	⧫				⧫				❖						❖	❖	◆	◆	❖
Society							❖			❖	❖	❖	◆	❖	❖	◆	⧫	⧫	⧫	❖					❖

Degree of contribution: ⧫ low; ❖ medium; ◆ high.

Table 4. Sample questions composing MiMaQ: content and themes.

Theme	Question
T03	If wood is used on flooring solutions (e.g., solid wood planks), were joints between elements and peripheral joints foreseen to assure cyclic expansion and contraction of elements?
T04; T19	If existing window frames were not maintained, do new frames have a similar or identical expression to original solutions (in terms of material, design, geometry, and/or typology), maintaining coherence and integrity with the building's facade?
T19	Are spaces, construction elements, or materials with heritage/architectural value identified, and is their preservation achieved through minimal and non-intrusive methods and techniques?
T20	Does the project foresee the use of recycled materials?
T02; T21	In case of applying new coatings over existing wall materials, were compatibility conditions provided for, and is there any reference to such aspects in the project?

The 50 questions that compose the final assessment should be answered by the user, considering the information regarding the rehabilitation project. However, to account for the possibility that certain questions are non-applicable (NA), it is suggested that the user generate an assessment form with extra questions. To obtain the final assessment form, the following information should thus be filled out by the user:

- "Total number of questions": number of questions that the form is intended to include (50 are suggested);
- "Number of extra questions": number of supplementary questions in case non-applicable questions are randomly selected by the system (10 to 15 are suggested);
- "Maximum number without 1st priority": maximum number of questions that the user wants with priority 2 or 3.

The result of the assessment relies on the number of questions answered positively. If all questions are answered positively, it can be assumed that the risk of poor quality in the rehabilitation project is very low and, therefore, no further procedures are suggested. On the other hand, if the number of negative answers is greater than a certain threshold, a more thorough analysis of the project is suggested. If the number of negative answers is over 25, a full review of the project, possibly carried out by an external team, is recommended. It is important to stress that noncompliance with certain aspects of the rehabilitation project, given the negative answers, should not be immediately perceived as proof of the poor quality of the rehabilitation project, but rather as a warning flag for the need to perform a more detailed evaluation [63].

Compared to the synthesis presented in Section 4.2, particularly in Table 1, it is important to highlight that the scope of MiMaQ is specifically tailored to existing buildings. Its focus on minimising poor-quality situations positions it as a quality assessment method. Nonetheless, like other tools, its incorporation of sustainability concerns underscores the indissociable relationship between quality and sustainability and, as shown in Table 3, it composes a holistic approach to both concerns by providing an assessment composed of 25 themes that contribute to five major concerns, namely technical performance, economy, environment, society, and heritage preservation, which are transversal to these two goals. These concerns are reflected in concise objective questions composing the method, which, nonetheless, does not attempt to replace other extensive, more complex existing tools in construction, such as sustainability assessment tools, but raises awareness towards specific aspects that can be promptly verified in rehabilitation projects.

Moreover, several aspects distinguish MiMaQ from other assessment methods or tools. Firstly, the 25 themes comprising this method address a broad range of concerns rarely covered in most methodologies. Secondly, MiMaQ offers a flexible approach, allowing users to select parameters of choice in the assessment, thereby adapting it to different scenarios and objects of study. Thirdly, it provides collaborative outputs designed to guide decision-making and facilitate the identification of factors contributing to poor-quality situations, enabling iterative use of this tool. Lastly, MiMaQ is intended as a prompt and practical tool within an otherwise complex context, simplifying user interaction during the decision-making processes in the design phase of rehabilitation interventions. Compared to most assessment tools, which require complex and long processes of application, MiMaQ's prompt approach improves overall efficiency since it minimises the time needed for execution.

5.3. Demonstration of Methodology Through Case Studies

To evaluate the functionality and efficiency of MiMaQ in fulfilling its intended objectives, and to investigate its responsiveness across different types of projects, the methodology was applied to two case studies, and the key results are discussed in Section 5.3.2 following three dimensions:

- Stability: This aspect examines whether repeated assessments yield consistent results in terms of the overall distribution of positive and negative responses for a given project.
- Comprehensibility: This dimension assesses whether the questions comprising MiMaQ enable a clear, structured, and easily interpretable evaluation of relevant aspects within a project. A formal analysis of both the structure and content of the questions was conducted to ensure legibility and clarity.
- Variability: This component evaluates whether assessments using different numbers of questions (25 vs. 75) produce similar conclusions regarding the potential risk of poor-quality outcomes in the projects under review.

