TOBB UNIVERSITY OF ECONOMICS AND TECHNOLOGY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MAPPING THE INTERACTION BETWEEN RESEARCH AND EDUCATION FIELDS OF SUSTAINABILITY IN ARCHITECTURE: A RETROSPECTIVE TIMELINE

MASTER OF ARCHITECTURE

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ABSTRACT

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Research communities produce and disseminate knowledge that relies on previous research output. Yet, as information and communication technologies advance, the amount of research output awaiting researchers has become massive. These outputs have been creating a network among academic literature. Decoding the meanings and relationships of these networks has become increasingly difficult. This study proposes a retrospective methodology for creating a research field timeline that unfolds the network of the related field based on bibliometric data and uses this timeline as a basis for discussion in a pictorial form. The aim is to purify the huge amount of bibliometric data as a result of the data-driven and ever-growing nature of the contemporary era and to utilize information visualization to produce readily perceptible visuals. Subsequently, this study utilizes the proposed methodology on a case study related to sustainable architecture and architectural education.

The sustainability paradigm has gained paramount significance since the introduction of the concept in the United Nations Brundtland Commission’s Report (1987). Along its journey, the concept of sustainability has contextually evolved and gained numerous definitions parallel to the remarkable increase in scientific research. Thus, the progressive academic research on sustainability has impacted both the education and practice fields of architecture. This study focuses on the evolution of the research on sustainability in architecture and its reflections on architectural education through bibliometric data in a historical context. So, the study highlights both the research and education fields of sustainability in architecture. To this end, the visualization of the bibliometric data analyses was utilized to stimulate the readers’ involvement. The study employs a variety of bibliometric data visualization software (VOSviewer, CiteSpace), network visualization software (Gephi), and data visualization software (Tableau). This study derives inputs from bibliometric analyses to create two multilayered timelines on the topics. The timelines illustrate the trends, patterns, and pivotal points of the related research fields by juxtaposing the milestone events. The bibliometric analysis also depicts the leading scholars, influential publications, and most intriguing research topics.

Keywords: Architectural education, Sustainable architecture, Information visualization, Timeline, Bibliometrics

ÖZET

Yüksek Lisans

MİMARLIKTA SÜRDÜRÜLEBİLİRLİĞİN EĞİTİM VE ARAŞTIRMA ALANLARI ARASINDAKİ İLİŞKİSİNİN HARİTALANDIRILMASI: RETROSPEKTİF BİR ZAMAN ÇİZELGESİ

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Araştırmacılar yeni bilgileri, geçmişte yapılmış araştırmaların sonuçları ışığında üretir ve sunarlar. Günümüzde bilgi ve iletişim teknolojileri geliştikçe daha fazla araştırma sonucuna ulaşabilme imkânı ve gerekliliği muazzam bir şekilde arttı. Araştırma sayıları arttıkça, araştırma çıktılarının akademik literatür içerisinde oluşturdukları ilişkiler ağı genişlemekte ve karmaşık olmaktadır. Bu ağın içerdiği ilişkileri ve anlamları deşifre etmek gün geçtikçe daha zor hale gelmektedir. Bu çalışma, bibliyometrik veri kullanarak araştırma alanının içerisinde oluşan ilişkiler ağını göz önüne seren bir yöntem önerir. Bu yöntemle çağımızın veri güdümlü doğası sonucu sürekli büyüyen bibliyometrik veri, araştırmacının ele aldığı konu ve araştırma sorusuna yönelik olarak sadeleştirilir; bilgi görselleştirme araçlarından faydalanılarak var olan araştırma sonuçları arasındaki ilişki ağları şematik olarak gösterilir. Elde edilen veri ile retrospektif zaman çizelgesi oluşturulur ve tartışma zemini olarak kullanır. Bu tez, önerilen metodu sürdürülebilir mimarlık ve mimarlık eğitimiyle ilgili örnek bir konu üzerinde uygulayarak test eder.

Sürdürülebilirlik kavramı, Birleşmiş Milletlerin 1987 Brundtland Komisyonu Raporunda tanıtılmasıyla birlikte olağanüstü önem kazanmıştır. Geçtiğimiz yıllar içinde, sürdürebilirlik üzerine yapılan araştırmalardaki kayda değer artışa paralel olarak, kavram bağlamsal olarak evrimleşmiş ve çok sayıda tanım elde etmiştir. Sürdürülebilirlik alanındaki ilerici akademik araştırmalar, mimarlığın eğitim ve uygulama alanlarını da etkilemiştir. Bu çalışma, bibliyometrik veri aracılığıyla mimarlık alanında, sürdürülebilirlik kavramının gelişimine ve mimarlık eğitimindeki yansımalarının tarihsel sürecine odaklanır. Böylelikle, bu çalışma mimarideki sürdürülebilirlik kavramının hem araştırma hem de eğitim alanlarını aydınlatır. Çalışma, bibliyometrik veri görselleştirme aracı olarak VOSviewer ve CiteSpace'i, ağ görselleştirme aracı olarak Gephi'i ve veri görselleştirmesi için Tableau aracını kullanır. Zaman çizelgesi, konu bağlamındaki önemli olayların yerleştirilmesine olanak tanır, araştırma alanındaki yönelimleri, örüntüleri ve döngü noktalarını sergiler, böylelikle, karşılaştırma ve nitel analiz için zemin sağlar. Bibliyometri analizi aynı zamanda öncü bilim insanlarını, etkili yayınları ve en ilgi çeken araştırma konularını gösterir.

Anahtar Kelimeler: Mimarlık eğitimi, Sürdürülebilir mimarlık, Veri görselleştirmesi, Zaman çizelgesi, Bibliyometri

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LIST OF ABBREVIATIONS

KT	: Knowledge Triangle
HEIs	: Higher Education Institutions
SUS-ARCH	: Sustainability in Architecture
SUS-ARCH-EDU	: Sustainability in Architectural Education
IUCN	: International Union for Conservation of Nature
UNEP	: United Nations Environment Programme
WWF	: World Wide Fund for Nature
UN	: United Nations
ICLEI	: International Council for Local Environmental Initiatives
WorldGBC	: World Green Building Council
WCED	**:** World Commission on Environment and Development
UIA	: International Union of Architects
UNESCO	: United Nations Educational, Scientific and Cultural Organization
SDGs	: Sustainable Development Goals
CSO	: Civil Society Organization
WoS	: Web of Science
SCI-EXPANDED	: Science Citation Index Expanded
SSCI	: Social Science Citation Index
A&HCI	: Arts and Humanities Citation Index
ESCI	: Emerging Sources Citation Index
CPCI-S	: Conference Proceedings Citation Index-Science
CPCI-SSH	: Conference Proceedings Citation Index-Social Sciences & Humanities
BKCI-S	: Book Citation Index-Science
BKCI-SSH	: Book Citation Index-Social Sciences & Humanities

1 INTRODUCTION

1.1 Overview

Research communities produce and disseminate knowledge. This knowledge relies on data and previous research outputs. Every research is intertextual; it becomes a node for its successors. There is an overwhelming amount of research output awaiting researchers. The research landscape is continually evolving as new topics and avenues for research emerge. This landscape consists of multiple research community networks supported with grants from both the national and international levels.

Researchers need access to resources that enable them to keep up with new research, pursue advances, and create new knowledge. "Science remains, first and foremost, a cumulative endeavor (Paré & Kitsiou, 2016, p. 157)." Any research output, be it a conference paper, a report, or an article, stands in-between the retrospective and perspective of a specific research field. Hence be it a novice or an experienced researcher, each one of us should know about and learn about past practices to say our words for the future.

Since the turn of the 21st century, online databases hosting numerous journals and online researchers' databases have expanded the dissemination of research to wider audiences. In addition to these databases, the rapid growth of information and communication technologies has accelerated the pace of change in today's world. Humans' cognitive abilities cannot keep up with such a rapid pace. It has become more of a challenge to review an academic field in the age of information. Research outputs are now part and participant of 'big data.'

The emergence of big data has led to an increase in demand for gathering, monitoring, and presenting information in a wide range of areas. It is becoming increasingly necessary to retrace information from big data so that it can produce quantitative and/or qualitative results that actors and researchers can use to make better decisions. Considering the production of academic knowledge, this thesis considers the research outputs either digital or reproduced for digital mediums, including their citations as part of the big data. The academic knowledge that exists in this big data paves the way for a network among diverse research outputs created by citations. Research outputs are nodes in these networks. Since citation networks keep growing, decoding the meanings and relationships among these nodes becomes increasingly difficult.

As information, in this case research outputs, is produced, and as it is processed, the need for new tools for building and then representing knowledge has arisen over the last two decades. Different concepts and methods have been introduced recently in terms of data visualization, such as mapping and infographics. As the data empirically grows, it also becomes harder to purify it in an efficient way to benefit from.

To understand the ever-growing stack of data, and keep up with it, data visualization presents some of the key solutions. The visual representation of data enables people to derive meaning in a short amount of time, rather than by researching and reading large volumes of literature. As such, visual representations are also useful in making knowledge more accessible to a broader audience. Hence the visualization of data has gained a tremendous acceleration parallel to the advancement in information technologies. Information visualization has been revolutionized by the accessibility of computers, programming literacy, and the ever-expanding data to become a new medium for art and culture (Manovich, 2011). Since each visualization must drive from its information, bibliometric data mostly stands as its core when visualizing a scientific research field. To describe the structure of a research field bibliometric data is utilized by bibliometric tools (science mapping tools) (van Eck & Waltman, 2010). This data contains various information about the related publication such as author’s name, keyword, title, source, type, and the date that it is published. This mathematical analysis profoundly shapes a network that is in the form of data according to the research criteria. However, by utilizing a variety of mapping tools it is possible to visualize the network that emerged from the bibliometric data analysis as illustrated in Figure 1.

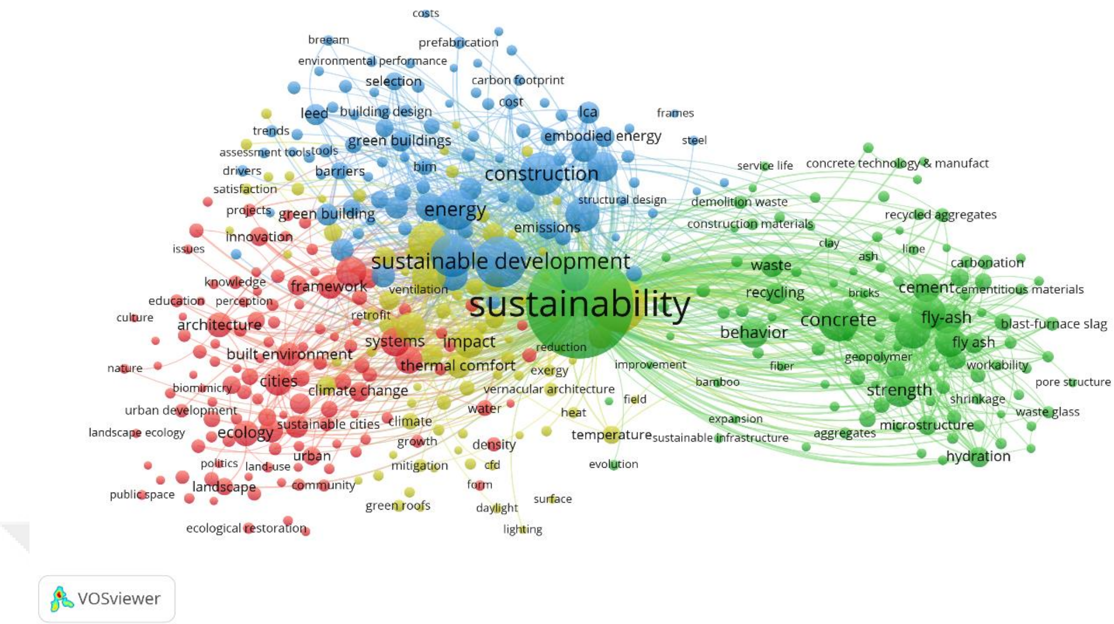


Figure 1-1: A sample of the keyword co-occurrence network created in VOSviewer

Timelines have been part of our daily lives and also scientific research since ancient times, nonetheless, the information age has significantly boosted their importance and accessibility (Rosenberg & Grafton, 2010). Timelines present quickly accessible information in organizations whose primary focus is on time. This aspect of timelines enables audiences to reconstruct links and correlations within the presented knowledge independently. For novice researchers, timelines are great tools because of their ability to communicate with the audience through historical manners. In addition, this organized structure of visualization involves the selection of varying inputs and elements in relation to time. Although contextually they may differ, when pursuing a field of study with a wide scope, it is important to discuss influential academics and works. Network visualizations created by the bibliometric analysis tools allow depicting the position of a researcher within a research field, hence they are not particularly designed to create research field timelines. This study suggests that the timeline of a research field has the potential to overlay the evolution of a research field to novice researchers. To this end, this thesis suggests a methodology that aims to utilize the mentioned aspects of timelines to comprehend the tendencies of a research field in chronological order.

