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Review

Towards Sustainability Assessment of the Built Environment: A Classification of the Existing Challenges

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Abstract: The application of sustainability assessment in a decision context is associated with various challenges that explain why the transition to action-oriented knowledge still needs to be fulfilled. Therefore, this paper aims to explore the associated challenges in sustainability assessment in the decision context of the built environment. Several publications are reviewed to provide a systemic understanding of the associated complexities. The challenges in sustainability assessment in the built environment are categorized at different levels, from understanding to measurement and implementation. The challenges are further categorized into definition, context, interpretation, data, measurement methods, uncertainties, indicators and indices, results, coordination, conflicts, and action-oriented knowledge. Moreover, according to the nature of each challenge, they are classified into epistemological, methodological, and procedural challenges. The novelty of this review is that it reviews and reports almost all fragmentedly reported challenges in sustainability assessment of the built environment in the literature within a holistic framework that provides a clear understanding of the state of the art and second discusses them within an integrated framework (the Sustainability Assessment Network) including the position of active-role players to resolve them, including strategists, scientist, and stakeholders.

Keywords: sustainability assessment; built environment; challenges; methods; policy making

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1. Introduction

The transition toward sustainability as the pattern of development that simultaneously aims to promote human well-being and conserve the life support system of planet Earth is recognized as a central challenge of the current century [1]. Over recent decades, the paradigm of sustainability and sustainable development has been popularized due to the growing awareness and consensus about the limitation of global resources to provide for the need of future generations anticipated by increasing global population and urbanization trends [2]. However, the lack of a general agreement on the exact interpretation of sustainability [3] due to its dynamic nature, inherent interdisciplinary character [4], and intrinsic complexity has led to endless attempts to provide a comprehensive definition [5].

The term sustainability has gone through several diverse definitions and interpretations, such as sustainability as "*the art of living well, within the ecological limits of a finite planet*" to a more holistic interpretation that includes not only the environmental aspect but also the economic and social aspects [6].

According to [7], several interpretations exist regarding the concept of sustainability that could be categorized into four main approaches. The first is described as the ecological interpretation, in which the socio-economic systems are assumed to be embedded within the global biophysical systems. The second is the economic interpretation, which emphasizes that social welfare and external environmental costs are associated with economic activities. The third is the thermodynamic and ecological–economic interpretation, in which the essence of ecological interpretation is accepted, but the entropic nature of economic–environmental interaction is also considered. The last approach to sustainability is the public policy and planning theory that accentuates environmental, economic, social, and institutional aspects and aims to achieve a balance or an integration of these perspectives. These days, the definition of sustainability based on three pillars, namely environment, economy, and society, has become the most prevalent and accepted version [5].

Within a decision context, sustainability assessment is a crucial step in evaluating the progress toward achieving sustainability. Therefore, sustainability assessment is now progressively becoming a common practice in different fields, from the product level to policy programming [8]. Sala et al. [8] introduced some of the current definitions of policy-oriented sustainability assessment to help decision-makers and policymakers make better decisions toward creating more sustainable societies [9].

Nevertheless, several in-depth questions at different levels, from problem understanding to measurement methods and the implementation of sustainability science, remain challenging and, in some cases, controversial within academia, industry, and public policy programs.

This paper explores the challenges relating to sustainability assessment in the built environment by reviewing the current opinions and recently published scientific articles. Then, a new classification system for all discovered challenges is presented to explore both the different layers and the nature of each challenge. Following the new classification system, a holistic framework is planned and explained, in which the relationship between these challenges is discussed and the strategists (public policymakers), scientists, and stakeholders, as the three major groups of actors, are assigned to resolve the challenges in a transdisciplinary and collaborative framework called the Sustainability Assessment Network.

2. The Classification of the Existing Challenges in Sustainability Assessment in the Built Environment

The existing challenges in sustainability assessment in the built environment are fragmentedly reported in different papers, and consequently, the question of what challenges should be further addressed in the future is fuzzy and a major challenge itself (Figure 1). To answer this question, several challenges reported in the literature were collected. To collect the relevant papers, the keywords including "sustainability assessment", "challenges", "built environment" and/or "buildings" were searched for within the papers published in Science Direct after 2015. Moreover, publications referring to the sustainability challenges in other scientific databases, including Nature-branded journals, were collected and reviewed. Finally, 74 publications, including scientific articles, reviews, and book chapters, were retrieved. Then, the challenges reported in these publications were categorized into different groups and presented in three layers, in which each layer expanded its previous layer.

The categorization into different groups presented in three layers helped us to better understand what challenges should be attributed to each sustainability assessment step. The first layer contains three groups of challenges, including understanding, measurement, and implementation. In general, understanding-related challenges mainly refer to the comprehension of what sustainability assessment in the built environment is through providing a comprehensive definition, realizing the context of the assessment and interpretation, measurement-related challenges address the challenges related to quantitative and qualitative analysis of sustainability, and implementation-related challenged include challenges in applying sustainability assessment into actions and policies and coordination of key-role players. These three groups of challenges are further detailed in the second layer, and the third level encompasses all the challenges reported in the literature (Table 1).

Figure 1. The challenges in sustainability assessment of the built environment reported fragmentedly in the reviewed publications representing the fuzziness of the correlation among them.

The second layer expands the previous layer to 11 groups of challenges including definition, context, interpretation, data, measuring methods, uncertainties, indicators and indices, results, coordination, conflicts, and action-oriented knowledge. The third layer contains all collected challenges reported in the literature, covering 44 different challenges fragmentedly reported in different publications. In the first layer, most discovered challenges are attributed to measurement, covering approximately 59% of all reported challenges. In the second layer, the challenges related to measuring methods, indicators and indices, definition, data, and uncertainties are the most reported in the literature.

