Sustainable Design, Construction, Refurbishment and Restoration of Architecture: A Review

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Abstract: Considering the serious challenges our planet is facing, the building environment and construction sector must minimize their high negative impacts and maximize their contribution to sustainability. Many alternatives could promote this change, but to effectively optimize our architecture, we must take the step of quantifying and qualifying the sustainability of our constructions by choosing the best assessment alternative in each case. Many assessment methodologies and tools exist and there have been numerous reviews of them. The main objective and novelty of this review is to present an updated critical overview of all the sustainability evaluation alternatives developed in research studies in the fields of architectural design, construction, refurbishment and restoration. To achieve this, the analysis follows a specific methodology based on recent similar reviews. The result is a database with 1242 eligible documents analyzed in this review and attached as supplementary material available for future studies. As a main conclusion, rating tools and life cycle methods were found to be the most commonly applied methodologies, while the most recent tendencies use combined methods and probabilistic scenarios. This review could be useful to move towards a more sustainable building environment.

Keywords: building sustainability assessment systems (BSAS); green buildings; rating tools; life cycle assessment (LCA); multi-criteria decision making (MCDM); life cycle cost (LCC); building environment

1. Introduction

In response to the serious current environmental problems at a global level [1], the building environment and its sector could contribute to mitigating their own high negative impacts [2] and move towards a less polluting model [3]. Architecture design and construction have a long history that contains numerous examples of low environmental impact buildings, from vernacular architecture [4] to more recent examples such as Gaudi's waste-based architecture [5]. These past eco-friendly solutions have been both cost-effective and socially respectful. They would be sustainable according to the current holistic definition of sustainability, provided by the Brundtland Commission report [6] and following studies [7] that have included economic, social and environmental areas. Some later research projects have addressed technical [8], governance [9] or cultural factors, among others [10]. At present, there are numerous sustainable architectural designs that result from using building information modeling (BIM; Appendix A presents a complete list of abbreviations in Table A1) [11], incorporating intelligent façade layers [12], passive energy solutions [13], nearly zero-energy buildings [14], the use of recycled construction materials [15] and vertical farming [16], among others.

To choose the best design for each case from all these interesting options, decision makers need strategies to evaluate and rank the sustainability of potential solutions and measures [17]. There are numerous alternatives, from compulsory standards [18] to sophisticated methodologies developed for a particular case study [19]. In between are numerous recognized tools and methodologies [20].

These may be holistic if they assess all branches, for example most rating tools [21], or partial if they assess only one branch, for example energy simulations combined with a life cycle assessment (LCA) that focuses mainly on the environmental requirement [22].

Nevertheless, to decide which assessment tools should be applied in each case, it would be useful to have a critical review of academic studies on these assessment strategies. Most reviews have focused on a specific type of assessment alternative such as simulation optimizations to achieve green buildings [23], LCA for building rehabilitation [24,25], the carbon emissions of buildings [26], multi-criteria decision making (MCDM) methods for the construction sector [27] and rating tools [28–32]. Consequently, there is lack of reviews that compare all available sustainability assessment approaches. The most comprehensive reviews exclusively study holistic sustainability assessments [21] or focus on specific topics such as the resilience of off-site construction [33].

These studies have contributed significantly to advancing towards a more sustainable building environment. To continue to move forward, this review aims to present an updated analysis of all the alternatives that are available to assess sustainable architecture and its design, construction, refurbishment and restoration, including holistic and partial approaches. To the best of the authors' knowledge, this is the first review that has this scope and perspective. The study is expected to be useful for decision makers to identify available assessment approaches, choose the best option for analyzing alternatives that improve the building environment's sustainability, and therefore apply the best alternative and contribute to improving sustainability at global level. This report achieves this by means of two analytic levels. The first evaluates studies on sustainable architecture assessment in general, while the second focuses on sustainable design, construction, refurbishment and restoration. The next section explains in depth the methodology followed to carry out this review. Section 3 shows the results, Section 4 contains a discussion of outcomes and Section 5 describes the conclusions.

2. Methodology

The methodologies used in similar reviews were considered in this study [21,27]. Figure 1 presents the steps that were followed.

