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Mapping the Interaction between Research and Education Fields of Sustainability in Architecture: A retrospective Timeline

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Abstract
Global research output grows exponentially each year. This paper attempts to drive meaning out of this big data on two fields of research in architecture. It maps the interaction between the research fields of sustainability in architecture and architectural education through the perspective of bibliometric data analysis and its visualization. Based on the analysis of bibliometric data, it draws and juxtaposes two timelines for the field of sustainable architecture and the field of architectural education. The objective is to propose a retrospective method that can provide insight for a broader understanding of sustainability and its impacts on architectural education. It utilizes VOSviewer, CiteSpace, and Gephi to visualize bibliometric networks, along with Tableau to analyze the number of journal articles and publications published across years. The paper presents initial findings concerning the leading scholars, trends, and patterns of the research areas, milestone events, and dominant studies to point out the significance of the cooperation between research and education fields of the related topic.
Keywords: Sustainable architecture; Architectural Education; Bibliometric Analysis; Visualization.

1. Introduction

SUSTAINABILITY, the buzzword of our era, originated from a very straightforward definition first coined in the Brundtland Report as "meeting our own needs without compromising the needs of future generations"("Our Common Future," 1987). Parallel to our increased knowledge on the cause(s) of climate change, as well as increasing social and economic inequalities, the concept has spanned multiple disciplines. Over time, it has gained multiple and ever-changing meanings and means, depending on the context in which it is used. The concept is still complex and yields ill-defined problems for many disciplines.

The concept of sustainability has also evolved in the field of architecture. While stepping into the academic and professional scenes with contradictory goals, advocating for diverse paths for sustainability in architecture, the concept has gained paramount importance in architectural discourse. To reduce the impact of the built environment on the environment, a considerable number of competing academic responses have emerged based "on different ideals of scientific knowledge, different "epistemic" criteria, as well as different varieties of scientific practice" (Jameson, 2001, p. 27). The debates on sustainable architecture and cities are shaped "by different social and diverse agendas, based on different interpretations of the environmental challenge and characterized by different pathways, each pointing towards a range of sustainable futures (Guy, 2010)." Hence, the "[c]ontested nature of sustainability" (Guy 2010; Guy and Farmer 2001; Guy and Moore 2007; Ruhi Sipahioğlu 2012), has become one of the major debates in the field of architecture.

From the early 2000s, likewise, we have seen a growing movement among architectural educators to mainstream sustainability within their curricula and syllabuses (Altomonte, 2009). As such, this study believes identifying which research tracks and paths towards sustainability are at the forefront of architectural education is imperative. This paper shares a methodology, developed as part of ongoing master thesis research,[1] apt to depict interaction between architectural education and architectural sustainability.

"Science remains, first and foremost, a cumulative endeavor (Paré & Kitsiou 2015, 157)." Any research output, be it a conference paper, report, or article, stands in between the retrospective and perspective of a specific research field. Even though information and communication technologies have broadened our access to research outputs and diversified our collaboration platforms, the world is changing so fast. Therefore, researchers need ways to keep pace with the proliferation of new research, pursue advancements, and build new knowledge in their field (Ruhi Sipahioğlu & Özgenç, forthcoming).

Owing to its advantage in yielding swift results, this study relies on bibliometric data analysis to cover such a wide array of studies in both fields. Most bibliometric networks presented in separate visuals makes deriving conclusions difficult for researchers. Hence this study proposes a visualization methodology that aims to make the results of

[1] This work is the part of the research conducted for the first author's master's thesis.

bibliometric data analysis more comprehensible. The existing literature reviews do not present a full picture of the state-of-the-art intersection of sustainability, architecture, and education from its advent to the present (Akinlolu et al., 2020; Darko et al., 2019; Det Udomsap & Hallinger, 2020; Pauna et al., 2018; Zhao et al., 2019). The goal of this study is to create a holistic and comprehensive retrospective map in the form of a timeline to provide insight into the current state of sustainability in architectural education and in sustainable architecture. The study first superimposes bibliometric data to identify fractures/alterations in two fields and then creates two timelines: (1) A timeline of sustainability in architecture; (2) A timeline of sustainability in architectural education.[2] The proposed methodology aims to introduce a way to reproduce the information that lies under the big data. Therefore, regardless of the research field, the methodology can assist in creating a more visual and complex bibliometric analysis. As illustrated by Figure 1, this paper is limited to the explanation of the diverse strategies employed to create content for both timelines.