Furthermore, these challenges are also classified into three categories based on the nature of each challenge that clarifies how these challenges should be tackled and what group of role-players in sustainability assessment are responsible for each category of challenges.

As already mentioned, the third-layer challenges are classified according to their nature into three categories called epistemological, methodological, and procedural (EMP) challenges. This classification helps to identify the type of each challenge and therefore aims to provide a basis to clarify the relations amongst several dispersed challenges in sustainability assessment in the built environment. In general, epistemological challenges refer to the main controversies involved in the understanding and perception of sustainability and sustainability assessment; on the other hand, methodological challenges deal with the intricacies of developing scientific methods for assessing sustainability aspects of the built environment that are a prerequisite to resolving the epistemological challenges. Meanwhile, procedural challenges deal with providing the requirements of implementing sustainability assessment practically, providing the input data to the methodologies of sustainability assessment and implementing the sustainability measures in practice at the built environment scale. These three categories of challenges are interconnected, which means that the answers to each category contribute to finding the solutions for the other two categories of challenges.

Through this classification, we define and discuss each EMP challenge category and explain how strategists, scientists, and stakeholders (3S), known as the main actors in sustainability assessment, could provide action-oriented sustainability knowledge within a holistic framework. In this framework, strategists are the players responsible mainly for legislating the policies and coordinating the application and implementation of sustainability measures at the built environment scale. Scientists are the community in charge of developing the scientific methodologies to measure different aspects of sustainability in the built environment, and stakeholders refer to all other groups that are targeted with sustainability policies, including producers, consumers, etc., in the built environment sector.

To better explain the different EPM categories of challenges, this section uses environmental sustainability assessment as an example. Therefore, regarding environmental sustainability assessment, epistemological challenges refer to the understanding of environmental sustainability and, for instance, discuss the question of what should be considered environmental sustainability assessment. What are the most important aspects and components of environmental sustainability assessment? What should be considered environmental sustainability assessment pillars on a local to a global scale? And what should be considered the most critical issues of environmental sustainability assessment to be tackled? These challenges should be resolved based on robust scientific methodologies and facts about the severity of each environmental impact category over the whole environmental system. In this example, it is clear that the solutions to the methodological challenges must be provided first to answer the epistemological challenges, since robust methodologies contribute to understanding the environmental sustainability assessment definition, and therefore they are the prerequisite for resolving epistemological challenges. Hence, mutual collaboration is needed between environmental scientists and those committees involved in environmental policymaking.

Methodological challenges—in this example, environmental sustainability assessment—include several questions such as impact assessment methodologies, measuring and quantification (e.g., the measurement method of global warming potential, etc.), weighting and normalization methods among different environmental impact categories, etc. These challenges have been widely discussed and surveyed among environmental scientists for many years. Therefore, several methods of impact assessment methodologies or weighting and normalization methods have been developed. Despite all previously developed methods, they are still known as open challenges in the field of environmental sustainability assessment methods [10]. The challenges mentioned above are examples of those widely discussed as a topic of study in the environmental life cycle assessment (LCA) of the built environment [11].

Resolving procedural challenges requires a high level of cooperation among stakeholders, scientists, and policymakers, since interoperability plays a significant role in establishing sustainability assessment frameworks. Data streaming is one of the main concerns in procedural challenges. It addresses data and information circulation among different involved groups as a prerequisite of any assessment. The format of data and information, both as input data and analysis outputs, is of high importance, as well as data availability and accuracy. While input data for sustainability assessment are typically provided by the stakeholders (e.g., producers, consumers, etc.), policymakers play a significant role in legislating the regulations for publishing such data in an open-access form. The procedural challenge includes, but is not limited to, defining the minimum required data communication amongst involved groups to flawlessly carry out each step of the assessment, decision-making, and implementation. For instance, the lack of data in environmental sustainability assessment is still a severe barrier to fully employing life cycle environmental assessment in building science [12]. Furthermore, implementing the results of sustainability assessment into policies, resolving the conflicts of stakeholders in the building sector, coordinating stakeholders, etc., are other examples of procedural challenges regarding sustainability in the building sector. Figure 2 and Table 1 represent all of the collected sustainability challenges categorized into different groups and classified into epistemological, methodological, and procedural categories as described above.