S1	Preparation	i) Define review topic, subtopics, format and boundaries ii) Choose databases: main and complementary iii) Define searches and search keywords iv) Define the search procedure
S2	Identification	i) Obtain data from database searches ii) Remove outliers by topic and format
S3	Classification	i) Classify results by the main characteristics of the research ii) Identify the studies that are most closely related to the review
S4	General study	i) Obtain and compare the general results ii) Assess results chronologically and bibliography
S5	Detailed study	i) Obtain and compare the detailed results ii) Analyze in detail the research studies that are most closely related to the review

Figure 1. Main steps followed in this review.

The first step (S1) was to organize the review into four subphases. In the first subphase, the review topic, subtopic, format and the boundaries of the studies that were to be included were defined. In the

second phase, the databases were defined, and the main and complementary databases were selected. The main database was the first to be searched and its results were used as the basis of the review, while the complementary databases added to and confirmed the main database results. In searches of the complementary databases, duplicates were eliminated and, progressively, negative keywords were applied according to the previous results. Then, the researchers defined the searches to be carried out and the exact search keywords. They considered the possibility of using other specific search options available in the database. Finally, the fourth phase defined the search procedure for each database, which meant defining limits in the maximum number of studies analyzed in each database and, if applicable, the order of priority when reviewing them. Section 3.1 explains in detail the results of applying this phase in state-of-the-art studies. The possibility of searching more articles from references within each article was also considered in this subphase. In the second step (S2), the eligibility of studies obtained from the search was analyzed by identifying the outliers that were beyond the boundaries defined in the first step. Step S3 classified these studies depending on their general topic and detected studies that were most closely related to the specific topic of this review. Then, the fourth step (S4) focused on a general analysis of eligible studies, considering chronological and basic information. Consequently, the eligible studies were also classified depending on how each related to the main objective of this review. Finally, the most closely related studies were assessed in detail. The assessment was mainly based on the abstracts and basic information. The following five research features were considered: (a) general approach, (b) research location, (c) specific topic, (d) application and (e) assessment type, phase and alternative.

3. Results

This section presents the results of the review's five steps while the following section presents the analysis carried out in the last two steps, which were presented in Figure 1.

3.1. Preparation

The research review's main topic is based on the Section 1: sustainability assessment of architectural design, construction, refurbishment and restoration. The topic is divided into four subtopics: (St1) sustainability assessment (SA) in design; (St2) SA in construction; (St3) SA in refurbishment; and (St4) SA in restoration. The limits of the topic and subtopics are established by the design scale. Thus, studies at the scale of buildings are most closely related to the review topic. Articles that are less closely related to the search topic are focused on:

- a larger scale, for example urban planning and landscape;
- a smaller scale, for example materials.

Studies included in the search are in the format of academic studies including research articles, congress papers, books and book chapters. Other contributions, such as patents, citations and entire congresses or special issues, are not included.

The main database was the Web of Science Core Collection database [34] as the review was focused on academic studies, and the results of this search are more limited and could be more completely studied with the available resources. The complementary databases that were consulted were first Google Scholar [35] and second Scopus [36]. These databases were selected considering the existing reviews mentioned in the above sections.

Searches and their keywords in this review were defined considering the aforementioned topics and subtopics and the general results obtained using the main database. The objective was to obtain from the main database over 100 results per subtopic by using the aforementioned subtopic title as keywords or synonyms, and up to three trials. Table 1 presents the resulting keywords that were selected. The definition of these research words also took into account similar previous reviews and related technical literature in the general field of architecture [37,38] and in the specific fields of construction [26,39], refurbishment [40,41] and restoration [42]. Thus, St1 included architecture and its

design, considering the holistic approach to architecture from the Vitruvian Triad approach [43] and its conception process. St2 considered the building sector, construction and technologies of architecture and buildings and, therefore, focused on the technical part of architecture, on the "firmitas" part of the aforementioned Triad [43]. Both St3 and St4 addressed the renovation of buildings, and focused on sustainable retrofitting, rehabilitation and refurbishment of existing buildings [44] in the case of St3, while St4 centered on the sustainability of historical and heritage architecture [45]. The authors decided not to use other search options, such as the root of the family word and the symbol asterisk, because the keywords were clear as a whole word from the outset, and the resulting academic studies were consistent with the research project. Furthermore, due to the number of results, references within the articles were not searched in depth to find more articles.

Table 1. Search and keywords definition.