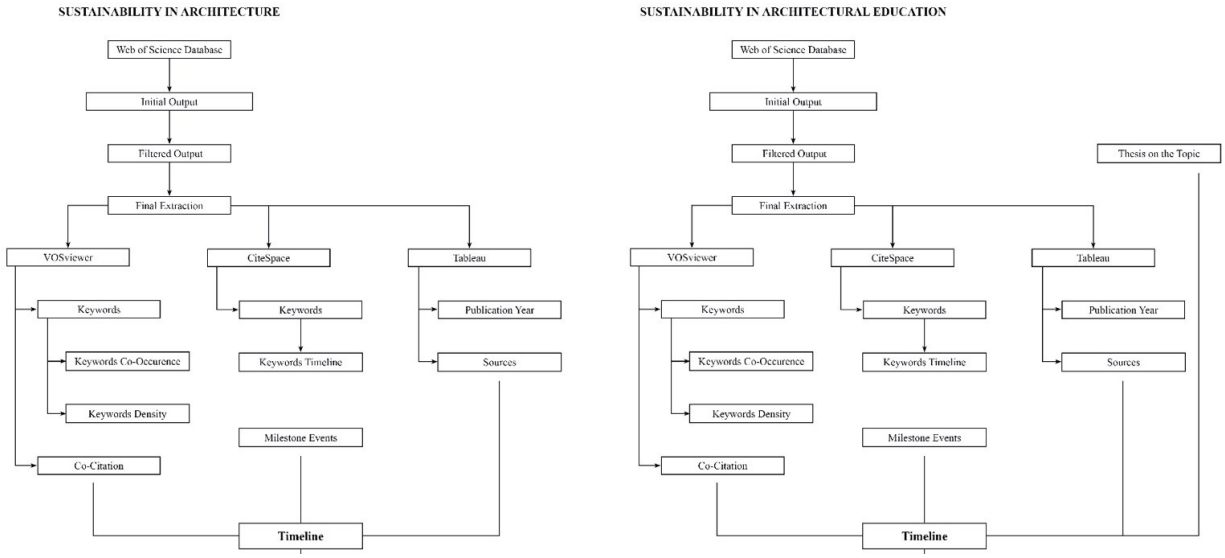

Figure 1. The timeline construction process (Developed by the authors).

2. Methodology

The term bibliometrics was first introduced by Alan Pritchard as "the application of mathematics and statistical methods to books and other media of communication" (1969). Using the quantitative analysis of the data, he proposes, one can gain insight into research relating to a specific area of study (Akinlolu et al., 2020). The bibliometric data analysis utilizes science mapping tools for visualizing mathematics of scientific research and describe their structure (Van Eck and Waltman 2010; Akram et al. 2019). In short, it is the mathematical analyses of publications' properties such as author, keywords, source, type, etc. Bibliometrics uses statistics and quantitative analysis to investigate and present the existing developments of research fields (Reuter, 2008; Zou et al., 2018). The bibliometric data analysis allows for the construction of a network based on the inputs provided by the accumulated papers, keywords, authors, countries, organizations, and countries. The bibliometric mapping approach is a way to visualize the state of the art of a research field to know what options the researcher has to widen their lines of research and to initiate new focuses in a research field.

The study compiled literature data of both fields from the Web of Science (WoS). The WoS core collection database includes the most reputable and influential journals and is therefore considered as the most authoritative data source for studying publications in most subjects (Song, Zhang, and Dong 2016; Zhao 2017). While WoS and Scopus do overlap, Archambault et al. (2009) found that the articles and citations collected from the two databases were highly correlated, yielding similar bibliometric analysis results. Like most databases, WoS provides basic information about all articles found via the query, including author, title, abstract, publication year, journal name, keywords, and references, among others and allows downloading countless items in just a few operations.

2.1. Data Collection and Analysis: Sustainability and architecture

To identify the relevant studies that lie at the intersection between "sustainability" and "architecture" the following approach is used to query the database (Table 1). To store all citations, a bibliography management tool called Zotero

[2] This study is part of an ongoing master thesis research that will overlap these timelines to compare/contrast the key trends in both fields to illuminate how the research fields relate to one another.

was used. After the collected data was stored in Zotero, the required import formats for the bibliometric visualization tools (VOSviewer and CiteSpace) were identified, and data were transferred to other programs (Tableau and Gephi).

Table 1. Number of records per database categorized based on document type.