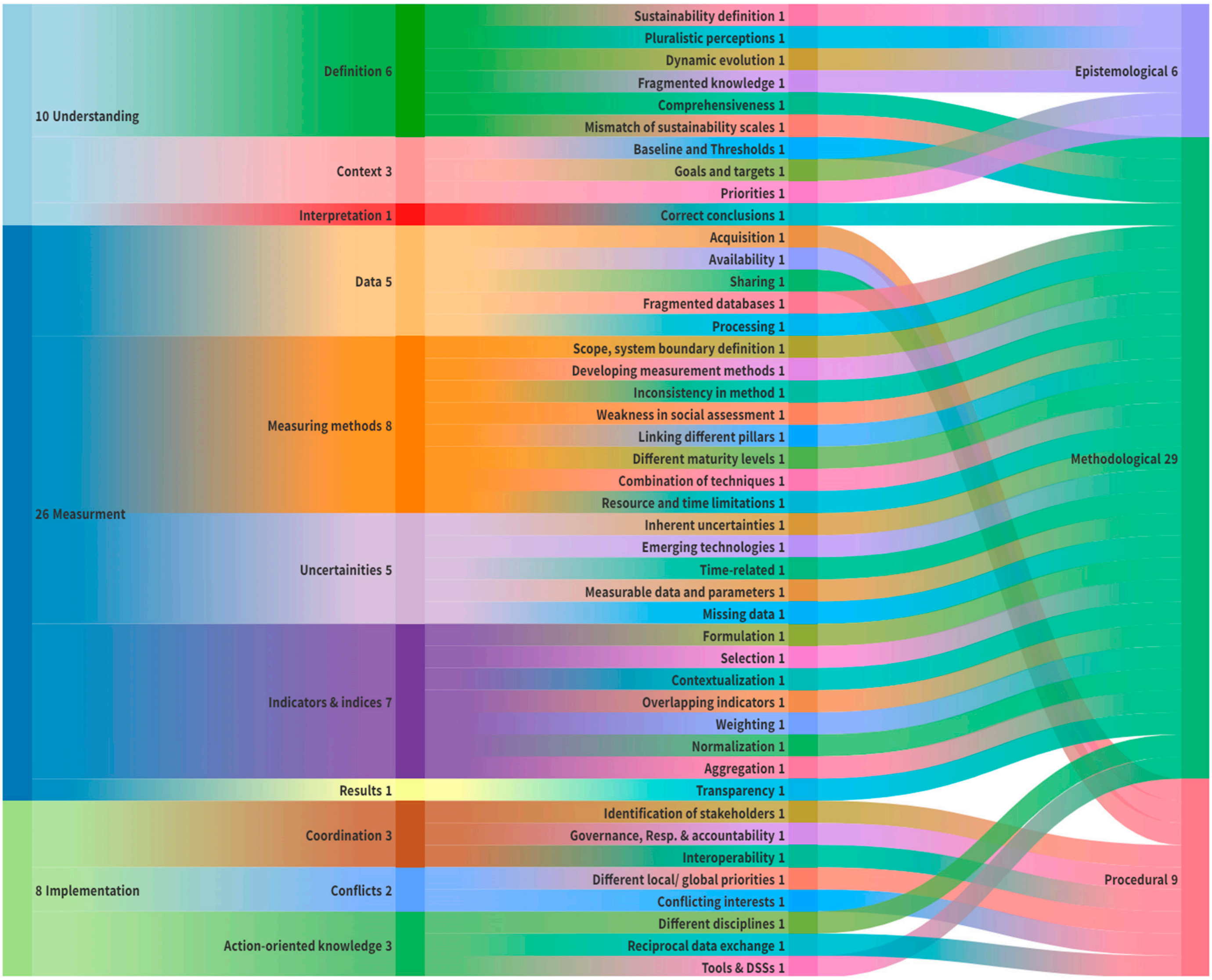

Figure 2. The classification of the challenges in sustainability assessment into layers and categories.

As shown in Table 1 and Figure 2, the challenges related to sustainability assessment definition, databases, measurement methods, selection, and the aggregation of indicators alongside the methodological weakness in measuring methods of the social dimension are the most addressed ones in the reviewed papers. Based on a critical review, almost all existing challenges in sustainability assessment are reported in this table and classified into pre-described categories to provide a holistic view of all sustainability assessment challenges. Likewise, the associated challenges for all sustainability pillars, including the environment, economy, and society, or those aspects that might draw more attention in the future, such as the institutional dimension, could be similarly classified into epistemological, methodological, and procedural challenges as described in this section.

Table 1. The three layers of the existing challenges in sustainability assessment of the built environment are classified into Epistemological, methodological, and procedural challenges, E: epistemological, M: methodological, P: procedural.

1st Layer	2nd Layer	N.	3rd Layer	E	M	P
Understanding	Definition	1	Sustainability definition [13–23]	✓		
		2	Pluralistic views and perceptions [14,17,24–30]	✓		
		3	Dynamic evolution of the problem [20,24,31–33]	✓		
		4	Different types of knowledge and fragmented knowledge [14,27,29,30,34]	✓		
		5	Mismatch of sustainability scales related to time, space (local to global), and disciplines [8,11,20,29,35–37]		✓	
		6	Comprehensiveness and Knowledge creation amongst different disciplines [14,20,27,29,34,35,37–41]		✓	
	Context	7	Baseline and Thresholds [19,32]		✓	
		8	Goals and targets [8,19,42,43]	✓		
		9	Priorities [3,30,31,44]	✓		
	Interpretation of results	10	Correct conclusions [10,14,45–49]		✓	
Measurement	Data challenges	11	Data acquisition [11,14,49–51]			✓
		12	Data availability [8,11,12,18,21,23,30,52–56]			✓
		13	Data sharing [11,55,57]			✓
		14	Working with different data sources-Selection of specific data in fragmented databases [22,38,43,50,58]		✓	
		15	Extensive data processing [11,12,59]		✓	
	Measuring methods challenges	16	Scope, system boundary definition [8,12,22,54]		✓	
		17	Developing measurement methods—Allocation of impacts to different categories [13,15,17,19,21,22,40,43,59–65]		✓	
		18	Inconsistency in quantitative and qualitative measuring methods [14]		✓	
		19	Weakness in social assessment [10,11,19,21–23,32,35,58,66,67]		✓	
		20	No clear methodology links the three dimensions [12,23,27,39,50,52,54,58–60,68]		✓	
		21	Different maturity levels in the three dimensions [11,14,33,35,52,58,59,67,69]		✓	
		22	Combination and harmonization of metrics and techniques [27,29,39,43,50,54,58,59]		✓	
		23	Resource and time limitations for the in-depth assessments [11,14,29,31,70]		✓	
	Uncertainties	24	Inherent uncertainties of sustainability [8,22,33]		✓	
		25	Emerging technologies' uncertainties [11,14]		✓	
		26	Time-related uncertainties [11,12,31,45]		✓	
		27	Uncertainty of measurable data and parameters [35,53]		✓	
		28	Uncertainty due to missing data [11,43,53]		✓	
	Indicators and indices	29	Formulation of indicators [11,12,16,23,32,43,45,59,64,71]		✓	
		30	Selection of indicators [5,11,18,19,21,23,24,45,54,56]		✓	
		31	Contextualization of indicators [15,32,45,69]		✓	
		32	Overlapping indicators [43,72]		✓	
		33	Weighting among indicators [3,8,10–12,22,43,44,59,73–75]		✓	
		34	Normalization [10,11,22,59,60,74,75]		✓	
		35	Aggregation [8,11,12,23,33,39,54,59,60,66,68]		✓	
	Results	36	Transparency [8,11,22]		✓	
Implementation	Coordination	37	Identification of stakeholders [8,22,32]			✓
		38	Governance, Responsibility, and accountability—Coordinating independent actors and Involving stakeholders [8,24,44,76–79]			✓
		39	Interoperability [14,20,54,55]			✓
	Conflict	40	Different local/global priorities [30,31]			✓
		41	Conflicting interests among stakeholders [29,31,78]			✓
	Action-oriented knowledge	42	Action-oriented knowledge creation within different disciplines [20,27,29,41,46,47]		✓	
		43	Reciprocal knowledge and data exchange [27,40]			✓
		44	Integration in tools and decision-making support systems [8,13,24,31,33,44,50,62,72,73]		✓	