Topic	Search	Keywords	NRMD [1]
St1	St1a	Sustainability + assessment + architecture	332
	St1b	Sustainability + assessment + architecture + review	50
	St1c	Sustainability + assessment + architecture + design	201
St2	St2a	Sustainability + assessment + architecture + building sector	28
	St2b	Sustainability + assessment + construction + buildings + architecture	89
	St2c	Sustainability + assessment + construction + buildings + technologies	184
St3	St3a	Sustainability + assessment + refurbishment + buildings	85
	St3b	Sustainability + assessment + refurbishment + architecture	5
	St3c	Sustainability + assessment + retrofitting + architecture	11
St4	St4a	Sustainability + assessment + restoration + buildings	36
	St4b	Sustainability + assessment + restoration + architecture	8
	St4c	Sustainability + assessment + renovation + architecture	9

[1] Number of results in the main database. Legend: St1: subtopic one, which is sustainability assessment (SA) in architecture; St2: subtopic two, which is SA in construction; St3: subtopic three, which is SA in refurbishment; and St4: subtopic four, which is SA in restoration.

The search procedure was defined as follows. First, the search in the main database was carried out and all the results were considered. Then, the searches were carried out in the complementary databases, considering up to the first 100 most relevant studies only. When the secondary databases were searched, the results that were added dropped to below 10% in the first secondary database and 1% in the last database.

3.2. Identification

The searches were carried out from July to October 2020. The results are depicted in Table 2. The total results were 2859 studies, from which 53 were directly discarded because they did not meet the format of documents included in this research, as explained in Section 3.1. Then, after detecting duplicates, the sample of 1535 documents was defined.

From these 1535 results, 293 were discarded because they were outside the boundaries of the research review. Out of these discarded documents, 71% were about sustainability but not about architecture, as they focused on industrial products and civil works, among others. A further 14% were about architecture but not about sustainability, 8% did not meet important criteria such as having an abstract in the English language, and 7% had no connection with the topics in this review.

Table 2. Results from the searches.

Topic	Search	No. of Results in Databases			No. of New Results in Databases		
		Main	1st cmp.	2nd cmp.	Main	1st cmp.	2nd cmp.
St1	St1a	332	100	100	94	86	34
	St1b	50	100	37	49	73	12
	St1c	201	100	100	117	43	29
St2	St2a	28	100	31	6	67	12
	St2b	89	100	100	70	37	27
	St2c	184	100	100	161	54	49
St3	St3a	85	100	72	84	58	23
	St3b	5	100	7	0	50	1
	St3c	11	100	7	0	71	2
St4	St4a	36	100	44	22	67	18
	St4b	8	100	10	0	56	1
	St4c	9	100	13	0	61	1
Totals		1038	1200 2859	621	603	723 1535	209

Legend: St1: subtopic one, which is sustainability assessment (SA) in architecture; St2: subtopic two, which is SA in construction; St3: subtopic three, which is SA in refurbishment; and St4: subtopic four, which is SA in restoration. No.: number; cmp.: complementary.

3.3. Classification

The 1242 eligible research documents about sustainable architecture were classified according to their general topic into the following 10 subgroups:

(1) Buildings and its design: 381 documents
(2) Refurbishment and restoration: 305 studies
(3) Construction and technologies: 184 records
(4) Urban planning: 180 studies
(5) Materials: 58 documents
(6) Education: 54 studies
(7) Landscape: 28 records
(8) Energy systems: 27 documents
(9) Management: 17 records
(10) Real estate: 7 documents

From these documents, the most closely related to this review are the 870 studies in the first three subgroups, as this review focuses on buildings and their construction and refurbishment processes, without going into detail on other larger scale issues such as urban planning, landscaping and cities, or smaller scale approaches focused on material properties. Similarly, this review focuses on architectural solutions that are more closely aligned with passive solutions than with active engineering solutions. All 1242 eligible studies are described in general in the following subsection, while the three first subgroups are examined in detail in Section 3.5.