Findings from these applications yielded valuable insights into the transparency, stability, and replicability of the methodology, supporting future refinement and broader application across different contexts. It is important to highlight that these applications have been primarily aimed at evaluating MiMaQ's practical performance and adaptability, thereby laying the foundations for future, more complex testing.

5.3.1. Brief Description of Selected Case Studies

Case studies used to test the methodology consisted of two rehabilitation projects located in Portugal, selected to evaluate the applicability and robustness of the proposed methodology across varied contexts. These case studies differ in geographic location, intended use, and project type, thereby providing a basis to assess the method's performance under diverse conditions and to test its sensitivity to contextual variability.

Case Study 1, located in Coimbra, involved the conversion of a three-storey residential building into a student centre. The existing structure (Figure 3) was a limestone masonry building with timber structural elements (roof and pavements), built prior to the 20th century. It featured wood window frames and doors, and interior partition walls built using a timber-framed technique known as *tabique*. The project included several alterations aimed at adapting the building for its new function and improving overall performance. It also involved the construction of a second volume in reinforced concrete as an extension of the original structure.

Case Study 2, located in Guimarães, consisted of the rehabilitation of the external envelope of a multi-family residential building. The existing building (Figure 3) was a six-storey structure built in the 1980s, with a reinforced concrete frame and reinforced concrete walls. The rehabilitation project addressed various anomalies in the external cladding, particularly on the roof and exterior walls.

Case Study 1: Main facade (1) and timber roof structure (2).

Case Study 1: Inner compartment (1) and wooden window frame (2).

Case Study 2: Main (1) and rear facades (2).

Case Study 2: Iron window frames (1) and deterioration of exterior coating due to corrosion of metallic elements (2).

Figure 3. Photographs of Case Study 1 and Case Study 2 (adapted from [26]).

5.3.2. Discussion of the Obtained Results

To perform the proposed tests, the 650 questions that compose the MiMaQ methodology were completed to generate customised sets of 50 questions for each case study. This process was primarily aimed at assessing the applicability of each question to the specific project context. As a first result, an applicability rate of 52% was recorded for Case Study 1, whereas an applicability rate of 23% was recorded for Case Study 2. The lower applicability rate obtained for Case Study 2 can be attributed to the nature of the project, which was limited to the building's external envelope.

To evaluate whether MiMaQ offered stable results regarding the risk of poor quality of a given project, it was necessary to check whether the results obtained through different assessments offered similar results. To do so, 200 sets of 50 questions and respective responses were generated for each case study. Then, the obtained results were analysed to investigate the coherence of results in terms of "yes", "no", and "non-applicable" responses.

Figure 4 presents two histograms showing the number of assessments (sets of 50 questions) with a given number of "yes" responses, separately for Case Study 1 (CS1) and Case Study 2 (CS2).