Database	Search query	Number of records			
		Article	**Conference Paper**	**Review**	**Total**
Web of Science	**Fields and Keywords:** (AK=sustainab* OR AK=ecolog*) AND (SU=architecture OR SU=Construction & Building Technology) **Refined by:** Document Types; (Article or Review or Early Access) Timespan: All **Indexes:** SCI-EXPANDED, SSCI, A&HCI, ESCI. Languages: English **Date Received:** 19 November 2020	3437	56	181	3674

The timeline construction process involves three categories of methodology used for both fields: (1) numerical documentation, (2) text mining, and (3) scientometric analysis. As shown in Table 2, each category includes diverse tools for analysis and visualization.

Table 2. The categories of methodology detailing methods, goals, and tools

Method	**Goal**	**Analysis tool**	**Visualization tool**
Numerical documentation			
Number of articles	To analyze the number of articles published across years	Tableau	Tableau
Number of journals	To analyze the number of journals published across years	Tableau	Tableau
Journals Publishing on the topics	To analyze Co-citation analysis (source name); and bibliographic coupling (sources)	VOSviewer	VOSviewer
Text mining			
Word co-occurrence analysis (All years)	To examine the co-occurrence of keywords and analyze the relationship and interaction between the subjects and emerging trends in research (1975-2020)	VOSviewer	Gephi & VOSviewer
Word co-occurrence analysis (5 years interval)	To examine the co-occurrence of keywords and analyze the relationship and interaction between the subjects and emerging trends in research (5 years interval)	CiteSpace	CiteSpace, Gephi
Burst analysis	To identify the burst interval of words for detecting subjects in a particular period and to capture the relation between burst intervals. Kleinberg's burst detection algorithm was used to identify sudden increases or 'bursts' in the frequency of words used over time.	CiteSpace	CiteSpace
Scientometric analysis			
Co-citation analysis	To measure the semantic similarity of documents by using citation analysis and citation relationships and to determine key references in the field	VOSviewer	VOSviewer

To analyze word co-occurrence in CiteSpace, the study set the number of years per slice to 5. It then selected the top 40% of the most frequently occurring items from each slice. The common practice among previous studies was to select between the top 50% to 20% of the items (Ding & Yang, 2020; Liao et al., 2018; Zhu & Wang, 2018). The analysis of subject categories with the strongest citation bursts by using Kleinberg's burst detection algorithm shows the emergent research front concepts (Figure 2).