3.4. General Results

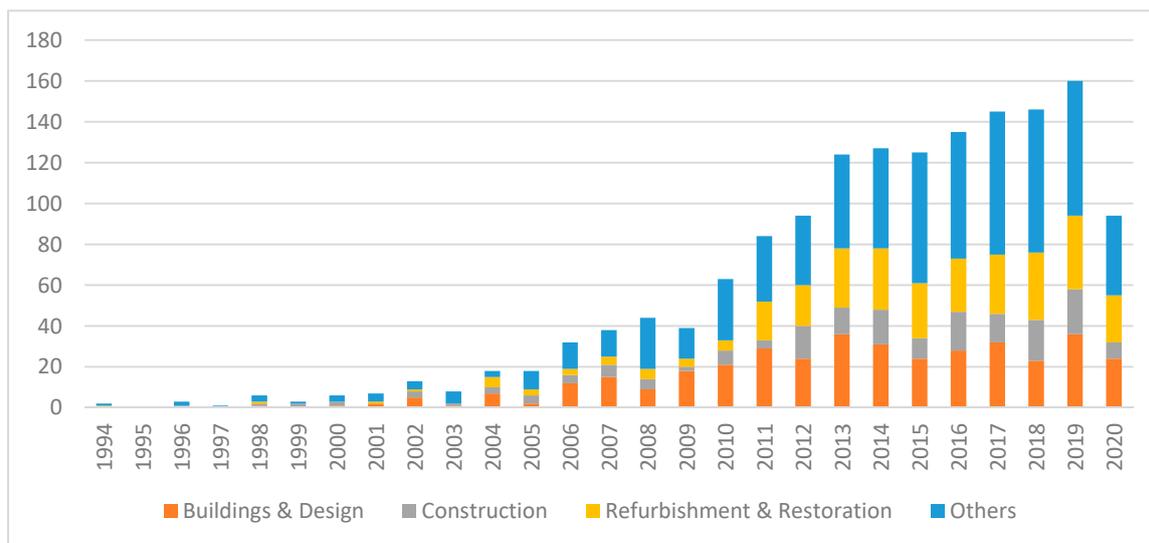The 1242 eligible documents are dated from 1994 to 2020 and distributed as shown in Figure 2.

Figure 2. Distribution over the years of the eligible research studies.

The document types were as follows: 59% research papers, 37% congress contributions and 4% book chapters.

3.5. Detailed Results

Out of the 870 studies that were most closely related to this review topic, 436 mainly had a theoretical approach as they described a new theory or model; 382 analyzed case studies using existing or new building sustainability assessment systems; and 52 reviewed part of the sustainability assessment in architecture. The distribution of these three groups of documents had an irregular, increasing curve during the study period, starting from the 1990s in the case studies and theoretical documents, and the 2010s in the case of reviews. Most documents had an international approach to their topic, while 336 dealt with a specific location. The specific locations were in Europe in 169 cases, in Asia in 119, America in 24, Africa in 22 and Australia in 7. The six countries in which the highest number of specific case studies were analyzed were Italy, Malaysia, Spain, Portugal, the United Kingdom and China. As expected, most studies were carried out in developed countries, but 25% centered on developing economies, starting from the 2000s. Most of these studies, 544, did not consider a specific building application. The most analyzed specific application was residential in 180 studies. Figure 3 presents the specific applications of these research projects.
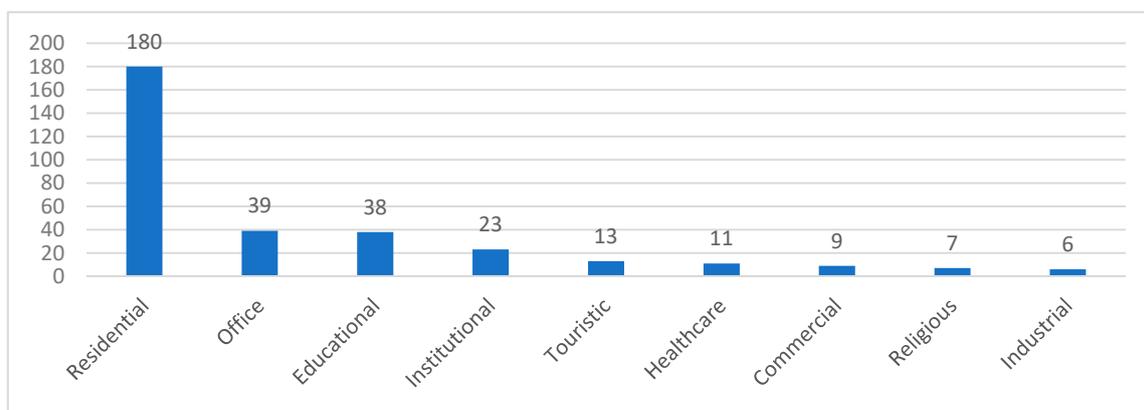

Figure 3. Distribution of the eligible research studies over the years.

Within the three general topics, 12 main specific topics were found, as depicted in Table 3.

Table 3. Main specific 12 topics within the general topics studied in depth.