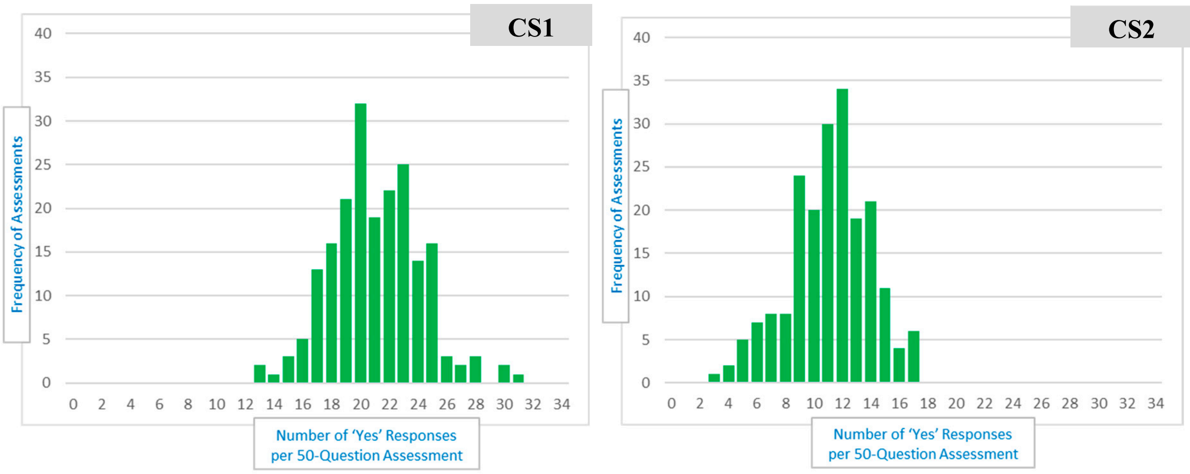

Figure 4. Distribution of 200 assessments according to the number of "yes" responses out of 50 questions: results for Case Study 1 (CS1) (1) and Case Study 2 (CS2) (2) (adapted from [26]).

The histograms presented in Figure 4 show that the results were stable within each case study. The bars are closely grouped, centred around a specific range of values, and both cases exhibit a distinct peak. In Case Study 1, the mode corresponds to 20 "yes" responses, observed in 32 assessments. In Case Study 2, the most frequent value is 12 "yes" responses, recorded in 34 assessments. The histograms further show that, in Case Study 1, 49% of assessments yielded between 20 and 23 positive responses, and 65% of cases between 19 and 24 "yes" answers. Similarly, in Case Study 2, 54% of assessments recorded between 9 and 12 "yes" responses, and 74% of assessments between 9 and 14 "yes" responses. These results suggest a consistent outcome when MiMaQ is repeatedly applied to the same objects of study, highlighting the stability of the method's output.

Having verified the stability of the method, a variability test was conducted to examine whether altering the number of questions per assessment would affect the conclusions regarding the potential risk of poor quality in the project. Even though the method was originally developed on the assumption that 50 questions would be sufficient to capture a diverse range of aspects while maintaining the tool's usability, assessments composed of 25 and 75 questions were also tested to determine whether comparable results would be obtained. In total, 200 assessments were therefore generated for each configuration (25, 50, and 75 questions), and the average percentage of "yes" responses was calculated for Case Study 1. The results are presented in Table 5.

Table 5. Average percentage of "yes" responses obtained in 200 assessments (sets of questions) using 25, 50, and 75-question configurations for Case Study 1 (adapted from [26]).

		Average Percentage (%) of "Yes" Responses for 200 Sets of Questions																				
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
N° questions in the assessment	25	0	0	0	0	0	0	0	0	1	2	2	16	14	25	42	31	33	21	8	2	3
	50	0	0	0	0	0	0	0	0	0	0	1	4	23	44	38	46	31	11	2	0	0
	75	0	0	0	0	0	0	0	0	0	0	0	1	11	39	59	58	26	6	0	0	0

Table 5 shows that, across the three configurations tested (25, 50, and 75 questions per assessment), the highest concentration of 'yes' responses falls within the 65% to 75% interval. This indicates that, regardless of the number of questions, the proportion of positive responses in Case Study 1 tends to remain within this range. For assessments composed of 50 questions, 64% of the cases (128 out of 200 assessments) fell within the 65% to 75% range. When the number of questions increased to 75, this proportion rose to 78% (156 out of 200 assessments), suggesting a higher degree of consistency.

These results suggest that increasing the number of questions per form improves the assertiveness of the method, as a greater proportion of results fall within the expected range. However, it is important to consider that increasing the number of questions negatively affects the tool's promptness, leading to a proportional increase in the time needed to complete the assessment, estimated at an additional 1.5 h. Therefore, while 75-question assessments may offer slightly greater consistency, this must be weighed against the reduced practicality in real-world applications. The findings suggest that the method remains robust across different configurations, and the added value of a longer assessment may be marginal relative to the increase in effort required. Even though the proportion of positive questions was similar regardless of the total number of questions, the 25-question assessments demonstrated less consistency, and the 75-question assessments reduced the promptness of the method, supporting the choice of maintaining the 50-question assessments as a balanced option.