2.1. Epistemological Challenges—Toward a Common Understanding in Sustainability Assessment

Epistemology, in general, refers to the theory of knowledge regarding its methods and scope, and by epistemological challenges, we aim to refer to those questions that come from the perception of sustainability and sustainability assessment and its scope. It mainly refers to *"what"* questions, such as what needs to be sustained, what are the sustainability pillars and what needs to be prioritized, etc. These challenges are identifiable by three characteristics: first, they contribute to the public perception of the question of sustainability assessment; second, they engage the attitude of policymakers as well as scientists; and third, their answers contribute to providing sustainable policies and regulations for action plans. These challenges originate from fundamental questions about sustainability at local and global levels and must be answered in a co-producing knowledge process in which the answers are provided by scientific communities in collaboration with public policymakers.

According to the three characteristics mentioned above, and the review results in this study, most challenges in the understanding layer belong to the epistemological category of challenges, such as the definition and the pluralistic perception of sustainability, and the fragmented body of knowledge in the sustainability assessment of the built environment alongside the dynamic evolution of the concept of sustainability assessment over time are the main epistemological challenges that ultimately lead to controversies in setting the goals and priorities for the sustainability of the built environment (Figure 3).

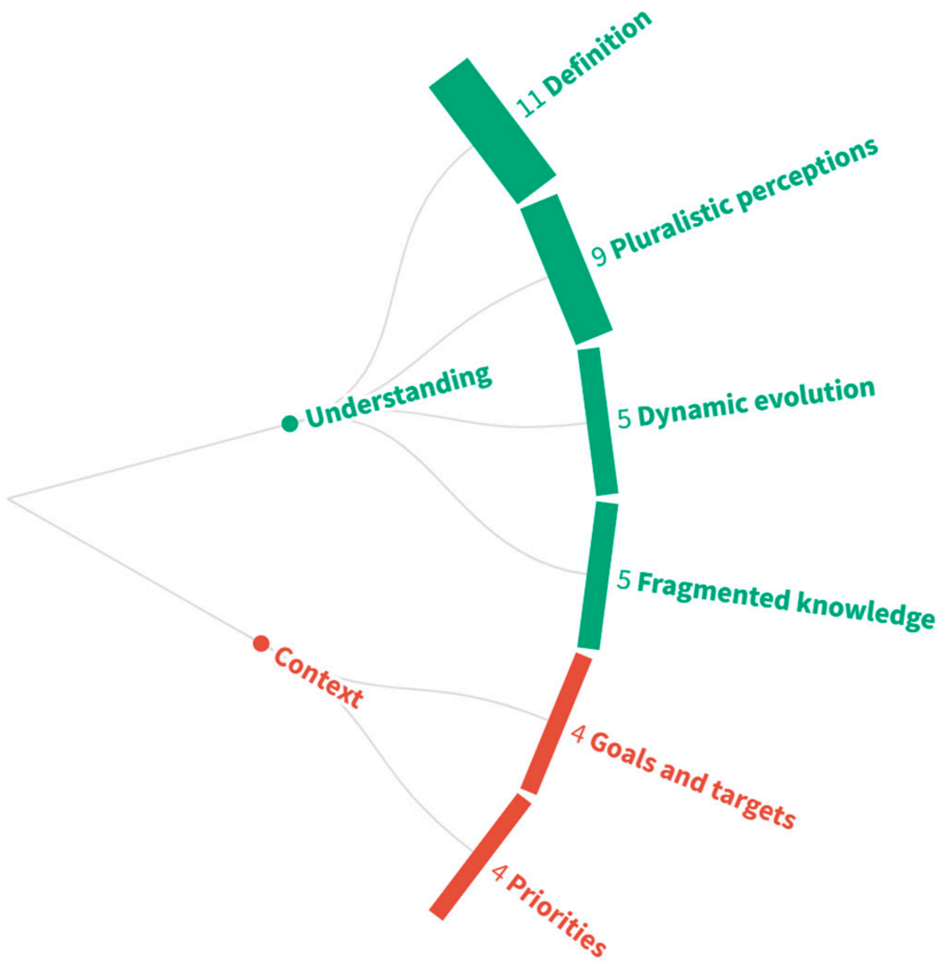

Figure 3. Epistemological challenges of sustainability assessment in the built environment in the reviewed publications. The numbers indicate the frequency of challenges reported in the reviewed publications.