1.2 Objectives

The overall aim is to present a strategy that utilizes information visualization to develop a methodology for creating a timeline of a research field. The intention is to present a nonrepresentational visual expression as the outcome for the reader to be able to generate knowledge and discussions of the status quo of a research field. Since, the preliminary source of information derives from the bibliometric data analysis of a research field, numerous outcomes are required to be unified to present a complex system of networks. One of the convenient ways of presenting multiple sets of information in a purified and understandable way is a timeline where readers acquire knowledge about a research field in a short amount of time. The superimposable structure of timelines enables revealing the complex system of networks of a research field. Thus, readers can expand the presented knowledge based on their understanding of correlations and connections. Moreover, the chronological structure of the timelines provides the user with an expression that exists in its historical context. In this manner, the visualization of a timeline that embodies the spirit of the moment is becoming a tool of reference. Another intention is to propose the application of the methodology regardless of the topic. Therefore, the methodologies used in the thesis are categorized into two, the overall thesis methodology, and the timeline methodology. The timeline methodology presents a method that benefits from bibliometric analysis and information visualization. Moreover, it aims to intersect the outcomes that are derived from bibliometric visualization with the important historical events.

1.2.1 The locus of the study

In the second half of the 20th century, the term sustainability came into sight as a global response due to the unmanageable energy requirements of humankind. Hence, alongside the advancements in information technologies and population growth, capitalist expansion required more resources day by day. As the problems that derived from the environmental imbalance of earth grew the more reflections of the term sustainability were able to be observed upon the political agendas, academic research, and education. This discourse then inevitably became an adjective for various disciplines and raised a respectable amount of awareness in responding to complex environmental problems (du Plessis, 2012). Since its literary introduction in Bruntland

Report (WCED, 1987) the term sustainability had an evolving past and gained different meanings over time. Nowadays, it can be argued that there is no exact definition of sustainability because of the exponential growth environmental effects have not been able to respond from a static worldview. Therefore, diverse conceptualizations of sustainability in different disciplines can be distinguished from one another.

Technological advancements and research have been conducted to find less harmful ways to produce energy without sacrificing daily activities (Ruhi, 2013; Ruhi Sipahioğlu, 2013). This approach of sustainability grounds its foundation in minimizing the effects of human activities upon the integrity of the environment in both social, and cultural domains. This ongoing worldview of sustainable development is defined as the mechanistic worldview (du Plessis, 2012). It is criticized by many researchers because its linear classification structure is lacking in responding to complex environmental problems (du Plessis & Cole, 2011; Robinson & Cole, 2015). Thus, in the last decade or so, a shift in the paradigm has been proposed with an empirical strategy to carry the concept a step forward. An integrated theoretical, design and development approach that can transform the way sustainability is conceptualized and practiced. In contrast to the mechanistic worldview's emphasis on the parts, the ecological worldview deals with the whole. As Capra stands out, the emphasis of ecological worldview is holistic, organismic, or ecological, and this perspective is known as "systemic" that implies "systems thinking" (Capra, 1995, p. 17).

In parallel to the sustainability debates, integration of the concept into the architectural discourse gained a huge amount of significance since architecture plays a crucial role in the development of the built environment. Similarly, to the general concept of sustainability, throughout its journey, sustainable architecture has acquired various meanings as well. However, the precursor intention to protect the environment by designing buildings that aim to reach a level of efficiency has remained the same. On the other hand, this intention is seen as an extension of the currently dominant mechanistic worldview that aims for a steady-state and conservation of the status quo (du Plessis & Cole, 2011).

Traditionally, the pursuit of knowledge itself has been a major driving force in research and innovation. The concept of the 'Knowledge Triangle' (KT) gained importance in recent years as a framework to conceptualize the relations between Higher Education Institutions (HEIs), the business sector, and society at large. Several mechanisms have been proposed in recent history to link the knowledge triangle components. These attempts aimed to interpret and illustrate the process of knowledge creation and its applicability for daily practices in a circular and sustainable state. As stated in the *Catalysing Innovation in the Knowledge Triangle* report by the European Institute of Innovation and Technology these concepts share common conclusions such as the non-linear nature of innovation and the multiple input and feedback loops that exist between the actors (EIT, 2012, p. 8). Hence, the frameworks can inform and guide practitioners, researchers, and students on a larger scale, a discrete understanding of the evolutions of diverse disciplines needs to be disjunctively studied. Therefore, regardless of the field, it is important to reveal the network of its actors-education, research, and businesses along with that field's evolution and development. Apart from the proposals of new mechanisms for the knowledge triangle, it is as important to reveal the status quo of that field to propose integrated solutions. On the other hand, it is also possible to study the multiple input and feedback loops between each actor. In other words, each actor is linked to the other in a nonlinear but circular state. These interlinked conditions of education, research, and businesses accompanied and sometimes led by the policymakers pave the way for innovations for the upcoming generations.

As one of the actors of the 'Knowledge Triangle', higher education shares the burden in developed societies to increase the quality of both human life and the environment. Two of the major components of knowledge creation are research and education. They share a structure where the two elements are in a feedback loop. However, it is necessary to provide a clear picture of the existing relationship between research and education fields of a discipline before suggesting a new mechanism that might enhance the overall efficiency. Moreover, considering the growing expectation for more specialized work towards subdisciplinary fields of study, the status quo of the integration of sustainability education into architectural education is becoming more crucial. Hence, in architectural education, the specialization of topics derived from the interdisciplinary nature of architecture reflects the separation of the practice and theory in the curricula. So apart from the several contemporary integrations, how the multiplicity of current sustainable architecture debates is internalized in the field of education is still unknown. Therefore, this thesis determines the locus of the study as the research and education fields of sustainability in architecture.

1.2.2 Scope

This study intends to contribute to the current literature by visually presenting and comparing the bibliometric data of sustainable architecture, and sustainability in architectural education research fields. Finally, it aims to present a retrospective analysis to provide the basis for discussions of the status quo of sustainable architecture and sustainability in architectural education.

Furthermore, this study aims to test the developed timeline methodology with a case study within the scope of the thesis. As shown in figure 2, the intersection of architectural education and sustainability in architectural research is the case for this study. Timeline methodology is meant to be developed without the restrictions of the research topics, whereas it presents a method that is adaptable to every research area.

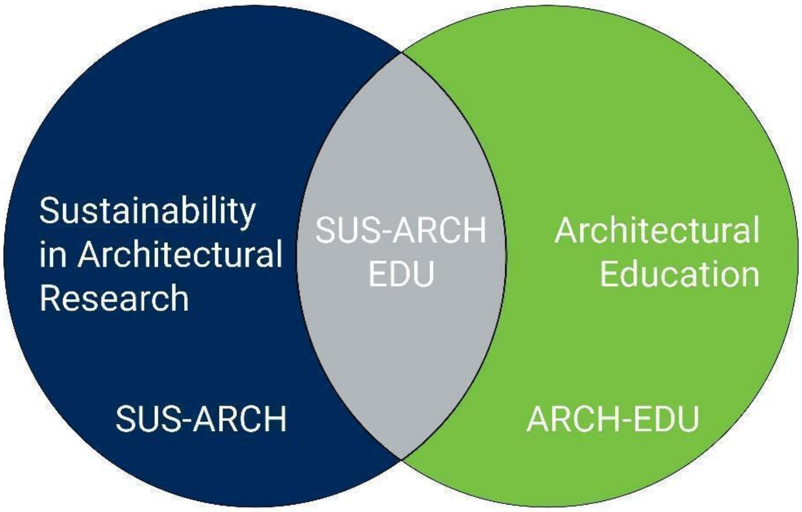


Figure 1-2: Figure representing the scope of the case study fields

In the next chapter, under the research methodology, the timeline methodology is going to be explained.

1.3 Research methodology

This section navigates the reader over the research methodology pursued throughout the thesis research. Figure 3 details the research levels pursued in this study in terms of data, output and the analytic methodology followed.

The research evolved in three levels; problem statement (level 0), timeline methodology (level 1), overlap (level 2). The research begins with **Level 0** which is the declaration of the problem statement. To do so, the literature review is conducted to reveal both the evolution and the state of the art of the research fields. Existing literature was reviewed for two different topics; research and education in the fields of sustainability and sustainability in architecture, and information visualization, network visualization, and timelines. Moreover, whilst conducting the review of the existing literature two of the most influential parameters stand out as the important events and funding agencies. Since the beginning of the history of sustainability, the state of the art of the concept has been led by the policymakers both financially and politically. There are numerous events held to encourage the academic research conducted towards the field and huge amounts of fundings to draw more researchers' attention. Following the initial literature review, **Level 1,** the overall methodology of the development of the timelines is introduced. At this level, the bibliometric analysis tools for decoding the system of networks throughout the literature are presented to clarify timelines and mapping strategies. To further the timeline methodology, the process is categorized into two sections according to the research topics which are sustainability in architecture, and sustainability in architectural education. These two subsections are intended to detail the development of the timelines. After the introduction of the bibliometric analysis tools, the limitations and outcomes are presented for SUS-ARCH and SUS-ARCH-EDU. Apart from the outcomes of the bibliometric analysis tools, two other inputs are reviewed and correspondingly presented for the timelines; important events related to the evolution of the research topics, and calls from various funding agencies. In consequence, the discovery of the leading effect of policymakers is due to the literature review. Finally, for these two subsections, the collected outputs from bibliometric data analysis policy results are presented via a multilayered timeline. **Level 1**, timeline methodology is concluded by acquiring two different timelines that are presenting the status quo of sustainable architecture and sustainability in architectural education. The next process is to overlap these two timelines for **Level 2.** Overlapping the two timelines provides the user with a simplified information visualization of both fields through chronological interactions. The final step aims to generate discussions and conclusions via the visual representation of the interaction between two research fields. The attempt of decoding the outcomes of the final timeline is framed by the results of the scoping study. The final discussions provide chronological evolution, state of the art, and future insights for both research fields.

	DATA	OUTPUT	METHOD
LEVEL 0 Problem Statement	**Existing Literature** Sustainability in Architecture	Evolution of The Concept of Sustainability; Trends of Sustainability Within Architecture. *Research Questions.*	Literature Review
	Existing Literature Information Visualization	Evolution of Information Visualization; Network Visualization and Timelines *Research Questions.*	Literature Review
	Important Events (UN-EU-IPCC)	Policy Makers	Literature Review
	Important Events + Funding Agencies (UN-EU-IPCC+UNESCO-UIA Charter)	Policy Makers	Literature Review
LEVEL 1 Timeline Methodology	Bibliometric Analysis Tools	Policy Makers	Method Development
SUS-ARCH	SUS-ARCH Data (Research)	Research Outputs	Bibliometric Analysis
	Calls From Funding Agencies	Policy Makers	Literature Review
	Bibliometric Results + Policy Results	SUS-ARCH Timeline	Visualization
SUS-ARCH-EDU	SUS-ARCH-EDU Data (Research)	Research Outputs	Bibliometric Analysis
	Thesis Outputs (Turkey, Proquest)	Research Outputs	Literature Review
	Bibliometric Results + Policy Results	SUS-ARCH-EDU Timeline	Visualization
LEVEL 2 Overlap	Timelines	Discussion	Output Analysis

Figure 1-3: Research Methodology

1.4 Summary

Apart from this introduction, the thesis consists of five chapters.

Chapter 2 (level 0) introduces the state-of-the-art of information visualization studies and the reasons for choosing this method in this research.

Chapter 3 (level 0) reviews the paradigm shift occurring in the field of sustainability in architecture and major challenges awaiting the field of architectural education. This chapter informs the research about the important events impacting the research field and therefore feeds the level 1 phase on sustainability, architecture(sus-arch), and sustainability, architecture, and education(sus-arch-edu).

Chapter 4 (Level 1) overlays the steps pursued in creating the two timelines. It first briefly explains the analysis programs used in the study with a particular emphasis on the terminologies used in these programs and then proceeds with the data collection and analysis methods.

Chapter 5 (Level 2) overlaps both timelines to compare/contrast the key trends in both fields to illuminate how the research fields relate to one another. The conclusion chapter also shares the findings of the thesis and suggests further research avenues in the field.