General Topic	Specific Main Topics	Number of Studies
(1) Buildings and their design	(1.1) Sustainable solutions	244
	(1.2) Design process	66
	(1.3) Policies, legislations and strategies	31
	(1.4) Users' perspective	24
	(1.5) Affordable buildings and economic issues	16
(2) Refurbishment and restoration	(2.1) Rehabilitation	155
	(2.2) Energy retrofitting	73
	(2.3) Heritage	77
(3) Construction and technologies	(3.1) Technologies	75
	(3.2) Construction processes	48
	(3.3) Construction elements	37
	(3.4) Construction sector and industry	24

The first general topic included five specific topics. The first, "(1.1) Sustainable solutions", covered assessment, monitoring and case studies about green [46,47], smart and intelligent buildings [48] among others. The second, "(1.2) Design process", was about the conception process of green architecture [49,50]. The third, "(1.3) Policies, legislations, strategies", included these issues and competitions [51,52]. The fourth, "(1.4) Users' perspective", was about the inhabitants' perspective of sustainable buildings [53,54]. Finally, "(1.5) affordable green buildings and economic issues" focused on economic issues and the affordability of sustainable architecture [55,56]. The second general topic had three sections. The first, "(2.1) Rehabilitation", was on the renovation of buildings, with a focus on maintenance and refurbishment of components [57,58]. The second, "(2.2) Energy retrofitting", addressed the energy-based renovation of buildings [59,60]. Finally, "(2.3) Heritage" included valuable historical buildings and their restoration [61,62]. The third general topic had four subtopics. The first, "(3.1) Technologies", studied construction methods, systems and techniques [63,64]. The second, "(3.2) Construction processes", included building procedures and their phases [8,39]. The third, "(3.3) Construction elements", was about building components such as facades and structures [65,66]. Finally, "(3.4) Construction sector & industry" dealt with the building business, including new circular economic models [67,68].

Only 366 studies (42%) had a holistic approach to sustainability and studied its three branches of sustainability—according to its current holistic definition [6,7]—while the rest took a partial approach; 236 focused on environmental and economic issues such as energy efficiency studies [69,70] or studies incorporating LCA and life cycle costs (LCC) [71,72]; 182 focused on the environmental branch such as LCA [73,74] or low carbon studies [75,76]; 36 were on socio-environmental issues, for example [77,78]; 25 emphasized the social branch with social life cycle assessment (S-LCA) [79,80] and other methods; 13 centered on economic aspects with LCC [81,82]; and 12 on socio-economic aspects, for example [83,84]. Few studies focused on other sustainability branches or specific indicators [85]; for example, only 37 studies addressed cultural issues, from which 25 were about heritage [86], six about refurbishment [87] and six about architecture [38]. These cultural studies were published from 1994 to 2020, irregularly distributed over the years, with a slight increase in the last two years. Figure 4 shows the indicators that were considered in depth in the eligible studies over the years while Figure 5 presents these results in relation to the four main studied topics: design, construction, refurbishment and restoration.
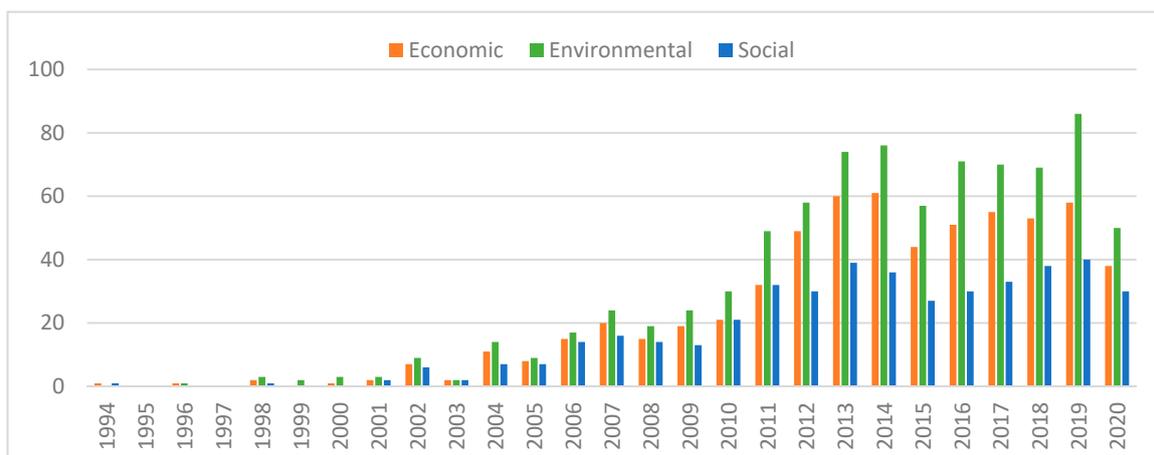
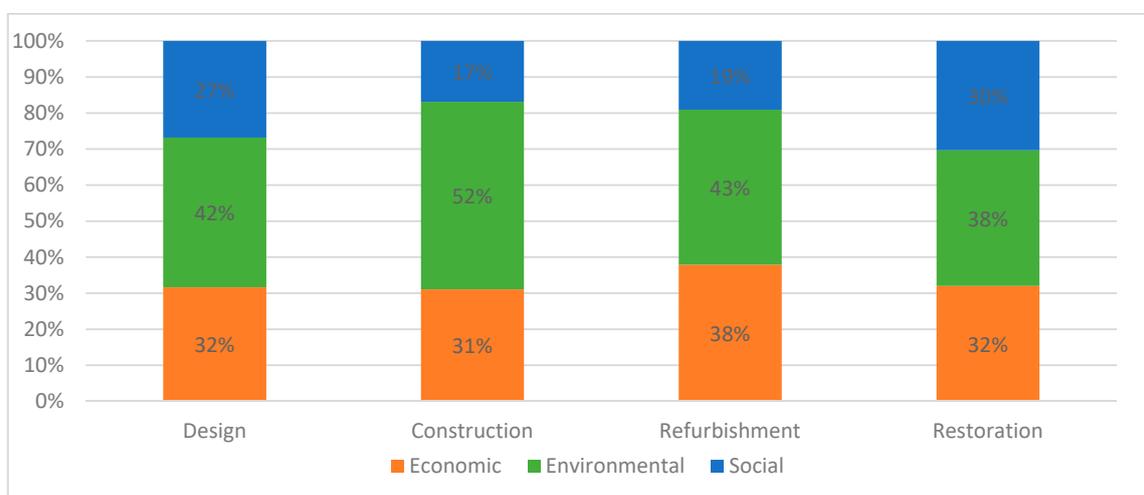**Figure 4.** Distribution of the studied branches of sustainability over the years.