All these challenges have the three characteristics described before. Although the solution for these challenges must be created based on scientific methodologies and engaging policymakers, it requires a dynamic dialogue among scientific communities and public policymakers, who are together responsible for drawing the future trajectories for sustainable development. Therefore, although epistemological challenges and questions are described first, the answers to these challenges are mainly provided through scientific-based methods, which leads us to the second category of challenges, named methodological challenges.

2.2. Methodological Challenges—Toward Measuring Sustainability

Most methodological challenges mainly refer to "*how*" to measure sustainability and the progress toward sustainability. Methodological challenges account for most challenges discovered in the literature, covering around 66% of all reviewed challenges. Although epistemological challenges are mainly centered around the definition of sustainability, methodological challenges exist at all layers and groups of challenges, such as understanding, measurement, and implementation. At the understanding layer, the concept of sustainability assessment has been expanding and covering different and new disciplines over time, and therefore providing comprehensive methods to include and integrate different disciplines requires methodological advances and working with different forms of knowledge in sustainability assessment for drawing correct interpretations and conclusions needing compatibility, comparability, and harmonization among the adopted methodologies. At the measurement level, several challenges could be classified as methodological challenges that need methodological advances—for instance, establishing how to manage the inconsistencies of qualitative and quantitative measuring methods, managing data from different sources, and the data processing acceleration [80,81]. Managing the uncertainties related to missing data, time scales, and emerging technologies is another methodological challenge. Furthermore, the assessment methods of the sustainability pillars are not equally developed, and the measurement in the social dimension still requires methodological advancement.

The definition and selection of indicators and indices that are contextualized and globally agreed upon represent further methodological challenges. Normalization, weighting methods, and the aggregation of indicators alongside the transparency of results are other examples of methodological challenges in a specific form of sustainability assessment called LCA, and are cited in many research works. There is also a methodological challenge in linking different sustainability pillars through a holistic formulation of sustainability assessment reported by several researchers, as shown in Table 1. Developing methods to create action-oriented knowledge based on the results of the sustainability assessment and integrating these methods into decision-making support systems (DSSs) are other methodological challenges that could be highlighted at the implementation level. Figure 4 represents several methodological challenges in the literature at the second and third layers of the discovered challenges in this paper.

Methodological advancements help to reinforce and form the body of knowledge in sustainability assessment and concern transforming fragmented data into quantitative and qualitative information about various aspects of sustainability. Scientific societies are responsible for resolving the methodological challenges that would benefit both policymakers and stakeholders, such as producers and/or consumers, to understand the impact of their activities and the effectiveness of sustainable measures and regulations.

2.3. Procedural Challenges—Towards Implementing Sustainability Assessment

Procedural challenges mainly refer to those challenges that might hinder the implementation of sustainability assessment, such as the lack of data, the identification of stakeholders and accountability, interoperability, governance, and managing the conflicting interests of stakeholders. They affect the measuring process of sustainability and impose the sustainability regulations as integral steps in measurement and the effective implementation of sustainability measures, since it requires the systemic coordination of all involved actors in the field.