2 VISUALIZING A RESEARCH FIELD

A research activity may begin with an intuition or a blast of action but accumulating knowledge and experience through experiments, readings, writings, and exercises is imperative for researchers. Researchers have access to tools, facilities, and experience, but it may sometimes take a coincidence for a result to emerge, just as Archimedes or Newton did. Most of this accumulation resides today in reference lists of research outputs.

This chapter discusses the role of references in contextualizing a research area and several concepts equipping this study in visualizing research fields. The first part suggests the interdependence of research outputs through the concept of intertextuality and then discusses the rhizomatic relationships among these references. The second part introduces the reader to the characteristics of networks and recent developments in network visualizations. The third part details the bibliometric analysis types.

2.1 References and citations

2.1.1 Research publications as inter/hypertexts

Intertextuality characterizes every piece of research and publication. The concept of intertextuality that Julia Kristeva initiated in her essay “Word, Dialogue and Novel” (1986) proposes “the text as a dynamic site in which relational processes and practices are the focus of analysis instead of static structures and products.” All texts are interconnected as “a mosaic of quotations.” Not only authors but also readers draw on these connections as they produce or read a text (Badenhorst, 2019). As research builds upon previous research, new texts include all those layers. Tang et al. (2016) explain how this knowledge is built as follows:

> “Authors′ citations of other people′s work (intertextuality) are the foundation of and building blocks for academic writing and research that indicate the intellectual structure

> of a problem space. Exploration of these citations can document the established literature that serves as the empirical basis and theoretical justification for research questions, designs, procedural decisions, explanations, and supplemental support for knowledge claims (K.-Y. Tang et al., 2016, p. 249)."

Mostly said for literary works, but this connotes with the case of scientific literature that any publication contains 'multiple writings' (Barthes, 1986, p. 54). This creates a multidimensional space in which thoughts, diverse approaches are weaved together in the sense of a fabric of quotations. These texts, as Barthes (1986) proposes, result from thousands of sources of culture.

Each research publication in constructing a new meaning re-constructs/synthesizes the past/existing research by mediating through past research. A literature review becomes the cornerstone where "intertextuality is embedded in the discipline (what arguments count) and where meaning-making only happens in relation to what is required (Badenhorst, 2019, p. 265)."

Citations not only situate research but also allow researchers "to persuade, to present an argument and to convince readers to accept their work (Badenhorst, 2019, p. 264)." It is the selection of citations that reflect the significance, originality, and significance of the research stated (Badenhorst, 2019). Writers align themselves with certain perspectives by citing specific authorities. By citing, then, we help establish an epistemological framework in the context of the discourse community, with the discipline or reader. Academics can link their texts to academic cultures by using citations (Hyland, 1999). These practices (among others) are fundamental to academic knowledge creation. Reference refers to the recontextualization of source texts into a new argumentation. As a result, while references pile up, communities of practices begin to form through multiple networks. Owing to today's online citation formats, each text connects to these networks through hypertexts. Each research publication is an assemblage of hypertexts that pertain to any text with references (hyperlinks) to other texts. A reference cited in a text contains details ranging from its place of publication, date, and authors to facilitate tracing these accumulated layers of history.

2.1.2 From hypertexts to networks

Citations create networks among diverse research activities. Rather than a tree-like authoritarian network model, these networks are released from "rigidness and unidirectional progress, where everything returns to a central trunk through vertical and linear connections (Lima, 2011, p. 44).” Based on rhizomes proposed by Deleuze and Guattari (1987), these networks pave the way to embrace multiplicities and multilinearities. In these networks, we may not speak of a central authority. In Deleuze and Guattari’s book, it reads “[i]n contrast to centered systems with hierarchical modes of communication and pre-established paths, the rhizome is an acentered, nonhierarchical, non signifying system without a general and an organizing memory or central automaton, defined solely by a circulation of states (Deleuze & Guattari, 1987).”

In contrast to a tree's topology and individual branches, this flexible network yields a map that allows connecting any point, in this case, essays or articles, to any other point, in this way nodes intercommunicate in a non-linear manner. “The rhizome pertains to a map that must be produced, constructed, a map that is always detachable, connectable, reversible, modifiable, and has multiple entryways and exits and its own lines of flight (Deleuze & Guattari, 1987, p. 21).” This thesis suggests the principle’s applicability to research communities communicating via citations in the form of hypertexts. This theory helps the present study to comprehend the intricacies of a research field’s evolution regarding complex challenges.

2.1.3 From rhizomatic networks to the pictorial turn

For newcomers of a scientific field immersing into these rhizomatic networks and understanding the intricacies of the discourse is a big burden. Each research, as described previously, is intertextual, thereby becoming a node for its successors. In the absence of the sub-textual conventions, newcomers tend to only be aware of the surface-level conventions (Badenhorst, 2019). Doing a review is tedious work in the information age. Information and communication technologies have broadened our access to research outputs and diversified our collaboration platforms. New topics, research avenues, and design strategies emerge over the course. New networks emerge, supported with international or national grants. The world is changing so fast, and the constant is the pace of change that goes beyond our cognitive abilities and time. Hence researchers require means that empower them to keep pace with the proliferation of new research, pursue advancements, and make new knowledge.

Grasping the evolution of a discipline and most probably one of its sub-research fields may require one to read thousands of pages. Depicting a rhizome through words is possible but would take forever in case of the inclusion of all the nodes. As Larkin and Simon (1987) stated in the title of their article "Why a diagram is (sometimes) worth ten thousand words" or Shneiderman explains "[a] picture is often cited to be worth a thousand words and, for some (but not all) tasks, it is clear that a visual presentation-such as a map or photograph-is dramatically easier to use than is a textual description or a spoken report (1996, p. 336)."

In 1994, W.J.T. Mitchell underlined a shift in our society as "the pictorial turn" to call our predilection towards images rather than texts (Mitchell, 1994). Visual culture beyond being the subject matter of art history, film, and media studies, has become a means for "describing a complex set of relations between visual phenomena, meanings, and actions (Stanworth, 2002, p. 107)," as a shortcut. World-making that is pictorial rather than textual requires visual literacy as well as experience and experience. While spanning a variety of disciplines, the study of these relations expands the role of images as they become meaning makers.
Upon this remark, reading rhizomatic relations among citations through network visualization becomes a remarkable discovery tool. As Lima explains:

> "[network visualization] is able to translate structural complexity into perceptible visual insights aimed at a clearer understanding. It is through its pictorial representation and interactive analysis that modern network visualization gives life to many structures hidden from human perception, providing us with an original 'map' of the territory (2011, p. 79)."

Bibliometric networks fall into this type of mapping. There lie numerous insights that can be deduced from the analysis of these network maps: (1) The role of each node; (2) The interaction among nodes; (3) The number of connections each node has. By performing this series of queries, it is possible to derive the topological truth of the analyzed network.

A network of citations would never be static and grow over time, so its map shall be always in a state of becoming. Such a map can only portray a stop in time and cast what is available at that time. Kitchin, Perkins, and Dodge (2009) underline that these maps shall be "understood as always in a state of becoming; as always mapping; as simultaneously being produced *and* consumed, authored *and* read, designed *and* used, serving as a representation *and* practice; as mutually constituting map/space in a dyadic relationship" (2009, p. 22). In this case network visualizations shall reframe maps as a process in contrast to end-products and define "a reciprocal relationship between mapmakers and map readers (Casebeer, 2016, p. 7)."

Today there exist multiple software tools for constructing and visualizing these bibliometric networks that are introduced in the last section of this chapter. The following part discusses in detail why the present study embarks on devising a methodology based on information visualization to construct timelines out of these bibliometric networks and data for discussions of the status quo of sustainable architecture and sustainability in architectural education.

2.2 Information visualization

Our society has become data-generating, data-disseminating and data-dependent, so have researchers, who are immersed every day in the plethora of these research outputs filling out their screens. The development of the concept of big data has brought up the need to gather, monitor, and present information in various fields. In the age of big data, a lot of information needs to be retracted to produce quantitative results apt for involved actors/researchers to arrive at informed decisions. Yet, the growth of information and its processing requires new tools for making and then representing new knowledge. Therefore, many new techniques like mappings and infographics have been developed recently.

Information visualization is a form of visual art that grabs the viewer's attention and keeps it there. The presentation of massive amounts of data in a pictorial format provides the user with key insights and a summary of the patterns that were not apparent in the data. The use of visual representations can make knowledge accessible to a wider audience. Hence, information visualization comes to designers' and researchers' assistance to obtain and present large amounts of information.

Information visualization as it is interpreted today was relatively unknown before the 21st century. Alongside the advancements in technology and computational analysis researchers and scientists now have the opportunity to work on a tremendous amount of data that can be stored in and shared to every corner of the globe. This liberation in technology drastically accelerated the dissemination of knowledge and brought up the possibility to augment the existing or non-existing networks. Lev Manovich (2011) summarizes this ongoing shift in the techno-cultural phenomena of the last two decades of network and visualization by stating the ubiquity of computers, the increase in programming literacy, and the wealth of data made available by the Internet revolutionized information visualization throughout the 21st century, leading to its rapid expansion as a new medium for art and culture.

Interestingly, the contemporary understanding of information visualization is a relatively straightforward process considering the amount of data and the network that it aims to decode. According to Manovich (2011), information visualization is commonly used as a tool for discovering patterns, connections, and structures of a dataset. Further, he relocates information visualization as a systematic method that can contribute to the discovery of new knowledge about the world alongside many others, e.g., experiments, mathematical modeling, simulation.

Johanna Drucker offers a more simplistic definition as follows: "The standard approach to information visualization is to generate a graphic from live or static data… A set of quantitative values is charted on a grid, plane, or space governed by a regular, standard metric (2020, p. 10)." Despite this, the most simplistic definition fails to capture the system of thought underlying the method. In an attempt to further clarify the definition, Drucker (2020) argues that the final result obscures the interpretative efforts that go into shaping data, hence the interpretative dimensions of the activities shaping the data are lost. This argument can be compared to a similar question faced by academic researchers once the analytical process is completed. Luther and Schünemann (2018) explain the problem as the researchers struggle to convey the results of their research in a manner that is accessible to a broad audience, following they refine this struggle in today's paper-based publishing environment, it appears to be an even bigger problem even though this can be seen as a general qualitative research problem. Briefly, how researchers shape the data is often missing and this is a problem that can be put forward as one of the biggest gaps in academic research. Another major step towards an academic publication is analyzing hundreds or thousands of documents and visualizing this step.

As an alternative, it is possible to demonstrate the interpretive effort in shaping the aforementioned data and analytic processes by refining itself through visualization and the networks that surfaced visual complexity. In this regard, Lev Manovich (2011) expands on the advancements and structural complexity of contemporary information visualization. Manovich clarifies how contemporary information visualization is or should be denser, more complex, and more varied from the prevalent applications for three reasons:

> "First, contemporary designers, artists, and computer scientists are trying to represent considerably more data than ever before. Second, they want to represent relations between more dimensions of data than is possible with older graph types such as bar charts (one dimension) or scatter plots (two dimensions). The third reason is aesthetic and ideological: if nineteenth-century techniques for graphs fit the scientific paradigm of reduction (breaking nature down into the simplest possible elements and defining rules on how these elements interact), our current interest lies in understanding the phenomena of complexity (think chaos theory, emergence, complexity theory), which is reflected in the kinds of visualizations we find appealing (2011, p.12)."

Upon this review, it is difficult to categorize information visualization in terms of scientific or artistic production. However, it is a scientific method that aims to express complexity through design and is eventually evaluated as art. As Manovich suggests, information visualization distinguishes itself from its peers by one key feature, that is, *design.* Apart from the efficiency and functionality of the final product, contemporary researchers aim to produce visuals that stimulate the viewers'/readers' involvement with its pictorial qualities. Manovich (2011) also broadens the relationship between visualization and art by stating that data visualizations can also function as art in a different sense: an activity that emphasizes certain parts of the world and represents them in a particular way to make statements and ask questions about it. Therefore, data visualization's primary intention is not simply to present data but to communicate and share a common concern about our world. Ultimately, information visualization can be regarded as a work of art. Additionally, as the contemporary perception of information visualization is now valued as a cultural and artistic artifact, it is anticipated to be unique just as other cultural fields that cross art's path.

The uniqueness and the originality of the outcome of information visualization are directly related to the process of handling the information and producing the visuals. Information visualization should go beyond simply displaying the existing data but should also produce new knowledge alongside. As a result, one of the requirements of being a work of art in the postmodern era is to not reproduce something preexisting but to create something new. According to Drucker (2020), visual representations, as well as serving as representations of existing knowledge, are also primary channels for knowledge generation. In short, visualizations can create and embody information as well as represent it.