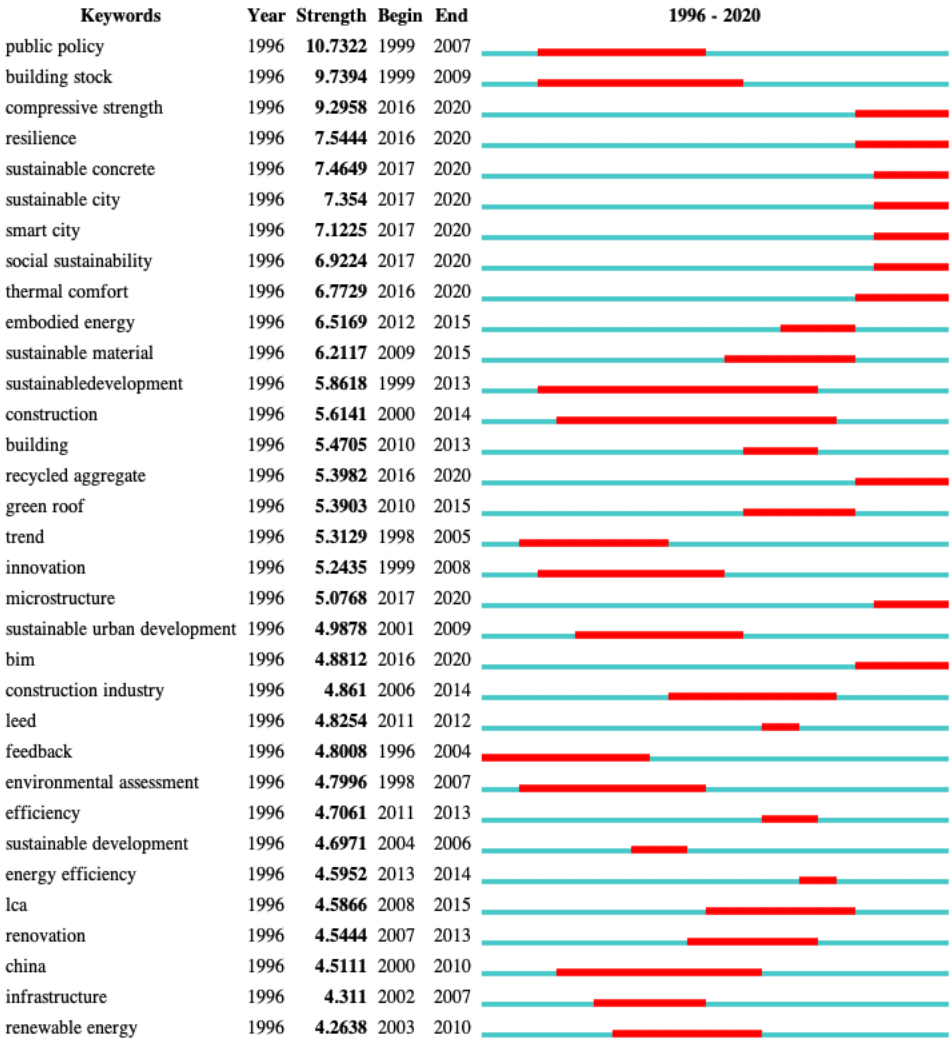

Figure 2. Keyword citation burst across years taken from Citespace

VOSviewer determined 14 co-citation clusters (resolution at 2.00) according to the co-citation of these references. The cluster size equals the number of member publications. Table 3 shows these clusters sorted by size. These clusters are then named by the authors based on the analysis of publications' abstracts.

Cluster #1 'material-concrete' (38 members) is the largest one, followed by 'theory and sustainability transition' (29 members) and 'life cycle assessment (LCA)' (28 members). The mean year means the average year of publication of a cluster and reveals whether it comprises old documents or more recent documents. Hence, cluster #2 is formed of older documents than any other ones. Additionally, the representative document of each cluster is the one that was most co-cited in the respective cluster.

Table 3. Clusters determined in the co-citation analysis

ID	Cluster Label	Size	Mean Year	Representative Documents	A brief explanation about the cluster members
1	Material: Concrete	38	2005	(Damtoft et al., 2008; Flower & Sanjayan, 2007; Gartner, 2004)	Research on the reduction of the CO2 emission from cement production; the potential of concrete recycling to increase the rate of CO2 uptake; the thermal mass of concrete to create energy-optimized solutions for heating and cooling residential and office buildings.
2	Theory: shift, transition, regenerative, dialogy between built	29	2000	(Cole, 1999, 2005; du Plessis & Cole, 2011)	Research on the definition of 'green building' with a close relationship between environmental assessment of buildings.

	environment-nature & assessment				
3	Life-cycle assessment (LCA)	28	2005	(Sartori & Hestnes, 2007)	Research on buildings' life cycle energy with a focus on the correlation to the building operational energy demand.
4	Sustainable Urban Scale / Smart cities	27	2006	(Haapio, 2012)	Research on sustainability assessment of neighborhoods and cities; smart cities; urban planning.
5	Analytic hierarchy process, key indicators, multi-criteria decision making	18	2004	(Hill & Bowen, 1997)	Members of this cluster directly correlate with cluster #6 because they focus on determining key indicators for building environmental assessments.
6	Building environmental assessment	17	2008	(Ding, 2008)	Research on diverse building environmental assessment tools.
7	Cost of green buildings & barriers for the adoption of green buildings	16	2007	(Newsham et al., 2009; Zuo & Zhao, 2014)	Research on the life-cycle cost of green buildings and barriers for the adoption of green buildings.
8	Green roof, buildings	16	2008	(Saiz et al., 2006)	Alternative applications of green roofs and their correlation with urban heat islands.
9	Material: recycled aggregate	15	2006	(Etxeberria et al., 2007)	Research on recycled materials used in concrete production.
10	Material: building materials (local, vernacular, earth, recycle)	15	2008[3]	(Zabalza Bribián et al., 2011)	A broad cluster ranging from research on material selection for reducing embodied energy of buildings.
11	Building Information Modeling	12	2011	(Azhar et al., 2011)	Research on building information modeling with a particular focus on their use in building certification processes.
12	Post-occupancy, Thermal Comfort, Energy consumption	9	2005	(Pérez-Lombard et al., 2008)	Research on building energy consumption based on post-occupancy evaluations with respect to thermal comfort parameters
13	Material: selection, optimization	3	2007	(Thormark, 2006)	Research on making informed decisions about material selection, it has a direct correlation with cluster #10.