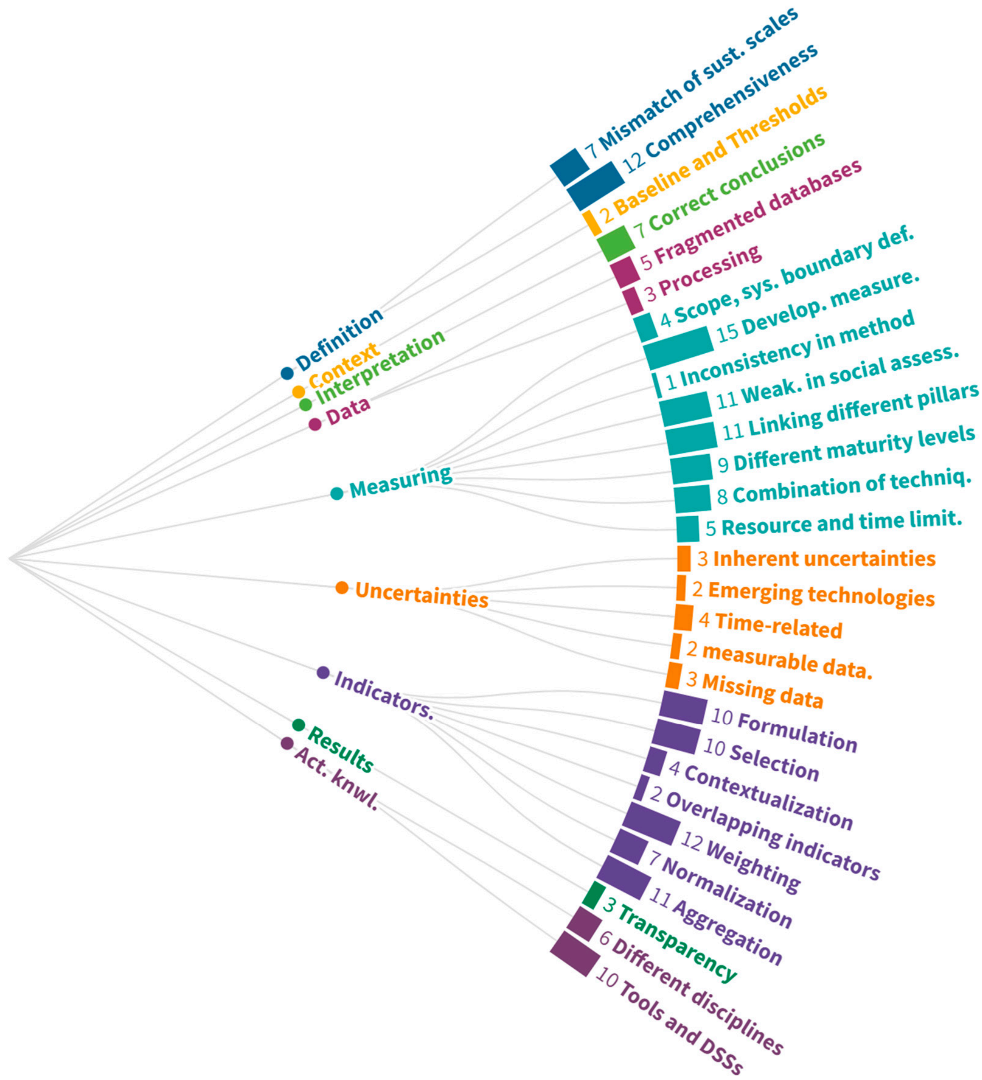

Figure 4. Methodological challenges of sustainability assessment in the built environment in the reviewed publications. The numbers indicate the frequency of challenges reported in the reviewed publications.

The availability and accessibility to comprehensive and updated databases play a significant role in facilitating the measurement process. This matter concerns access to required data and the format by which inventories store and communicate the stored data. The data both originating from research works and produced by industry are fragmented, either in the form they are prepared or the databases they are stored. However, the progress towards creating global data inventories in the field of environmental sustainability is a step forward, but has not eradicated the data availability challenges. The problem becomes even more complicated in qualitative data sharing, where ethical and practical challenges are more difficult to resolve [55]. Therefore, more actions need to be taken by all involved actors to prepare data inventories and make them publicly available alongside preparing and following the standards for these steps.

Resolving the challenges of quantitative and qualitative data sharing contributes not only to scientific efforts, but also to policymaking [57]. The feedback data from the engaged stakeholders help policymakers to improve their policies [28]. In this case, not only the data circulation but also how to identify, manage and coordinate the stakeholders are recognized as procedural challenges in implementing sustainability assessment. To implement sustainability assessment, other procedural challenges are found in the literature, mainly concerning the governing and coordination of key role players for cumulative efforts towards fulfilling the requirements of sustainability assessment [8,76,77,79], and providing a definition of responsibilities [78], alongside managing conflicting interests among different groups of stakeholders [29,31,78] reported by several researchers for effective the implementation of sustainability assessment. Figure 5 illustrates the procedural challenges identified in the reviewed articles in this paper.

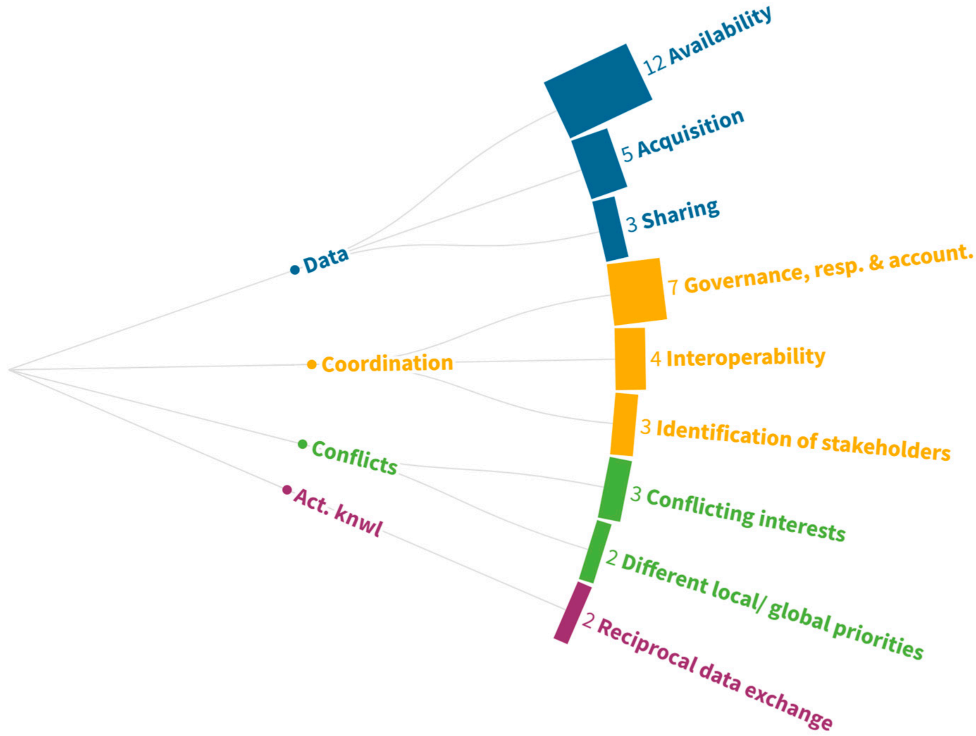

Figure 5. Procedural challenges of sustainability assessment in the built environment in the reviewed publications. The numbers indicate the frequency of challenges reported in the reviewed publications.