The distinction between representational and non-representational approaches of visual expression by Drucker (2020) provides further clarification about the categorization of visual expression. First, representational forms stand for a pre-existing, already formulated knowledge in the form of a graphic statement. They are the visual forms of what they present from a transformative and a separative state. Drucker clarifies this approach as follows: "[A] portrait may represent a specific person, a graph may represent a data set, and an anatomical drawing may represent a body or its systems and parts realistically or schematically (2020, p. 28)." Second, a nonrepresentational visual expression primarily aims to assert information or knowledge, to put it in another way something new is created by the visual image, an existing entity is not reproduced. Likewise, Drucker wrote: "An architectural sketch brings forth the image of a building, a geometrical diagram creates a proof … an act of connecting one or more words in a text with a line creates an interpretation, or a drawing of an arrow creates a model of time or temporality (2020, p. 27)."

This thesis aims to assert a methodology that utilizes bibliometric analysis through information visualization and produces a nonrepresentational visual expression as the final product to base the discussion upon. While considering the distinction of the nonrepresentational approach towards visual expression, one of the key features that diversifies the concept is the quality of the network representation. This approach intends to present a visual expression to decode a complex network through data analysis and information visualization.

2.2.1 Visualizing networks

Manuel Lima (2011) asserts that network representation is typically split into two main categories today: Graph drawing (under graph theory) and network visualization (under information visualization). He clarifies the distinction by stating that unlike graph drawing, which focuses primarily on mathematically drawing graphs, network visualization involves basic design principles tailored towards providing an efficient and comprehensible representation of a system (Lima, 2011, p. 79). There are numerous definitions and interpretations of networks depending on the discipline that studies them. It also makes it possible to extract insights from the structures that are visually presented such as nodes, lines, words, and so on. The goal of network visualization is to transform the core information of a complex structure into visual insights that can be understood. The modern network visualization provides an original map (guide) of the territory, where structures hidden from human perception are given life through pictorial representation and interactive analysis (Lima, 2011, p. 79). According to Lima, network visualization as a potential decoder of complexity consists of five key functions: document, clarify, reveal, expand, abstract.

- Document: Mapping a system that is not previously depicted as documenting and recording the surveyed structure for future research. This thesis utilizes bibliometric analysis as a tool for documentation.
- Clarify: Making a system easier to understand and more transparent. The process of simplification is intended in various steps from data analysis to visualization.
- Reveal: Finding a pattern or developing a new insight about the system. This thesis intends to reveal the impact of two different fields.
- Expand: Providing the basis for further exploration by being used for other purposes. Ultimately, the final product will be able to allow further expansions as will be discussed in the thesis.
- Abstract: Exploring the abstract representation opportunities offered by a networked schema. This thesis exploits information technologies to produce abstract and unique outcomes (Lima, 2011).

The ultimate and most challenging input to provide a comprehensive understanding of the changing dynamics for network visualization is indeed time. Time provides an opportunity to explore and investigate how different variables/parameters, measured in terms of relevance, evolve in a network. The visualization of information begins with documentation, in this case, bibliometric analysis, so the information must first be gathered and presented thoroughly. The input of time additionally enhances the possibility of expanding the scientific references studied. From a holistic perspective, there is also an advantage to developing visuals that prompt the reader/viewer's minds with the accessibility of time for an overall view of the network. Lima (2011) argues that any depiction of networked systems must incorporate the critical dimension of time since they are affected by the natural progression of time. Thus, creating a timeline is one of the efficient ways to interpret the parameter of time in a complex system of network.

If numerous data sources are required to be unified to present a complex system of networks, a timeline is a convenient approach since multiple sets of information need to be purified. The purification of a network in chronological order is intended to assist inexperienced researchers in learning their field in a short amount of time. A field's volume of information collections is growing so rapidly it is difficult to get a complete picture. As such, a timeline's superimposable structure allows for the overlap of knowledge and different fields. For a field in transition, the use of a timeline can streamline the creation of a dynamic temporal tracking model (C. Tang et al., 2019). Accordingly, Larsen and Harrington Jr. (2021) wrote that as more research is conducted, that knowledge can be integrated with existing knowledge. This attitude towards synthesizing the knowledge also brings out the opportunity to study the network of various disciplines. From a holistic point of view, it is almost inevitable to integrate knowledge and methods from different disciplines to comprehend a system of a network in research fields. Surely, a timeline allows interdisciplinarity using a real synthesis of approaches. Similarly, Larsen and Harrington Jr. (2021) comments on the perception of a timeline by stating that its dating scheme and typology of periods help establish a consistent communication process, especially among interdisciplinary research collaboratives.

This thesis examines the bibliometric data as a means to solve that problem. Bibliographic data analysis ought to enable the representation of research trends without the challenges outlined above. A detailed discussion of bibliometric data analysis will be outlined at the end of this chapter.

2.2.2 Timelines

Timelines have a long history dating back to ancient times when Greek and Roman scholars compiled “lists of priests, Olympians, and magistrates (Rosenberg & Grafton, 2010, p. 26).” Timelines, however, have never been more important or accessible than today.

From the modern perspective, timelines represent one of the key facets of contemporary user interfaces since they can display a readily available sheer volume of information with an emphasis on time as the axis of an organization (Rosenberg & Grafton, 2010, p. 246). As mentioned above, utilizing a timeline will allow one to construct a dynamic temporal tracking model for a field that is in constant flux. The question is how this structure would ease comprehending the tendencies of a research field in chronological order. It is important to note that timelines are meant to convey historical information to their audiences. This allows the audience to develop their own connections and correlations based on their ability to reconstruct. A network's relations must be presented in a specific context to comprehend events or the status quo historically. Certainly, a timeline needs to reflect the zeitgeist. Daniel Rosenberg and Anthony Grafton (2010) in their book *Cartographies of Time* interpret the contemporary applications of timelines as it was evolved as a new method for expressing and quantifying chronological relationships, as a result, it caught on especially well, precisely because it embodied the historical spirit of the moment. On the other hand, they also underpin the lasting utmost challenge; providing a form that was intuitive and mnemonic, and that could be used as a tool of reference (Rosenberg & Grafton, 2010).

The use of timelines in architecture is not new. While the thesis will address the timelines dedicated to the case study topic in the next chapter, Charles Jencks' timeline on 20th century architecture deserves attention.

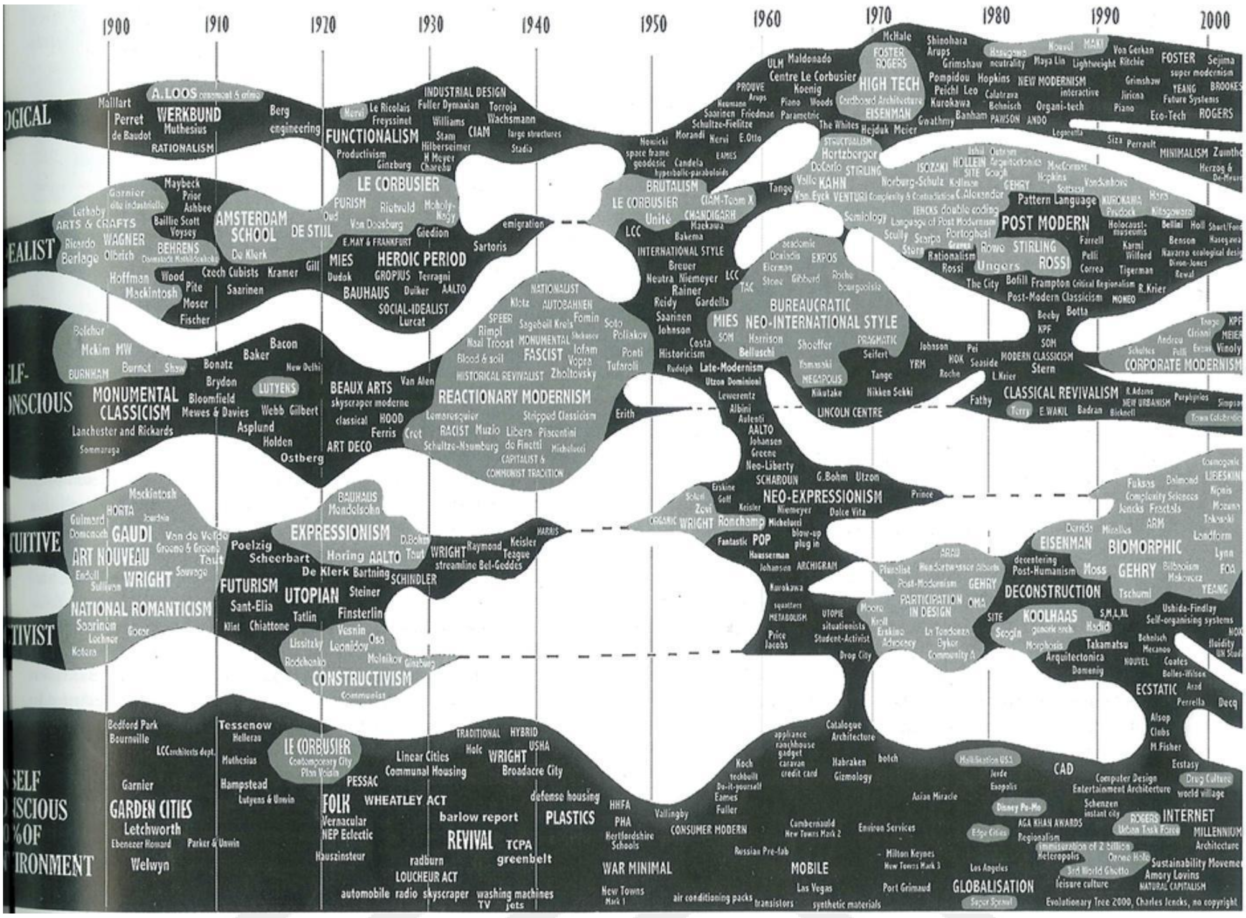


Figure 2-1: Jencks's 'The Century is Over, Evolutionary Tree of 20th Century Architecture' with its attractor basins (2000, p. 77)

According to Jencks, the selection process of the timeline's constituents is critical:

> "Usually when historians look at the recent past they do so with the eyes and taste that rigidly exclude the variety, contradictions, mess and creative wealth of a period, and we applaud them for so doing. All history writing is selective and based on theories of what really matters, and there is no way around this limitation. But there are ways to compensate for perspectival distortion and over the last 30 years I have devised a method, the evolutionary tree, which if it is not completely inclusive is at least balanced in its selective effects (Jencks, 2000, p. 77)"

The selection of timeline elements always carries a bias. This thesis makes use of bibliometric data and their visualization tools to erode this bias. However, it is sensitive to the fact that certain institutions and personalities may have a discursive power within scientific communities and receive more citations than other research scattered around the world. However, this critique exceeds the scope of this thesis.

Another crucial notion in creating a timeline is the incorporation of a field's relevance to the developments in diverse research fields. The following example on media theory considers the relationships between art, new media art, science, technology, war, and media theory.

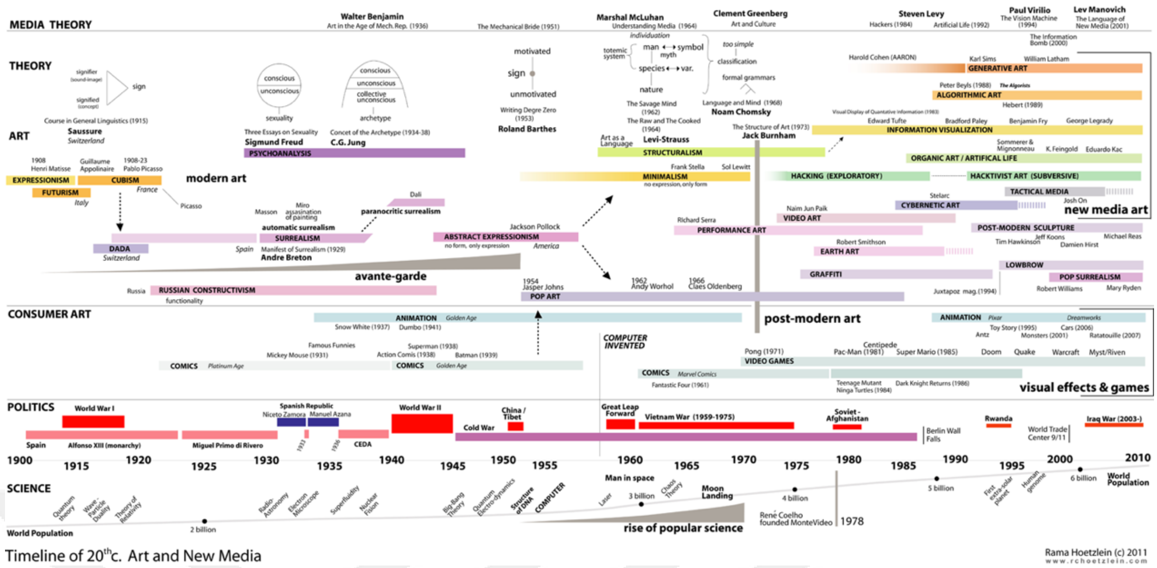


Figure 2-2: Timeline of 20th Century Art and New Media (Hoetzlein, n.d.)