The comparison of the co-citation clusters with keyword clusters determined by Citespace[4] (Figure 3) shown as a timeline justifies the cluster names. The next step in this analysis involves the examination of the betweenness centrality of these nodes hence they overlay the correlation between diverse clusters. A citation burst indicates that the scientific community has paid or is paying particular attention to these articles. Co-citation references are determined based on the top 40% of cited references in 5 years slice. If a certain citation receives burst this means a growing number of publications are referring to these articles at that period.

[3] One citation to Fathy H., 1986, Natural Energy and Vernacular Architecture was excluded for the calculation of the mean publication year.
[4] The study used log- likelihood ratio (LLR) algorithm for cluster analysis for determining cluster labels with respect to uniqueness and coverage.

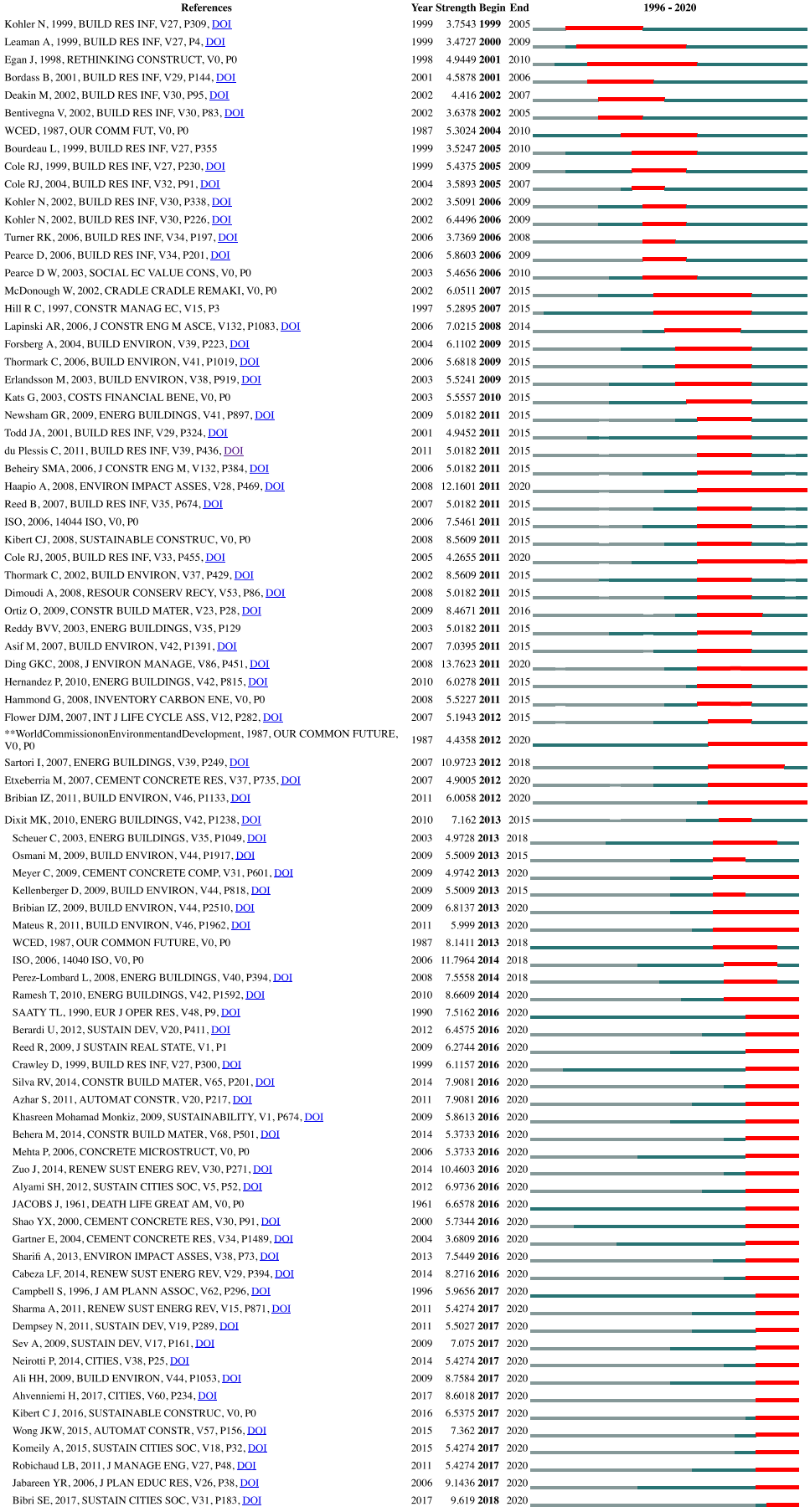

Figure 3. Citation burst analysis of co-citated articles

2.2. Data collection and analysis: Sustainability and architectural education

The study pursued the same categories of methodology for this research field as well, therefore this section only defines divergent parts if relevant.