3. A Holistic Framework in Sustainability Assessment: Co-Knowledge Production and Implementation

Sustainability assessment, from its understanding to the measurement and implementation, needs an interdisciplinary effort and requires a holistic transdisciplinary approach by which several levels of associated challenges should be resolved. For instance, the epistemological challenges cannot be resolved unless robust methodologies are developed by scientific communities, which requires a high level of cooperation amongst various scientific disciplines and a strong commitment by the stakeholders to provide adequate access and transparency to data inventories. Therefore, sustainability assessment would not reach the required level of maturity unless all EMP challenges are addressed within a holistic framework in which all key actors, including strategists, scientists, and stakeholders (3S), are committed to playing their roles systematically and coordinately, as described below.

Strategists in this paper refer to those in charge of designing, legislating, and imposing future regulations. Scientists are those responsible for developing scientific methods to measure and monitor sustainability, and stakeholders are considered all groups who are subjected to sustainable regulations, such as producers, consumers, designers, engineers, etc.

To realize this framework in this paper, we illustrate the Sustainability Assessment Network, in which the relationship between EPM challenges and the involved groups (3S) of each challenge category is discussed (Figure 6). The Sustainability Assessment Network proposed here is a conceptual area where the classified challenges of sustainability assessment are assigned to the relevant groups involved in realizing and implementing sustainability assessment.

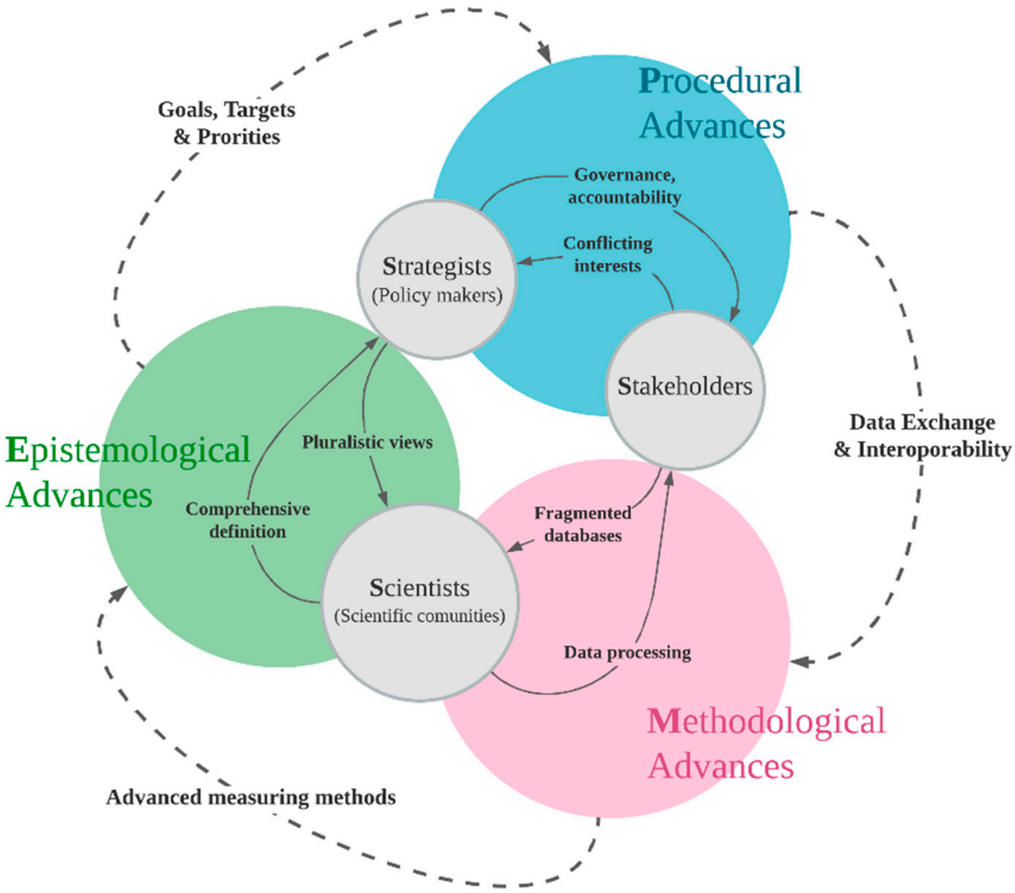

Figure 6. The Sustainability Assessment Network.

Figure 6 illustrates the complexity and interdependency of the challenging areas of a sustainability assessment framework. As shown in Figure 6, addressing the challenges in sustainability assessment requires interdisciplinary cooperation and transdisciplinary coordination among the key role players in a sustainability assessment network. Such coordination can guarantee the effectiveness and consistency of interdisciplinary efforts to resolve the associated challenges of sustainability assessment.

The answers to epistemological challenges for contributing to generating action-oriented sustainability knowledge are the prerequisite for legislating sustainable regulations. This knowledge is the output of the interdisciplinary research works by scientific communities and informs policymakers about the sustainability measures to be taken and their impacts. Although resolving epistemological challenges is a prerequisite to creating action-oriented knowledge for legislating sustainable policies, the answers to epistemological challenges are provided by scientific societies to establish a comprehensive understanding of sustainability assessment and possible solutions to achieve sustainability targets. Therefore, scientific communities are responsible for addressing the epistemological challenges through advanced methods in sustainability assessment to provide a clear and comprehensive understanding of sustainability assessment. Such an understanding of sustainability assessment and its boundaries, therefore, helps strategists and policymakers to put sustainability measures into action as well as provide solutions to procedural challenges relating to sustainability assessment. Therefore, epistemological challenges can be described in an agenda where scientific communities contribute to enlightening the concept of sustainability assessment for policymakers to legislate and enact regulations.