1.1 Bibliometric tools

The purpose of bibliometrics is to investigate and present the current state of research fields through statistical analysis and quantitative methods (X. Chen et al., 2021). Alan Pritchard introduced the term bibliometrics in 1987 and described it as “the application of mathematics and statistics to books and other forms of communication (Broadus, 1987).” The quantitative analysis of the data can provide insights into research related to a specific field (Akinlolu et al., 2020). The bibliometric data analysis utilizes science mapping tools for visualizing mathematics of scientific research and describing their structure (van Eck & Waltman, 2010). It refers to the analysis of publications' properties, such as author, keywords, source, type, etc. It allows for the construction of a network that is based on the inputs provided by the accumulated papers’ keywords, citations, references, authors, countries, organizations, and countries. The bibliometric mapping approach involves visualizing the state of the art of a research area to decide what options the researcher has to widen their research focus or to start new lines of inquiry within a specific area of study.

1.1.1. Types of analysis

Co-authorship

The co-authorship analysis studies a research field's social structure. The affiliations and locations of the authors in the bibliographic data allow one to use co-authorship analysis at the institutional and country level. A co-authorship network links researchers, research institutions, or countries based on the number of papers they have authored together.

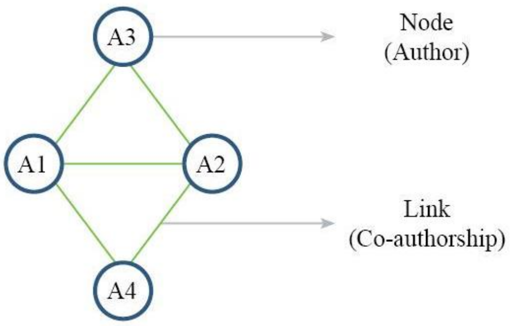
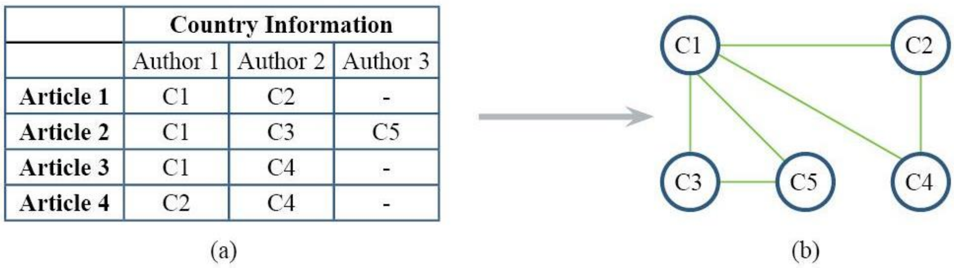


Figure 2-3: Sample of co-authorship network. Adapted from:



	Country Information		
	Author 1	Author 2	Author 3
Article 1	C1	C2	-
Article 2	C1	C3	C5
Article 3	C1	C4	-
Article 4	C2	C4	-

Figure 2-4: (a) co-authorship data (authors from different countries); (b) corresponding network

Co-occurrence of keywords

A co-word analysis analyzes a research field's conceptual structure by using the author's keywords. It is the only method that compiles a measure of similarity from the content of the documents, while the other methods tie documents together indirectly through citations or co-authorship. Co-occurrence of two keywords refers to the number of publications that both keywords occurring together in the keyword lists. Nodes in this network represent keywords, and co-occurrences of two nodes represent links. The link weight is based on how often a pair of words appear in multiple articles (Radhakrishnan et al., 2017). In this sense, based on the patterns and strength of the links between keywords as they appear in the literature, a network can be constructed that represents cumulative knowledge of a domain and allows the identification of significant knowledge components.

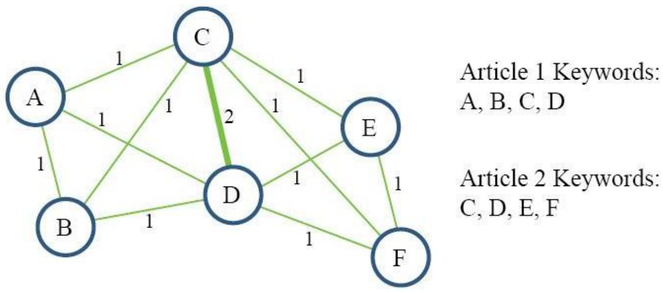


Figure 2-5: Example of a simple keyword co-occurrence network, source: (Radhakrishnan et al. 2017)

Bibliographic Coupling

The third method is bibliographic coupling, which, in contrast to the previous technique, uses the number of references shared by two documents to determine similarity. Accordingly, a greater overlap of references between the two papers would suggest a stronger connection between them. A bibliographic coupling occurs when two publications refer to a common third work.

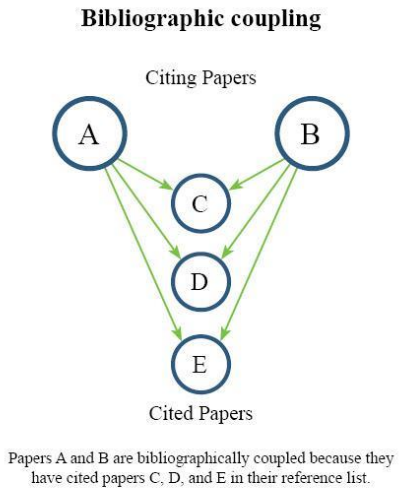


Figure 2-6: Bibliographic Coupling, source (Gipp & Beel, 2009).

Co-citation

Small proposes co-citation analysis to detect the intellectual structure of a research topic (Small, 1973). Co-citation is given when two items are cited together by a third paper. This analysis considers that two papers cited together have a thematic similarity, and a higher frequency of co-citation implies a greater affinity between them. Small applies co-citation analysis to documents, but this analysis can also be extended using other units of analysis, such as authors or journals. Author co-citation aims to detect which authors are most frequently cited together, while journal co-citation analysis shows which sources are cited most frequently.

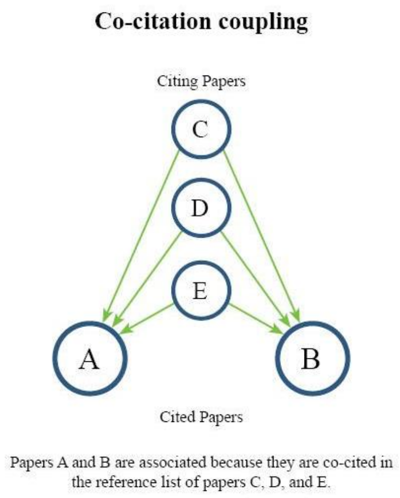


Figure 2-7: Co-citation analysis, source (Gipp and Beel 2009).

1.1.2. The pros and cons of the bibliometric networks

A scientific domain is a cohesive and logically organized body of knowledge. The concept of domain analysis employs bibliometrics to extract unheeded implications from information and seek new frontiers of understanding (C. Chen, 2016). These tools are excellent for mapping knowledge domains via the visualization of bibliographic records in a short time out of thousands of bibliographic data. Yet two issues triggered this study to focus on creating timelines out of these network visualizations.

Bibliometric networks assist researchers in understanding the evolution of research topics over time. However, they do not offer a chronological order of these topics. But regarding two Greek words appearing in the classical literature for time, “chronos” and “kairos,” they do lack explaining why certain research topics appeared at a specific time.

> “One term -chronos-expresses the fundamental conception of time as measure, the quantity of duration, the length of periodicity, the age of an object or artifact, and the rate of acceleration as applied to the movements of identifiable bodies, whether on the surface of the earth or in the firmament beyond. The questions relevant to this conception of time are: 'How fast?', 'How frequent?', 'How old?' and the answers to these questions can be given, in principle at least, in cardinal numbers or in terms of limits that approach these numbers. The other term-Kairos-points to a qualitative character of time, to the special position an event or action occupies in a series, to a season when something appropriately happens that can not happen at ‘any’ time, but only at 'that time', to a time that marks an opportunity which may not recur (Smith, 1969, p. 1)”

Network visualizations cannot provide information about what motivated researchers to perform certain experiments, such as grants or political involvement. Second, the network visualizations become so dense and intricate that usually lead review papers to focus on the statistically leading publications appearing first as the representatives of research clusters.

1.2 Summary

This chapter discussed the reasons for visualizing a research field via bibliometric network visualizations. Considering both the pictorial turn and big data, it explored the implications of how researchers could better comprehend the evolution of diverse fields within a short time. The chapter discussed in detail how network visualizations may go beyond the mere representation of bibliographic data to create new knowledge utilizing timelines.

3 SUSTAINABILITY AND SUSTAINABILITY IN ARCHITECTURE

The thesis proposes a method to create a timeline of research fields based on bibliometric analysis. To illustrate the application of this method, it carries a case study analysis in the field of sustainability in architecture. The bibliometric analysis of research fields is generally limited to its intrinsic agenda. However, to overlay the evolution of research fields, it must also examine the extrinsic developments, like political and economic cornerstone events. This chapter intends to derive these cornerstones into three parts.

The first part presents a brief history of the concept of sustainability to the point where the contemporary debates about the three competing interests began: economic development, environmental preservation, and social equity. The second part details the different meanings of sustainable architecture given over the last three decades, by considering the various approaches to sustainability. It also examines the contemporary assessments of the leading architectural examples regardless of the fertile ground cultivated by the diverse design schemes offered to reduce the impact of the built environment. Parallel to these debates, this part entails the call for a paradigm shift that aims at a more ecological attitude towards the concept in contrast to the current paradigm defined as the mechanistic worldview. The third part reviews the challenges the field of architectural education faces for the ever-changing nature of the sustainability concept and the cornerstone documents affecting the education field.

3.1 The concept of sustainability

The concept of sustainability emerged in the 1970s as a result of the depletion of non-renewable energy resources and pollution caused by overpopulation and the use of fossil fuels. In the second half of the 20th century, the newly acquired technological innovations led to a new era of capitalist expansion. The acceleration in information processing and sharing due to the advancements in telecommunication technologies drastically increased the pace of international business and financial operations. Therefore, this globalization trend has raised awareness towards environmental problems that occur on a global scale. A series of debates and interventions took place at this point within the international arena. The first of these attempts was the World Commission on Environment and Development (1987), also known as the Brundtland Report.

The Brundtland Commission's report introduced sustainability and sustainable development as an indispensable guide to future human actions. The report defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs (1987).” This definition, appearing in the references of many publications of the 1990s and 2000s, is thus a *cornerstone* of the field. Later, Munro described the concept similarly in 1991 in the IUCN publication Caring for the Earth: “to improve the quality of life while living within the carrying capacity of living ecosystems (IUCN; UNEP; WWF, 1991).”

Sustainability and sustainable development are the two mainstream notions currently used in environmental debates. According to Robinson (2004), while the government and the private sector prefer the concept of ‘sustainable development,’ academics, environmentalists, and non-governmental organizations favor that of ‘sustainability.’ At the Rio Conference in 1992, Agenda 21 was adopted as a complementary sustainability action plan. Among the notable outputs of that conference was the triangular model created based on definitions of sustainability and sustainable development. The International Council for Local Environmental Initiatives (ICLEI) commissioned by the UN proposed the final model with the analogy of a three-legged stool as follows: “sustainability initiatives could not stand as a whole without equal support from the three constituent social networks that represent the interests of ecology, economy, and equity.” According to Moore (Moore, 2007), this model hypothesizes that there can be no sustainable development unless three competing interests within society are simultaneously balanced. Popularly called 3 Es, 3 Ps, or triple bottom line, the model includes economic development, environmental preservation, and social equity. Practitioners and researchers have widely adopted this triangular model of sustainability.