Table 4. Number of records per database & Number of records per database categorized based on document type

Database	Search query	Number of records			
		Article	Conference Paper	Review	Total
Web of Science	**Fields and Keywords:** (AB=(architectur* AND sustainab*) OR TI=(architectur* AND sustainab*) OR AK=(architectur* AND sustainab*)) AND (AB=(education) OR TI=(education) OR AK=(education)) **Refined by:** Document Types; (Proceedings Paper Or Review Or Article Or Early Access) And [Excluding] Web Of Science Categories: (Agriculture Multidisciplinary Or Allergy Or Hospitality Leisure Sport Tourism Or Archaeology Or Medical Informatics Or Biochemistry Molecular Biology Or Biology Or Chemistry Analytical Or Computer Science Hardware Architecture Or Demography Or Computer Science Software Engineering Or Folklore Or Food Science Technology Or Health Care Sciences Services Or Nanoscience Nanotechnology Or Telecommunications Or International Relations Or Materials Science Textiles Or Remote Sensing Or Medical Ethics Or Medicine General Internal Or Mining Mineral Processing Or Meteorology Atmospheric Sciences Or Respiratory System Or Nutrition Dietetics Or Psychology Educational Or Spectroscopy Or Rehabilitation Or Toxicology Or Transportation Science Technology Or Transplantation Or Women S Studies) Timespan: All **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI Languages: English **Date Received:** 21 November 2020	120	137	3	260

While surveying the outcomes, certain incoherent publications were identified, hence given the number of publications is low, six hundred (600) records were manually scanned for relevance. According to the research criteria the total number of records reduced to two hundred and sixty (260) papers. This manual elimination process was crucial for the outcome to be consistent and coherent. The study also included thesis studies retrieved from Turkish Thesis database and ProQuest. Figure 4 and Table 5 shares the results of keyword citation burst and co-citation analyses.

Figure 4. Keyword citation burst analysis

Table 5. Cluster identified in the co-citation analysis

ID	Cluster Label	Size	Mean Year	Representative Documents	A brief explanation about the cluster members
1	Integrating sustainability knowledge into architectural education	13	2007	(Wright James, 2003)	Reviews on integrating sustainability knowledge into architectural education (general comparative studies)

2	Implementation of sustainability in specific courses and studios	10	2011	(Altomonte, 2009)	Reviews on integrating sustainability knowledge into architectural education (detailed analysis of courses)
3	Understanding sustainable architecture	6	2005	(Guy & Farmer, 2001)	Research on making informed decisions about material selection, it has a direct correlation with cluster #10.

A future study will analyze bibliographic coupling to determine research tracks in the field. In this study, co-citation analysis proved valuable in overlaying the timeline. Figure 5 illustrates the burst of references identified in the analysis.

Figure 5. Citation burst results from Citespace

3. Results

The study incorporates the following layers into its timeline based on the results obtained from three categories:

1. Key events (political, scientific declarations, actions) that may had an impact on the field
2. Analysis of keywords with 5 years interval
3. Citation burst of keywords
4. Citation burst of co-cited publications and clusters determined by co-citation analysis
5. Results from the analysis of terms expected to have frequency in near future (framed in orange boxes on the timeline)
6. Terms (framed in black boxes) for which the study expected a higher frequency.

The United *Nations' Framework Convention on Climate Change* was set at the first event triggering both the academic and educational fields of sustainability. A 5-year interval was used to improve apprehension of the timelines. Furthermore, to create the timeline, keywords and co-citation bursts were also evaluated in 5-year intervals. According to the co-citation analysis, there are 14 clusters for sustainability in architecture, and 3 clusters for education (Table 3 and 5). Clusters are named after the content analysis of documents' abstracts. Clusters are listed on the timeline according to their sizes. Also shown on the timeline are the leading publications in each cluster. Publications' names and their authors are placed in boxes for the bursting period and the dot lines correspond to the publication year. The associated cluster number appears beside each publication.