Figure 5. Distribution of the branches of sustainability within the four main topics.

Most studies focused on a specific phase: 362 on post-occupancy [88,89] and 256 on the design period [90,91]. Most of the eligible documents contained an analysis: 444 used quantitative methods [92,93], 80 studies mixed quantitative and qualitative methods [94,95] and 106 analyses were based on qualitative analyses [96,97]. As mentioned in the introduction, these studies were expected to address different sustainability assessment alternatives. There were five main groups of well-known methodologies and numerous other specific evaluation approaches. The first and largest group was rating tools, which was the topic of 185 studies and included numerous certification systems. Some of the systems were international, with the most commonly applied being Leadership in Energy and Environmental Design (LEED) [98,99] with 41 studies and the Building Research Establishment Environmental Assessment Methodology (BREEAM) [100,101] with 27. Other studies described specific systems for particular locations [102,103] or historical buildings since 2014 [86,104]. The second largest group was the 179 life cycle approaches, composed of 141 LCA, 35 LCC, but only three life cycle energy assessments (LCEA) [105], three life cycle sustainability assessments (LCSA) [106,107] and five S-LCA [108]. The third group comprised 82 MCDM studies, such as the integrated value model for the evaluation of sustainability method known as MIVES [109–112]. The fourth was a heterogeneous group of 63 studies that adopted transversal techniques such as questionnaires, surveys [113,114], guidelines and checklist definitions [115,116], strengths, weaknesses, opportunities, and threats [117] or designing techniques [118]. Then, there was a set of 42 energy and thermal simulations [119] and monitoring [120]. Finally, there were 351 studies on other less commonly known