Scott Campbell (1996) remodeled the triple bottom line, illustrated in Figure 1. Each tree corner represents a competing interest, and the sides represent the conflicts caused by the competing interests of the three Es. As shown in the diagram, the model envisions provoking debate regarding the conflicts between economic, environmental, and social interests and in turn achieving the ideal sustainable development at its core.

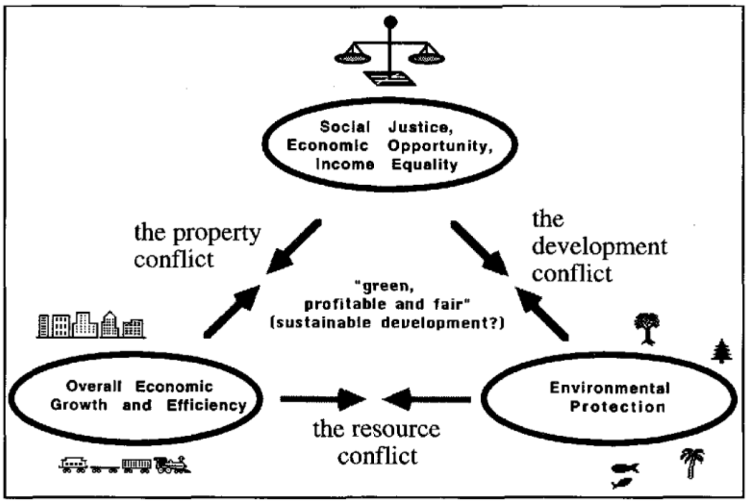


Figure 3-1: Campbell's diagram: The triangle of conflicting goals for planning, and the three associated conflicts (Campbell 1996)

Moore (2007) criticizes this vector-like logic explanation of sustainability by stating that empirical evidence suggests that any model of sustainability, no matter how complex, does not represent the nuance or improvisation of history, past, or future. The discourse around this model provides a universal approach to climate change mitigation and its impact on the environment.

Since the contingency of history is directly related to a geographical location, these deductive models tended to obscure local discourses driven by local historical processes. Thus, the problems associated with each corner of the model are contextually distinct. Nevertheless, despite the tripolar model not leading to one interpretation of living with nature, it still controls the development of sustainability discourse and establishes a system of rules (Ruhi, 2013). According to Ruhi (2013), many institutions use it as an a priori tool to conceptualize and measure sustainable development. This tripolar model has found its place in assessing the environmental qualities of the built environment yet as will be discussed below, the field is replete with diverse approaches. Another criticism can be raised based on the model, which is its methodology. This will however be examined in detail based on the critique of the mechanistic worldview that derives solutions by combining the parts of the problem individually to create a whole.

3.2 Sustainability in architecture

Buildings today account for 36% of global energy demand and 37% of energy-related CO_2 emissions in 2020 according to the annually published Global Status Report for Buildings and Construction report by the UN Environment Programme (2021). According to the status report, there has been a minor decrease in both energy demand in buildings and CO2 emissions caused by building operations compared to recent years which is considered as a result of the pandemic. The data, however, may be misleading since it primarily reflects lockdowns related to the pandemic. However, the buildings and construction sector need to be decarbonized by 2050 to reach the Paris Agreement that aims to protect human life on Earth (United Nations Environment Programme, 2021). Hereby, architecture plays one of the crucial roles that requires designing the built environment to the desired state of sustainability and comfort.

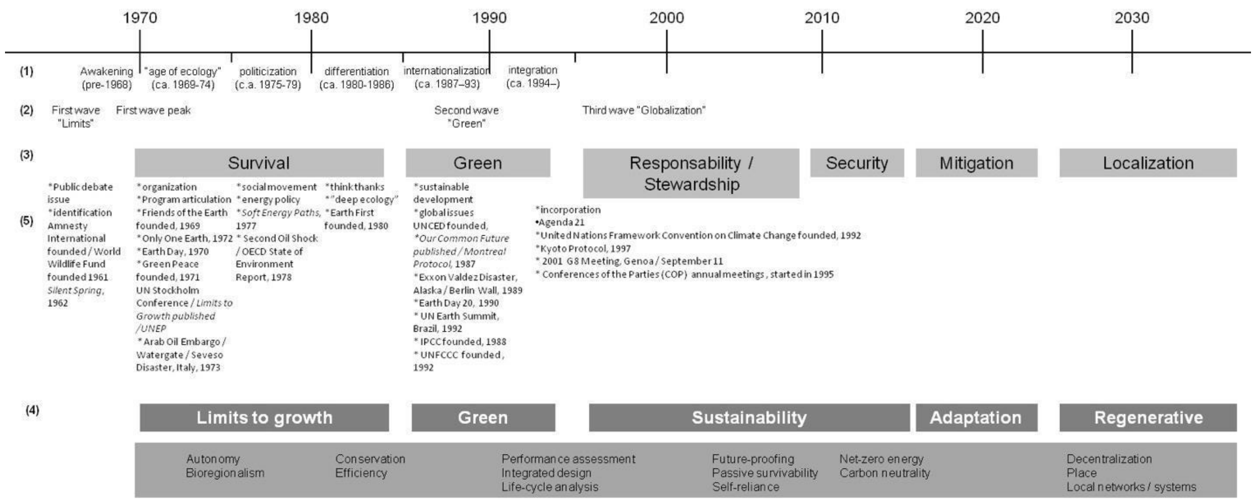
3.2.1 The reflection of the environmental debates on architectural discourse

Parallel to the environmental debates discussed above, the integration of sustainability into architectural discourse gained paramount significance. This integration process has been depicted before in diverse timelines.

The timeline developed by Ruhi (2013) overlaps four different timelines suggested by Jameson (2001), Elkington (2004), and Cole (2011) (Figure 2). The timeline identifies the key events catalyzing environmental awareness, the key concepts for sustainability in the field, and methods developed using these concepts to address these problems. The first strand in Figure 2 (1) refers to Jameson's categorization, which emphasizes the breadth of social and political movements that helped establish environmental consciousness. The rise of an environmental consciousness has gone through six phases, regardless of the time frames across countries. According to strand (2), drawn from Elkington, there are three waves of public pressure on environmental issues. Identified as "limits," the first wave runs parallel to the emergence, ecological era, politicization, and differentiation periods. The second wave, "green", marks the period of internationalization. The third wave, "global", corresponds to the integration period. The third (3) and fourth (4) strands by Cole (2011) makes projections of environmental debates related to architectural sustainability. How these environmental debates have shaped the sustainability discourse in architecture is also reflected in this timeline.

Throughout the past 50 years, the sustainability discourse has suggested many approaches to tackling complex environmental problems (du Plessis 2012). As a part of a holistic thinking system, these notions are in an infinite loop where it is aimed to design the built environment in a self-sustained state.

Yet, the timeline adopted a conventional methodology that aims to decode the network of sustainability in architectural discourse within a chronological order. Thus, this timeline is produced by overlapping the previous works of leading researchers alongside a systematic literature review. Therefore, it takes tremendous time and effort in shaping it.



(1) The phases by Jamison

(2) The phases by Elkington

(3) The phases by Cole

(4) Architectural reflection of these concepts as given by Cole

(5) The cornerstone events and articles

Figure 3-2: Table Representing the Phases of Environmentalism (Ruhi 2013)

Shady Attia's "Timeline of modern history of architecture" provides another perspective by including buildings representative of diverse sustainability paradigms. He also acknowledges the influencers of these paradigms.

Paradigm	Years	Influencer	Paradigm
Bioclimatic architecture	1908–1968	Olgyay, Wright, Neutra	Discovery
Environmental architecture	1969–1972	Ian McHarg	Harmony
Energy conscious architecture	1973–1983	AIA, Balcomb, ASES, PLEA	Energy efficiency
Sustainable architecture	1984–1993	Brundtland, IEA, Feist	Resource efficiency
Green architecture	1993–2006	USGBC, Van der Ryn	Neutrality
Carbon neutral architecture	2006–2015	UN IPCC, Mazria	Resilience
Regenerative architecture	2016–Future	Lyle, Braungart, Benyus	Recovery

Table 3-1Sustainability paradigms influencing architecture in 20th and 21st century (Attia, 2018, p. 8)

Figure 3-3 Timeline of modern history of architecture (Attia, 2018, p.8)

From the start of the 20th century, Attia (2018) identifies five influential paradigms that shaped the sustainability of architecture and built environments. He accounts that the economic and ecological crises associated with industrialization profoundly affected the architectural discourse over the last 120 years (Table 1.1 and Fig. 1.3). Attia warns that his classification shall not be considered as a rigid interpretation of "the evolution and relation between sustainability and the creation of the built environment (2018, p. 7)."

As the 21st century unfolds, sustainability has been reflected heavily on the political agenda and economic decisions following the world's first greenhouse gas emissions reduction treaty; the Kyoto Protocol in 1997. There have been many attempts regarding different topics in various scales that aim to unite both developed and developing countries in a global partnership. As one of the most prominent political actors, **the United Nations** gathered countries together numerous times to stand against global problems. Thus, these crucial attempts were considered as milestones - which are listed on the table below- in tackling climate change because of their global influence in political agendas and diversity of participants.

Table 3-2: The events on sustainable development

Event	Location-Date	Outcome	Importance
Millennium Summit	New York, September 2000	Millennium Declaration	Elaboration of eight Millennium Development Goals (MDGs)
World Summit on Sustainable Development	Johannesburg, August 2002	The Johannesburg Declaration on Sustainable Development and the Plan of Implementation	Built on Agenda 21 and Millennium Declaration by emphasizing on multilateral partnerships
United Nations Conference on Sustainable Development, Rio+20	Rio de Janeiro, June 2012	The Future We Want	Launching the process of SDGs that builds upon MDGs
United Nations Sustainable Development Summit 2015	New York, September 2015	2030 Agenda for Sustainable Development	Adaptation of 17 Sustainable Development Goals
The twenty-first session of the Conference of the Parties (COP 21)	Paris, December 2015	Paris Agreement on Climate Change	International treaty to limit global warming below 2℃ adopted by 196 parties
The twenty-six session of the Conference of the Parties (COP 26)	Glasgow, October 2021	Glasgow Climate Pact	Completing the Paris Rulebook

This study aims to reveal whether these cornerstones influenced the development of the research on the built environment.

3.2.2 Multiple definitions of sustainable architecture

For nearly four decades, designing/imagining a built environment has been described in many adjectives under the umbrella of sustainability, like green Buildings, eco-

Design, sustainable design, ecological design, bioclimatic design. Canizaro and Tanzer (2007) identified at least five competing definitions of sustainable, green, or ecological architecture, based on their analysis:

1. "Buildings and environments that help to establish an integrated relationship with nature.
2. Buildings and environments that preserve and/or improve local ecosystems and which focus on long-term planning and a wider geography.
3. Buildings and environments that result from civic action in which environmental quality, understood both physically and socially, is essential.
4. Buildings that satisfy a series of benchmarks (i.e., LEED) defined by experts, interested parties, and politicians.
5. Buildings and environments that save and/or conserve energy and satisfy our real and perceived needs (Canizaro & Tanzer, 2007, p. 4)."

Regardless of this diversity in definitions and understandings, the core lies in protecting the environment by designing buildings to reach an efficient level, thus consuming efficiently. Sustainability in concept/intent remains the same, but the implementation methods have changed.

The empirical evolution of sustainability in architecture has brought up the need to determine how to count something as sustainable. Building benchmark methods, like LEED, currently used for assessing buildings' impact on the environment and human health emphasize this fact. Consequently, 'sustainable design' inevitably refers to green buildings. In the upcoming sections, bibliometric data from academic studies on sustainable architecture will be used to support this argument. However, as can be seen in Canizaro and Tanzer's five distinct definitions of sustainability in architecture, there are various approaches to producing sustainable space. Another research conducted by Guy and Farmer (2001) also aims to conceptualize the six competing logics of sustainable architecture (Table 1).

Table 3-3: The six competing logics of sustainable architecture (Guy & Farmer, 2001)

Logic	Image of Space	Source of knowledge	Building Image	Technologies
Eco-technic	global context macrophysical	technorational scientific	commercial modern future oriented	integrated energy efficient hightech intelligent

Eco-centric	fragile microbiotic	systemic ecology metaphysical holism	polluter parasitic consumer	autonomous renewable recycled intermediate
Eco-aesthetic	alienating anthropocentric	sensual postmodern science	iconic architectural new age	pragmatic new nonlinear organic
Eco-cultural	cultural context regional	phenomenology cultural ecology	authentic harmonious typological	local low-tech commonplace vernacular
Eco-medical	polluted hazardous	medical clinical	healthy living caring	passive nontoxic natural tactile
Eco-social	social context hierarchical	sociology social ecology	democratic home individual	flexible participatory appropriate locally managed

To exemplify this diversity in current architectural sustainability practice, in their website, World Green Building Council (2021) shares the most cutting-edge sustainable buildings via a world map verified by the established assessment tools. As can be observed from the successful attempts according to the assessment tools, green buildings' primary goal is to attain an equilibrium where there is no waste and maximum resource efficiency.