Finally, the last test involved a formal review of the comprehensiveness of the questions used in the method, focusing on both content and structure, with the aim of identifying necessary improvements to the initial formulations. Building on the previous assessments, where all questions were answered across both case studies, this process led to a systematic double revision of all 650 questions that comprise the MiMaQ framework.

Despite the substantial number of questions reviewed, only 45 questions—representing 7% of the total sample—were identified as requiring revision. For these, one or more of the following changes were proposed: adding or adjusting examples included in the questions; reviewing the assigned priority level; reformulating or introducing assumption; removing and simplifying redundancies; reassessing the question's relevance to the identification of poor quality risk; splitting complex questions into two or more simpler questions; and rephrasing questions to be more general or, where appropriate, more specific.

These proposed changes will be considered in future research, particularly in relation to the continued refinement of MiMaQ and its potential adaptation to other contexts or domains. This comprehensibility review complements the preceding analyses by supporting the method's content validity and its clarity in practical application.

6. Conclusions

Despite the well-known importance of pursuing sustainability and quality in construction activities, challenges remain in fulfilling these goals. Tackling quality within the right timeframe and considering a broad range of aspects in built environments is key to addressing a complex aim. Furthermore, acknowledging links with other goals, such as sustainability, and recognising its pertinence in fields which are pivotal for wellbeing and quality of life, such as housing, remains an overlooked area of both research and practice, especially in terms of easy-to-use tools and methods that can aid decision-making. This is particularly relevant in interventions in existing buildings, which are complex and require more flexible approaches than those used for new buildings.

This research synthesised information on the concepts of quality in the construction sector and the importance of the design phase towards this goal. Then, the role of housing in people's quality of life was stressed, and insights were given on how sustainability and quality are related within this context. Also, a review of assessment methods and tools used for tackling both concerns is presented, discussing concerns addressed and relevant features in the field of existing buildings. Finally, an innovative tool developed in

Portugal with the goal of identifying and mitigating poor-quality situations and promoting sustainability in rehabilitation actions is presented herein, focusing on its suitability as a screening method. This tool introduces an innovative approach to minimising the risk of poor quality in rehabilitation actions by offering a prompt assessment method. It verifies compliance with a focused number of key aspects across 25 thematic areas and has proven effective in supporting both the evaluation and guidance of design projects. Case study tests demonstrate that the proposed methodology produces coherent and stable results, laying a solid foundation for future refinements and broader applicability.

From the analyses and evidence presented in the preceding sections, several conclusions can be drawn. First, addressing quality-related issues in construction activities remains essential, and there is a clear need to pursue practical strategies and tools. This is particularly relevant for rehabilitation interventions, especially in contexts where such practices are not yet widespread, such as in Portugal. Second, investing in quality during the design phase has been shown to enhance performance, sustainability, functionality, and durability. However, emerging perspectives on design quality, including economic, environmental, technical, and social dimensions, must also be considered to advance the field. Third, the concepts of quality and sustainability in construction are inherently linked and must be understood in a comprehensive and multidisciplinary way, taking into account broader implications for human wellbeing, quality of life, and the creation of healthier, more sustainable environments. Furthermore, although existing assessment methods often focus on technical and functional performance, they rarely address heritage preservation.

The literature consistently underscores the need for simple and flexible tools that support the decision-making process through adaptive and collaborative mechanisms. In response to this need, MiMaQ emerges as a practical assessment tool tailored to the design phase of rehabilitation projects. It provides stable and coherent results grounded in a holistic conception of quality, integrating heritage conservation with considerations of technical performance and environmental, social, and economic sustainability.

Future steps of research include widening the review of assessment methods to identify other criteria and concerns that are relevant to different methodologies in the field of existing buildings. Furthermore, exploring how the practical application of such tools contributes indeed to qualified and sustainable interventions, especially considering different typologies of existing residential buildings, is an important line of research with relevant practical applications to be pursued. The continued refinement of MiMaQ and its adaptation to other contexts and domains will be further explored, along with its wide application and testing regarding different typologies of buildings and interventions to analyse and improve further aspects of the tool. Finally, the comparison of results obtained through the application of MiMaQ with other existing tools can contribute to progressively validating this methodology, allowing for the identification of strengths and limitations.

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