or specific methodologies, including specific frameworks [121,122] and searches of key performance indicators [123,124], software developments [125], specific calculations [126] and methodologies for reviews, among others [40,127]. The aforementioned specific methodologies were combined and used together in 52 studies. A total of 28 studies combined life cycle methodologies [128,129]. A total of 16 studies combined BIM with other assessment methodologies [130], from which nine focused on design topic, four on construction, two on refurbishment and one on restoration [131]. Only four BIM-combined articles had a holistic approach to sustainability, eight focused on environmental issues and five on environmental and economic issues. The most recurrent combination was LC methodologies with BIM [132,133] in 14 studies. Apart from these, seven projects combined rating tools with life cycle methodologies [134], four combined LCA with MCDM [135,136], and two combined energy modeling with BIM [137,138]. Figure 6 presents the applications of the most common groups of methodologies (rating tools, life cycle and MCDM) and the combination of them over the years.
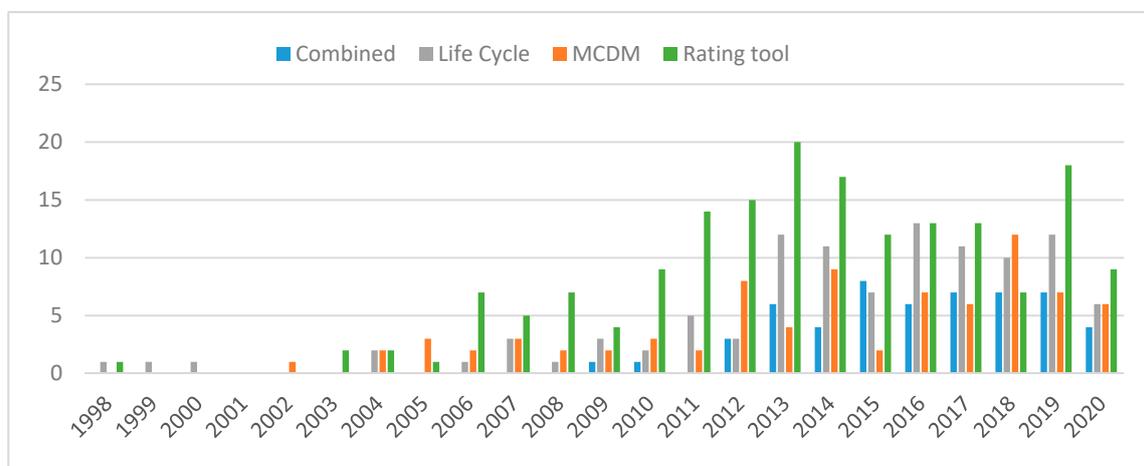

Figure 6. Distribution of the sustainability assessment methodologies over the years.

In terms of combined studies, the first methodologies that incorporated BIM emerged in 2013. In the last two years, 2019 and 2020, BIM was the most frequently combined alternative. Less than 2% of the articles incorporated probabilistic scenarios, and most were from the late 2010s.

4. Analysis

This section discusses the results presented in the previous section, which were obtained using the methodology explained in Section 2. This methodology enabled a review to be carried out with the limited available resources, without compromising the rigor of the results. At the same time, the methodology could be used for a more detailed review given greater resources. Although this version focused on the abstracts of papers and limited the number of papers from complementary databases, it did consider the most relevant information in the articles and included the most relevant articles according to database criteria.

As presented in Figure 2, the evolution of the number of eligible studies per year since the early 1990s has been irregular but has increased steadily, except for occasional drops in some years. The result was similar in the three general topics of buildings, refurbishment, construction, and others. As a set, these eligible studies had an irregular, increasing tendency from 1994 to 2013. After this date, the number of studies remained more constant until 2019. Nevertheless, the general trend was an increase that could be attributed to growing research interest that was detected in previous similar reviews [17,139].

Focusing on the 758 eligible documents, this review found that sustainability assessment in architecture and its design, construction, refurbishment and restoration has been relatively recent. This area started to be studied in research projects published at scientific level in the 1990s, while the

reviews of this area started in the 2010s. As expected, the locations of the studied case studies were mainly in Europe, followed closely by Asia, and mainly in developed countries. The ranking of the specific applications of the documents presented in Figure 3 also coincides with previous similar reviews [21].

The most studied specific topics cover green sustainable solutions, rehabilitation and technologies. These studies were mainly partial instead of holistic, as indicated in previous research [33,140]. The most studied branches were environmental and economic issues, as depicted in Figure 4. Within the four main subtopics in this research, the study of these four branches had a similar common tendency as depicted in Figure 5. In all design, construction, refurbishment and restoration, the most analyzed branch was environmental, while the least studied was the social pillar. Construction was the subtopic with the most studies about the environmental branch, while refurbishment has more articles dealing with the economic pillar. Restoration has more studies on the social branch and differs from the other subtopics as there are less differences in the number of studies related to each branch. This coincides with the fact that this subtopic has far more studies focused on cultural issues and, therefore, could be labelled as the most social and cultural subtopic.