Figure 3-4: WorldGBC Online Case Study Library (WGBC, 2021)

Although, in the previous sections it is argued that the classificatory approaches towards sustainability and sustainable architecture neglect the complex set of relationships provided by a holistic sense of nature, the intention is to address how diverse the conceptualizations of sustainability in the field of design.

3.2.3 Shift in paradigm towards a new worldview

This study aims to point out an ongoing shift towards a new paradigm alongside the predominant worldview since the introduction of the concept of sustainability. Since it is the current worldview that has both created the environmental problems and is also trying to shape solutions by focusing on minimizing the environmental harm. Considering its potential impact on the timeline for this study, it is necessary to emphasize this call.

Today there are both legal regulations and promotions for designing/constructing sustainable built environments in leading countries. The traditional concept of sustainability, as we understand it today, aims to minimize the effects of human activities upon the integrity of ecological systems. However, efforts have been made by developing technology and researching a less harmful way to produce energy without sacrificing daily living activities. This ongoing worldview of sustainability is defined as the mechanistic worldview (du Plessis, 2012).

In technology development, the mechanistic worldview provides useful knowledge and laws, but it fails to address complex environmental problems. Capra offers a detailed explanation of how these worldviews are different:

> “The basic tension is one between the parts and the whole. The emphasis on the parts has been called mechanistic, reductionist, or atomistic; the emphasis on the whole holistic, organismic, or ecological. In twentieth-century science the holistic perspective has become known as "systemic" and the way of thinking it implies as “systems thinking” (Capra, 1995, p. 17).”

Over the last decade, there is a call for shifting the paradigm towards an ecological worldview that is intended to build upon the currently dominant 'mechanistic' worldview. However, it would be a mistake to interpret the mechanistic worldview as bad because it has created a foundation for the new research in the field. While referred to as a new worldview, it is in reality “emerging from an amalgamation of ancient worldviews and a new scientific paradigm based on the findings from both classical and new sciences (Du Plessis & Brandon, 2015).” The concept of ecological worldview is not proposed to replace or neglect the mechanistic worldview, in contrary Du Plessis and Brandon states that "it adds to the knowledge base by providing a different perspective which reveals different types of knowledge, with both of these worldviews providing valuable insights when applied within the appropriate context of analysis and its realm of validity (2015)." Du Plessis and Cole (2011) describe the desire of the buildings that are designed after the mechanistic worldview as a steady-state and conservation of the status quo.

Robinson and Cole (2015) argue that the current mechanistic sustainability paradigm fails to respond to complex environmental problems in four ways. First, the worldview presently used to publish political agendas is often based on demands for sacrifice and scarcity, which are by definition uninspiring compared to a participatory vision. Second, this narrative does not emphasize the disastrous outcomes of unsustainability. To date, it has focused primarily on harm reduction, with the reasonable goal of zero harm. To this end, "it has simply prolonged inevitable environmental decline by aiming to make things 'less bad' as opposed to finding ways to rehabilitate and improve unsustainable circumstances (Robinson & Cole, 2015, p. 133). Thus, it does not prompt net positive consequences. Third, the current paradigm has not incorporated numerous dimensions of sustainability, but rather, its primary focus is on the environment while assessing the biosphere's limit and carrying capacity. Though the concept of sustainability and sustainable development was introduced to indicate the integration of various dimensions such as ecological, social, and economic (WCED, 1987), the social dimension of sustainability drew far less interest both in political agendas and in the building and construction sector. Finally, scientific knowledge served as the primary resource for developing arguments for ecological limits and scarcity due to its unproblematic approach to knowledge transmission. This transmission however seldom recognizes the extent to which such understandings are based on "cultural, political, and other processes of knowledge constitution (Robinson & Cole, 2015, p. 134)."

Sustainability, along with its predecessor sustainable development, has essentially addressed the complex environmental problems in the last 30 years. However, both focus on analyzing parts of a system in isolation and fail to consider both anthropocentric and ecocentric dimensions of sustainable living, like sociological and psychological. Thus, a more holistic and comprehensive system of thought is essential.

With an empirical method, a system can expand the way sustainability is conceptualized and practiced in theory, design, and development. Therefore, in the last decade, the regenerative paradigm emerged for sustainability to take a big step forward to be part of Mother Earth rather than just live on it.

The ecological worldview is rooted in regenerative sustainability because it allows for human and natural evolution and collaboration in harmony. Mang and Reed clarify the basis of regenerative sustainability as the "almost infinite interrelationships of 'ecological systems' are the way living entities, including humans, relate to, interact with and depend upon each other in a particular landscape in order to pursue and sustain healthy lives (2015, p. 8)." Primarily, the regenerative paradigm consists of a healthier human interaction with nature instead of being a user or a client for various ecosystems. Accordingly, Du Plessis underlines the differences between the mechanistic and ecological worldviews as follows: "This worldview represented a shift from seeing the planet as a deterministic clockwork system in which humans are separate from nature to seeing it as a fundamentally interconnected, complex, living and adaptive social–ecological system that is constantly in flux (2012)." To be part of the ecosystem, human endeavors need to be catalysts for a positive impact on nature at every level. According to Mang and Reed, a positive impact on an ecological system involves "increasing its systemic capability to generate, sustain and evolve increasingly higher orders of vitality and viability for the life of a particular place (2015, p. 8)."

Du Plessis (2012) compares regenerative sustainability with the current sustainability paradigm and categorizes the conceptual differences into three ways. It is imperative to first shift towards a model that constantly emphasizes the similarities between human development and nature's creative approach. So, this developmental model favors the way nature behaves rather than how humans want it to behave. Second, sustainability must be re-defined to reflect the ever-changing and impermanent nature of our world. Third, living beings participate in the production, transformation, and evolution of the ecosystem they live in, so humans and nature are not two separate systems. Hence, human responsibility extends not only to the consequences of their actions, but also to the general health and well-being of the system (2012).

The regenerative paradigm suggests that a deep understanding of living systems requires collaborative and cooperative processes of designing the built environment.

Therefore, by involving designer, client and consumers in design practices, the regenerative paradigm redefines a regenerative development process while expecting the integration of both ecological and sociocultural dimensions of living systems (Svec et al., 2012) . As designers of the built environment, architects have a vital role in shifting this paradigm. Architects of our era must assimilate the regenerative way of living, producing, and consuming. Hence, embracing a regenerative understanding of living is a pedagogical and educational concern that policymakers, institutions, and educators must address.

3.2.4 Bibliometric analysis on the topic

From 2016 onwards, there is a growing interest in making reviews based on bibliometric network analysis tools. Complementary to the research methodology of the thesis, it is intended to briefly document the studies related to sustainability in architecture that embrace bibliometric network analysis as their research tool. This part details some of the previous reviews on the topic.

scale.

Table 3-4: Reviews that utilize Bibliometric Network Analysis, 2016-2021

Title	Author/Year	Details
A Bibliometric Review of Green Building Research 2000–2016	(Zhao et al., 2019)	Review of the journal articles published between 2000-16 and retrieved from WoS based on the topic of publications with the following keywords: *green building*OR sustainab building.** The paper details the research gaps in green building research, hence the deductions are only limited to the building scale.
A Scientometric Analysis and Visualization of Global Green Building Research	(Darko et al., 2019)	As among the first inclusive scientometric review of global green building research (GGBR) from 1974 till 2018, this review analyzes and visualizes the state-of-the-art of the GGBR. Researchers were able to identify and understand trends and patterns (including core research areas, journals, institutions, and countries), as well as how these relate to existing literature on green buildings. However, this review does not provide an indicative timeline showing the evolution of the field coupled with the events putting certain research topics on the agenda. The analysis remains again at the building scale.
A Bibliometric Review of Research on Sustainable Construction, 1994-2018	(Det Udomsap & Hallinger, 2020)	This review undertakes the analysis of publications concerned on the field of 'sustainable construction' (SCON) at the building scale. In the context of the SCON knowledge base, the findings of keyword co-occurrences confirmed the 'weakest' dimension of the SCON knowledge base was 'social sustain-ability', providing the 'leading edge of the sustainability literature was alternative materials.

A Healthy, Energy-Efficient and Comfortable Indoor Environment, A Review	(Šujanová et al., 2019)	The review focuses on research that ensure the indoor environment quality, therefore is limited to the analysis of design interventions at the building scale.
Bibliometric Analysis on Smart Cities Research	(Guo et al., 2019)	The review focuses on the analysis of research on smart cities.
Urban Sustainability Assessment: An Overview and Bibliometric Analysis	(Sharifi, 2021)	Even though the review topic of this paper does not coincide with the thesis topic, it has a parallel objective. Based on bibliometric data, the review creates citation network visualizations and then creates a visualization to show the conceptual structure and evolution of the field in sustainability assessment.

3.3 Sustainability in Architectural Education

As a component of the Knowledge Triangle, higher education crucially links research and practice fields of architectural sustainability. So, to better illustrate how the concept of sustainability found its place in architectural education, this part first explains what this study calls the milestones events or publications and then discusses the major challenges affecting schools of architecture.

3.3.1 Milestones in architectural education

To illustrate the milestones in architectural education, the study embarks on devising binding documents published around the world. Therefore, it focused on the key documents shaping the knowledge, skills, and competences that an architecture graduate must have after finishing his/her studies.

3.3.1.1 UIA-UNESCO *Charter for Architectural Education*

The collaboration between UNESCO and UIA (International Union of Architects) Education Commission generated a programme that aims to designate an international standard for higher education in architecture and the integrity of validated institutions. UNESCO-UIA Study Programme Validation is based on a series of guidelines that acts as an internationally validated assessment tool for quality in architectural education. First devised in 1996, UIA-UNESCO Charter for Architectural Education has been representing these guidelines for higher education institutions for twenty-five years. The first intent in shaping these skills related to professional, social, and cultural dimensions of building practice is to prepare architectural students for the upcoming challenges. The Charter was revised three times since 1996 (2005, 2011, and 2017).

The study first read through each version of the charter and made a content analysis by comparing the versions based on predefined keywords. It then juxtaposed these documents in the following table.

Preamble: As listed on the table, the initial charter from 1996 defines the role of architects as responsible for attaining ‘sustainable development’ in every cultural heritage. As of 2005, the term ‘sustainable development’ leaves its floor to the term ‘sustainable human settlements’.

Aims: The 2011 charter includes the following adjective into the preamble section. In this case, the education leading to licensure shall graduate ‘generalist’ architects. The 2005 chapter includes a list of objectives of architectural education. Therefore, a generalist architect shall graduate from a school that fulfills all the goals defined in the chapter.

General Considerations: The 2005 Charter for the first time refers to the “environmental and professional challenges of the contemporary world”. From 2005 onwards the definition of these challenges has not changed and exclusion of architects from their essential jobs on the market is explained to be a big burden.

As of 2005 Charter the qualities of place, defined as regional characteristic, shall be understood by architects who must oversee and address the needs of their local societies.

The 1996 charter defines a future vision for architectural schools to be ‘an ecologically balanced and sustainable development of the built environment’. But with the 2005 revision, the charter adds the term ‘rational utilization of available resources’ to the previous definition. Thus, it also expands the vision by mentioning the importance of making a technological application that include a comprehensive approach towards the material use.

From the 2005 Charter onwards, it can be observed that environmental education is suggested to be part of primary and secondary schools to raise both architectural and environmental awareness early on for not only architects but also users.

The 2011 Charter puts forth for the first time the architectural heritage education as an essential requirement for ‘understanding sustainability’ including the social context and the sense of place. This shift would hence enhance the preservation of cultural heritage.

The 1996 charter defines architecture as a matter of public concern since it is related to the wellbeing of the built environment and nature.

Objectives of Architectural Education: The 1996 charter points out the interdisciplinary nature of architecture, but it is the 2005 charter that highlights the relationship of the architecture discipline to the environmental sciences.

Initial charter lists the required fundamental knowledge in architectural education such as physics, technologies, and function. However, the notions of ‘ecologically sustainable design, environmental conservation, and rehabilitation’ were introduced in the 2005 revision.