Scientific societies are also responsible for resolving methodological challenges by developing advanced sustainability assessment methods. The primary goal of methodological advances is to translate the activity data from stakeholders into meaningful information representing the impact of activities on sustainability pillars to enlighten strategists and stakeholders about their policies and practices. Their final goal is to shape the updated sustainability knowledge accurately and understandably to its users. Therefore, by answering the methodological challenges, scientific communities contribute to providing two groups of role players including policymakers and stakeholders with information and understanding of the different types of impacts on sustainability pillars.

Procedural challenges, on the other hand, arise mainly during the measurement and implementation steps of sustainability assessment. Strategists are responsible for planning the regulations based on the action-oriented knowledge achieved through methodological advances. The regulations should be set while also considering the capabilities of the stakeholders; therefore, dynamic monitoring and receiving feedback from the stakeholders are required to revise procedures. A significant proportion of procedural challenges are related to data availability. This group of challenges might negatively affect the output of sustainability assessment tasks by increasing the data-related uncertainties or lack of adequate and reliable data. Therefore, dynamic interoperability among all actors to guarantee access to data inventories should be promoted in this holistic framework.

In summary, it should be highlighted that all the active groups, including strategists (public policymakers), scientific communities, and stakeholders, must work together to fulfill their assigned functions to resolve EMP challenges accordingly and effectively. The whole process relies on full cooperation, since each group must deliver input data or receive required information coming from the other group. To better clarify this, public policymakers and scientific communities must work together to determine the most critical aspects and priorities of sustainability. Scientific communities must collaborate with stakeholders to provide two-way data and information streams that make the methodological assessment feasible and understandable both for stakeholders and policymakers. Likewise, public policymakers should work together with stakeholders and scientists to better understand their needs and potential and regulate the whole collaboration framework amongst all involved groups.

4. Conclusions

This paper mainly contributed to providing a clearer and more comprehensive vision of the challenges related to sustainability assessment in the built environment. Several existing challenges associated with sustainability assessment in the built environment were reviewed and discussed. These challenges were classified into different categories according to the steps of sustainability assessment that they are attributed to. Therefore, challenges from the understanding to measurement and implementation levels of sustainability assessment were collected from the literature and further categorized into sub-categories including definition, context, interpretation, data, measurement methods, uncertainties, indicators and indices, results, coordination, conflicts, and action-oriented knowledge.

Reviewing the associated challenges reported in the literature reaffirmed that several controversial issues still exist in this field. Furthermore, these challenges have become more complex when public policymakers tend to approach sustainability assessment within a decision context. In this context, several challenges emerge that need to be systematically resolved. Therefore, to better understand and clarify the nature of these challenges, this paper proposed a new classification system to categorize challenges into three distinct categories.

Epistemological challenges, as defined in this paper, include those challenges related to the understanding and interpretation of sustainability and sustainability assessment. These challenges need to be resolved to define the sustainability pillars and the target of sustainable development programs. These challenges are fundamental not only to the overall sustainability assessment but also to defining each sustainability pillar. The challenges related to the definition of sustainability and sustainability assessment alongside the pluralistic perception of sustainability are found as the most cited epistemological challenges in the literature.

The second category relates to methodological challenges, referring to those challenges associated with measuring methods for overall sustainability and each sustainability pillar. For instance, several methods to measure environmental sustainability have been proposed and applied in the literature; however, there is still a continuous attempt to enhance the scientific methods to measure and monitor environmental sustainability. The need for developing an integrated sustainability assessment methodology able to measure all sustainability pillars through a combination of different methods is highlighted in the literature.

This paper highlights some of the most important examples of open challenges and questions as methodological challenges. It should be noted that these examples could be expanded or become more detailed when referring to a specific field of application (e.g., building science, etc.). It should be considered that more technological advances and complicated systems will need more advanced methods. Therefore, methodological development in this context will be continuously needed. The evolving interactions amongst environmental, economic, and social aspects indicate that methodological development and the interpretation of sustainability need to be updated over time. Amongst methodological challenges, the development of measurement methods, the comprehensiveness of assessment, the lack of a clear methodology to link and integrate the three pillars of sustainability, the weakness in assessment methods for the social aspect of sustainability, the formulation and aggregation of indicators, and developing integrated tool and decision support systems are found as the most commonly addressed challenges in the sustainability assessment of the built environment.

The third category of challenges involves procedural challenges that encompass the practical difficulties in the implementation of assessment methods in a decision context. The stakeholder's participation, data availability and preparation, and regulation of the cooperative frameworks amongst all actors in implementing sustainability assessment in decision contexts are the highlighted procedural challenges that need to be resolved to facilitate the effective implementation of sustainability assessment as a decision support system. Data-related challenges, including the availability of required data for sustainability assessment, alongside coordination challenges such as the responsibility and accountability of different involved actors in sustainability assessment, are found to be the most important procedural challenges in the sustainability assessment of the built environment in the literature.

In this paper, the Sustainability Assessment Network is illustrated as a conceptual area where all actors and engaged groups in sustainability assessment are gathered to resolve the classified challenges in a collaborative environment. The Sustainability Assessment Network emphasizes that the classified challenges will only be resolved if full cooperation and mutual understanding are achieved amongst the involved groups. Then, it would be possible to systematically identify and resolve different challenges of sustainability assessment in a decision context.

This review and classification of sustainability assessment in the built environment provide a basis for future research works and policy programs by which scientific researchers and policymakers in the field of sustainability assessment can better realize the main challenges and the solutions to tackle the associated challenges in a holistic, structured and coordinated way.

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