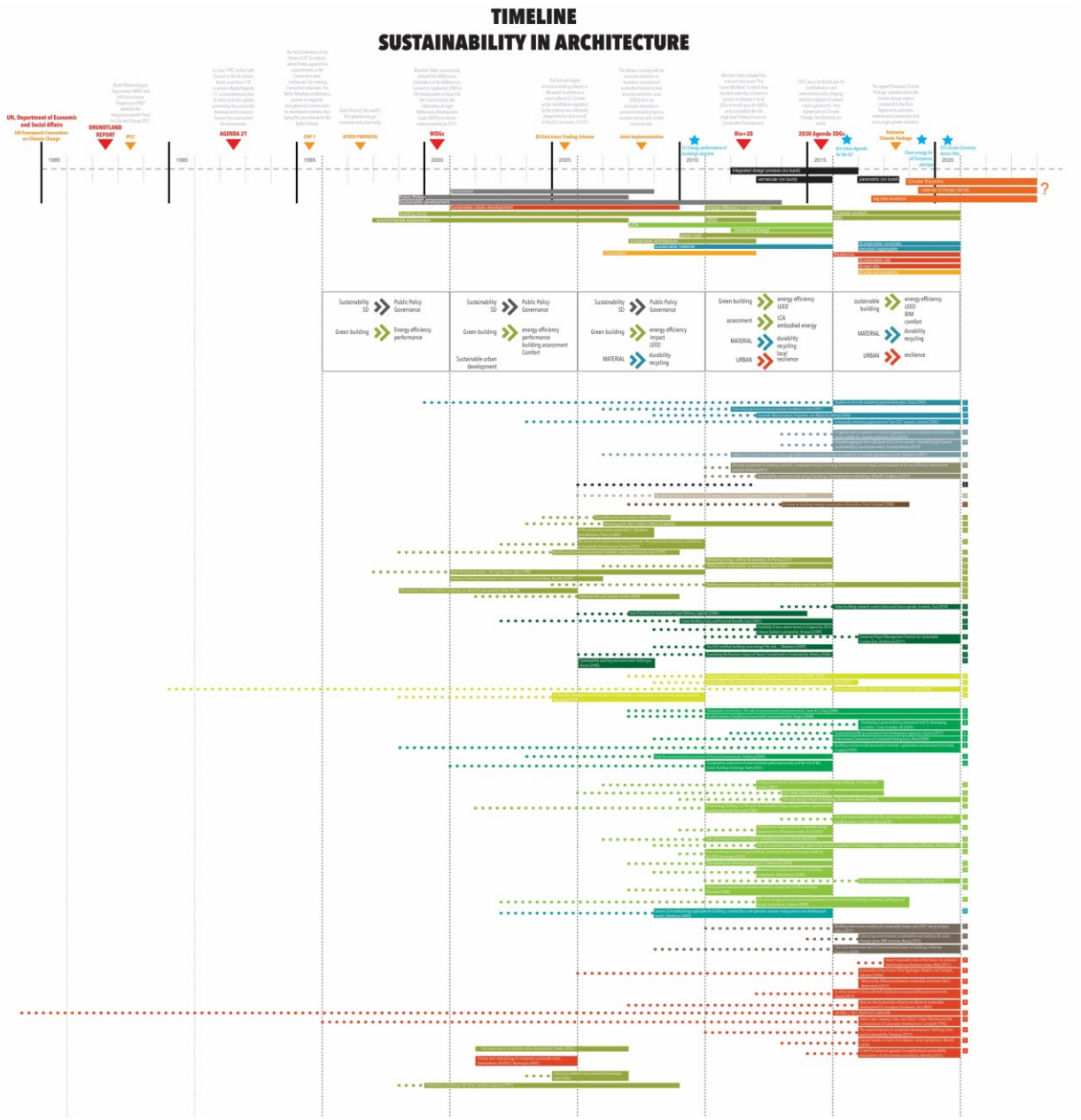

Figure 6. The timeline of Sustainability in Architecture

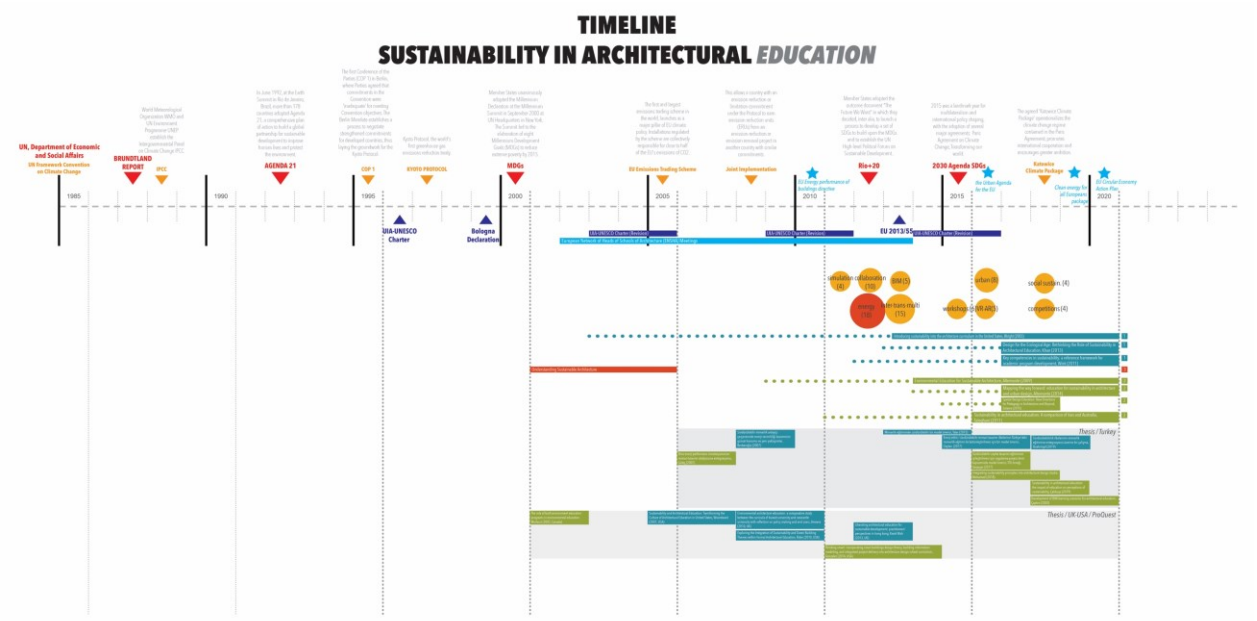

Figure 7. The timeline of Sustainability in Architectural Education

The resultant timelines unroll the evolution of both fields since the introduction of the concept sustainability. In this part, this paper shares the preliminary findings of the timeline analysis of the ongoing research.

- From the late 90s, till the late 2000s, the field is replete with publications on public policy and governance. This may imply that the field aims at creating ground for governing the new policy decisions and guide new research funding.
- Topics like urban resilience and sustainability are getting an increased focus in the field as of 2016s. Their main references drawback to the early 60s, from Jacobs (1961), Lynch (1960).
- Another hot topic within the same research scale is smart cities integrated with big data analytics. Parallel to this topic, the study determined that terms like big data analytics and internet of things have mean years of 2017 and 2019 respectively.
- Current research in material sciences focus on reducing the environmental impact of building materials, exemplified with extensive research on concrete and recycled content.
- Parallel to the research in the material the study, research on the life cycle assessment has become a hot topic in the field.
- Over the last five years, the term 'green building' is seen to have decreased in frequency, while leaving its place to 'sustainable building.'
- From the late 90s, given the increase in the number of publications on sustainability in architectural education, citation bursts occur since 2015.
- All thesis determined by the study focused on the analysis of formal education at the higher education institutions. In contrast, existing articles in the field include case studies from competitions, workshops, and summer schools.
- Between 2010-2015, research topics concentrate on education about energy-efficient building design. After 2016, the study determines a boost in urban scale examinations.

4. Conclusion

This study aimed to examine the interactions and correlations between architectural education and sustainability in architecture. The main concern was how to deal with the volume of publications in indexed journals since both fields and their literature are extremely extensive. As a result, it proposed a new methodology that uses bibliometric analysis and visualization tools to construct timelines of research fields as the basis for this examination. To this end, this study first superimposed the bibliometric data accumulated charts/analyses to identify fractures/alterations in both fields, then created two timelines to demonstrate the progression of each one.

This timeline indicates the necessity of making a detailed analysis of the teaching content and learning environment of publications from the education field through a scoping study. This will be the next step of this thesis study. Future research will include a further layer into the timeline, research funding calls, such as the EU-Horizon program, COST actions, EU Erasmus Program, to illustrate their impact on shaping the research tracks. Another study stream may focus on creating an interactive timeline for ease of access and exploration.

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Conflict of Interests
The authors declare no conflict of interest.

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