From the main groups of well-known methodologies, the most commonly used were the rating tools. These take a holistic approach to sustainability and are used for the certification of buildings. Versions of each rating tool for each country are available within the Green Building Council [141] and inspired by the pioneer BREEAM in the 1990s [142] and the GBTool [143]. These certification systems evaluate the design or post-occupancy of buildings using checklists that cover numerous indicators on economic, environmental and social issues and give a score that is normally used as an added value for buildings. In some cases, this is mandatory [100]. Some are internationally applicable and applied. The most widely used is LEED and BREEAM according to the number of certified projects, among other indicators [30]. This number of applications coincides with the trend in academic studies found in this review. The second most broadly applied assessment methods are the life cycle tools, such as LCA, LCC, LCSA, S-LCA and LCEA. Other environmental tools have been used less frequently, including material flow analysis [144], material and energy flow analysis [145] and other environmental indexes [146]. Both of these rating and life cycle methods are used at a professional level and are probably also the most used along with energy simulations and studies. In this present review, these energy studies were the fifth group of tools used, which the authors explain because this review focused on sustainability but not on energy. No search word covered this field because it was outside the scope of the study.

Finally, this study also discovered as new tendencies from the early 2010s the combination of sustainability tools [134], the combination of BIM and sustainability assessment tools [147], and the incorporation of probabilistic scenarios and uncertainty [148]. The first studies on the sustainability of artificial intelligence, digital fabrication and robotics are dated from the late 2010s onwards. To the best of the authors' knowledge, these new tendencies have not focused on cultural issues, apart from one article integrating heritage BIM tools for the sustainability assessment [131]. Since 2013, sustainability assessment models combined with BIM have been applied to design [130], construction [149], refurbishment [132] and restoration [131]. These models have been developed in theoretical articles [138], applied to case studies [150] and studied in reviews [107]. Therefore, the authors foresee that this BIM combination will continue the previously mentioned current increasing tendency in the upcoming years.

5. Conclusions

This research project has produced a database containing basic information from the 1535 studied documents, general information from the 1242 eligible research papers, and a more detailed study of the 870 records that were closest to this review topic. The database is attached as supplementary material on state-of-the-art studies. From this database, the main findings of the review refer to the

evolution of the most relevant studies on sustainability assessment alternatives for architecture and its construction, refurbishment and restoration. These findings are as follows:

1. The number of studies per year increased from 1994 to 2013, then remained more or less constant until 2019.
2. General theoretical and case studies emerged in the 1990s, while reviews started to appear in the 2010s.
3. The most commonly applied methodologies are rating tools, followed by life cycle methods.
4. The combination of assessment tools, the combination of BIM and sustainability assessment tools, and the incorporation of probabilistic scenarios and uncertainty started in the early 2010s. However, the first studies about the sustainability of artificial intelligence, digital production and robots in architecture are dated from the late 2010s onwards. Based on the analysis of the BIM-combined tools, the authors foresee an increase in the publication of related studies in the future.
5. The most analyzed sustainability branch was environmental, while the least studied was the social pillar. Construction was the subtopic with the most articles about environmental issues, while refurbishment has more studies dealing with economic aspects and restoration has more articles on the social pillar.

These findings may be useful to gain an overview of the alternatives applied over these years as well as examples of their applications. This review, like similar previous state-of-the-art studies, focused on searches using content keywords related to the topic. Nevertheless, there were results in which assessment tools were combined and integrated. The authors foresee future interesting reviews that focus on incorporating concepts such as integrated or integral approaches, which are considered crucial in some present and future research projects, studies, models or processes [151]. This study was limited to research studies and projects, as a basis to be extended through integrated and integral models and processes. The next research steps should include data from professional practice to determine to what extent these conclusions are related to the professional world. This could help active professionals to move towards more sustainable architecture.

Appendix A

Table A1. Abbreviations used in the text.

Abbreviations	Relevant Values
BIM	Building information modeling
NZEB	Nearly zero-energy building
LCA	Life cycle assessment
MCDM	Multi-criteria decision making
Mt	Main topic

Table A1. *Cont*.

Abbreviations	Relevant Values
St	Subtopic
SA	Sustainability assessment
LCC	Life cycle cost
S-LCA	Social life cycle assessment
LEED	Leadership in energy and environmental design
BREEAM	Building research establishment environmental assessment methodology
LCEA	Life cycle energy assessment
LCSA	Life cycle sustainability assessment

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