As of 2005, charter introduces a skillset that graduate architects must possess. From 2011 onwards, collaborative skills were added to the list because of the interdisciplinary nature of architectural practice

From 2005 onwards, the charter also lists abilities related to social studies in focus to architecture and client/user relationship since they all are part of the society.

Table 3-5: UIA-UNESCO Charters

	1996	2005 (Revised between 2004-2005)	2011 (Revised between 2008-2011)	2017 (Revised between 2014-2017)
Preamble	We, being responsible for the improvement of the education of future architects to enable them to work for a sustainable development in every cultural heritage, declare:	We feel responsible for the improvement of the education and training of future architects to enable them to meet the expectations of XXIst Century societies worldwide for sustainable human settlements in every cultural heritage. We are aware of the fact that, in spite of many outstanding and sometimes spectacular contributions of our profession, there is a surprisingly small percentage of the built environment which is actually conceived and realised by architects and planners. There is still room for the development of new tasks for the profession when architects become aware of the increasing needs identified and possibilities offered in areas which have not, up to now, been of major concern to the profession. Still greater diversity is therefore needed in professional practice and, as a consequence, in architectural education and training. This is particularly true for those who are working in a developing context, where the architects	We feel responsible for the improvement of the education and training of future architects to enable them to meet the expectations of XXIst Century societies worldwide for sustainable human settlements in every cultural heritage. We are aware of the fact that, in spite of many outstanding and sometimes spectacular contributions of our profession, there is a surprisingly small percentage of the built environment which is actually conceived and realised by architects and planners. There is still room for the development of new tasks for the profession when architects become aware of the increasing needs identified and possibilities offered in areas which have not, up to now, been of major concern to the profession. Still greater diversity is therefore needed in professional practice and, as a consequence, in architectural education and training. The basic goal of education is to develop the architect as a « *generalist* ». This is particularly true for those who are working in a developing	We feel responsible for the improvement of the education and training of future architects to enable them to meet the expectations of XXIst Century societies worldwide for sustainable human settlements in every cultural heritage. We are aware of the fact that, in spite of many outstanding and sometimes spectacular contributions of our profession, there is a surprisingly small percentage of the built environment which is actually conceived and realised by architects and planners. There is still room for the development of new tasks for the profession when architects become aware of the increasing needs identified and possibilities offered in areas which have not, up to now, been of major concern to the profession. Still greater diversity is therefore needed in professional practice and, as a consequence, in architectural education and training. The basic goal of education is to develop the architect as a « *generalist* ».

		could accept the role of an "enabler", rather than that of a "provider", and where the profession can meet new challenges. There is no doubt that the architect's capacity to solve problems, can greatly contribute to tasks such as community development, self-help programmes, educational facilities, etc., and thus make a significant contribution to the improvement of the quality of life of those who are not accepted as citizens in their full right and who cannot be counted among the architect's usual clients.	context, where the architects could accept the role of an "enabler", rather than that of a "provider", and where the profession can meet new challenges. There is no doubt that the architect's capacity to solve problems, can greatly contribute to tasks such as community development, self-help programmes, educational facilities, etc., and thus make a significant contribution to the improvement of the quality of life of those who are not accepted as citizens in their full right and who cannot be counted among the architect's usual clients.	This is particularly true for those who are working in a developing context, where the architects could accept the role of an "enabler", rather than that of a "provider", and where the profession can meet new challenges. There is no doubt that the architect's capacity to solve problems, can greatly contribute to tasks such as community development, self-help programmes, educational facilities, etc., and thus make a significant contribution to the improvement of the quality of life of those who are not accepted as citizens in their full right and who cannot be counted among the architect's usual clients.
Aims	That the new era will bring with it grave and complex challenges with respect to social and functional degradation of many human settlements, characterized by a shortage of housing and urban services for millions of inhabitants and by the increasing exclusion of the designer from projects with a social content.	architectural education constitutes some of the most significant environmental and professional challenges of the contemporary world	architectural education constitutes some of the most significant environmental and professional challenges of the contemporary world	architectural education constitutes some of the most significant environmental and professional challenges of the contemporary world
General Consi-derations		These challenges may include global urbanisation and the consequent depletion of existing environments, a severe shortage of housing, urban services and social infrastructure, and the	These challenges may include global urbanisation and the consequent depletion of existing environments, a severe shortage of housing, urban services and social infrastructure, and the increasing	These challenges may include global urbanisation and the consequent depletion of existing environments, a severe shortage of housing, urban services and social infrastructure, and the

		increasing exclusion of architects from built environment projects.	exclusion of architects from built environment projects.	increasing exclusion of architects from built environment projects.
General Considerations		That it is in the public interest to ensure that architects are able to understand regional characteristics and to give practical expression to the needs, expectations and improvement to the quality of life of individuals, social groups, communities and human settlements.	That it is in the public interest to ensure that architects are able to understand regional characteristics and to give practical expression to the needs, expectations and improvement to the quality of life of individuals, social groups, communities and human settlements.	That it is in the public interest to ensure that architects are able to understand regional characteristics and to give practical expression to the needs, expectations and improvement to the quality of life of individuals, social groups, communities and human settlements.
General Considerations	That the vision of the future world, cultivated in architectural schools, should include the following goals: - an ecologically balanced and sustainable development of the built environment;	That the vision of the future world, cultivated in architecture schools, should include the following goals : - a technological application which respects the social, cultural and aesthetic needs of people and is aware of the appropriate use of materials in architecture and their initial and future maintenance costs. - an ecologically balanced and sustainable development of the built and natural environment including the rational utilisation of available resources.	That the vision of the future world, cultivated in architecture schools, should include the following goals : - a technological application which respects the social, cultural and aesthetic needs of people and is aware of the appropriate use of materials in architecture and their initial and future maintenance costs. - an ecologically balanced and sustainable development of the built and natural environment including the rational utilisation of available resources.	That the vision of the future world, cultivated in architecture schools, should include the following goals : - a technological application which respects the social, cultural and aesthetic needs of people and is aware of the appropriate use of materials in architecture and their initial and future maintenance costs. - an ecologically balanced and sustainable development of the built and natural environment including the rational utilisation of available resources.
General Considerations		That issues related to architecture and the environment should be introduced as part of the general education at primary and secondary schools, because an early awareness of the built environment is important to both future architects and users of buildings.	That issues related to architecture and the environment should be introduced as part of the general education at primary and secondary schools, because an early awareness of the built environment is important to both future architects and users of buildings.	That issues related to architecture and the environment should be introduced as part of the general education at primary and secondary schools, because an early awareness of the built environment is important to both future architects and users of buildings.
General Considerations			That architectural heritage education is essential to:	That architectural heritage education is essential to:

			-understanding sustainability, the social context and sense of place in building design, and; -transforming the professional architectural mentality so that its creative methods are part of a continuous and harmonious cultural process (Refer to Appendix X, UIA paper on Heritage Education, of UIA Education Commission Reflection Group 7, on Heritage Education, Torino 2008) That cultural diversity, which is as necessary for human kind as biodiversity is for nature, is the common heritage of all humanity, and should be recognized and understood, for the benefit of present and future generations. (Refer to the UNESCO Universal Declaration on Cultural Diversity of November 2001).	-understanding sustainability, the social context and sense of place in building design, and -transforming the professional architectural mentality so that its creative methods are part of a continuous and harmonious cultural process (Refer to Appendix X, UIA paper on Heritage Education, of UIA Education Commission Reflection Group 7, on Heritage Education, Torino 2008) That cultural diversity, which is as necessary for human kind as biodiversity is for nature, is the common heritage of all humanity, and should be recognized and understood, for the benefit of present and future generations. (Refer to the UNESCO Universal Declaration on Cultural Diversity of November 2001).
Objectives of Architectural Education	Architecture is an interdisciplinary field that comprises several major components: humanities, social and physical sciences, technology and the creative arts.	That architecture is a discipline which draws knowledge from the humanities, the social and the physical sciences, technology, environmental sciences, the creative arts and the liberal arts.	That architecture is a discipline which draws knowledge from the humanities, the social and the physical sciences, technology, environmental sciences, the creative arts and the liberal arts.	That architecture is a discipline which draws knowledge from the humanities, the social and the physical sciences, technology, environmental sciences, the creative arts and the liberal arts.
Objectives of Architectural Education	4. Architectural education involves the acquisition of the following: -an adequate knowledge of physical problems and technologies and of the function of buildings so as to	That architectural education includes the following points: - An adequate knowledge of physical problems and technologies and of the function of buildings so as to provide them with internal conditions of	That architectural education includes the following <u>fundamental</u> objectives: - Adequate knowledge of physical problems and technologies and of the function of buildings so as to provide them with internal	That architectural education includes the following <u>fundamental</u> objectives: - Adequate knowledge of physical problems and technologies and of the function of buildings so as to provide them with internal

	provide them with internal conditions of comfort and protection against the climate;	comfort and protection against the climate.	conditions of comfort and protection against the climate. - Awareness of responsibilities toward human, social, cultural, urban, architectural, and environmental values, as well as architectural heritage. - Adequate knowledge of the means of achieving ecologically responsible design and environmental conservation and rehabilitation.	conditions of comfort and protection against the climate. - Awareness of responsibilities toward human, social, cultural, urban, architectural, and environmental values, as well as architectural heritage. - Adequate knowledge of the means of achieving ecologically responsible design and environmental conservation and rehabilitation.
Objectives of Architectural Education		That the following special points be considered in the development of the curriculum: - Awareness of responsibilities toward human, social, cultural, urban, architectural, and environmental values, as well as architectural heritage. - Adequate knowledge of the means of achieving ecologically sustainable design and environmental conservation and rehabilitation.		
Objectives of Architectural Education	6. Educational programmes should promote architectural design which considers the cost of future maintenance, also taking into account that, unlike traditional construction methods with low maintenance materials, some contemporary, experimental and unproved industrial systems and materials require constant and expensive maintenance	KNOWLEDGE Environmental Studies - Ability to act with knowledge of natural systems and built environments. - Understanding of conservation and waste management issues. Understanding of the life cycle of materials, issues of ecological sustainability, environmental impact, design for reduced use of energy, as well as passive systems and their management.	KNOWLEDGE Environmental Studies - Ability to act with knowledge of natural systems and built environments. - Understanding of conservation and waste management issues. Understanding of the life cycle of materials, issues of ecological sustainability, environmental impact, design for reduced use of energy, as well as passive systems and their management.	KNOWLEDGE Environmental Studies - Ability to act with knowledge of natural systems and built environments. - Understanding of conservation and waste management issues. Understanding of the life cycle of materials, issues of ecological sustainability, environmental impact, design for reduced use of energy, as well as passive systems and their management.

		- Awareness of the history and practice of landscape architecture, urban design, as well as territorial and national planning and their relationship to local and global demography and resources. - Awareness of the management of natural systems taking into account natural disaster risks.	- Awareness of the history and practice of landscape architecture, urban design, as well as territorial and national planning and their relationship to local and global demography and resources. - Awareness of the management of natural systems taking into account natural disaster risks.	- Awareness of the history and practice of landscape architecture, urban design, as well as territorial and national planning and their relationship to local and global demography and resources. - Awareness of the management of natural systems taking into account natural disaster risks.
Objectives of Architectural Education		SKILL - Understanding of systems of evaluation, that use manual and/or electronic means for performance assessments of built environments.	SKILL - Ability to work in collaboration with other architects and members of interdisciplinary teams. - Understanding of systems of evaluation, that use manual and/or electronic means for performance assessments of built environments.	SKILL - Ability to work in collaboration with other architects and members of interdisciplinary teams. - Understanding of systems of evaluation, that use manual and/or electronic means for performance assessments of built environments.

3.3.1.2 An Architecture Guide to the 17 Sustainable Development Goals

The United Nations presented the Sustainable Development Goals (SDGs) at their summit in New York in 2015, as mentioned above. Through the content that UN's SDGs provided, the International Union of Architects (UIA), partnered with the Institute of Architecture and Technology at the Royal Danish Academy – Architecture, Design, Conservation, and the Danish Association of Architects, has published a guide called *An Architecture Guide to the 17 Sustainable Development Goals* (Mossin et al., 2018) that consists of 2 volumes. The primary intention of this guide is to illustrate how architecture can contribute to each SDG through interacting with the built environment by presenting related case studies. There are 17 challenges to achieve a sustainable future:

1. No Poverty
2. Zero Hunger
3. Good Health and Well-Being
4. Quality Education
5. Gender Equality
6. Clean Water and Sanitation
7. Affordable and Clean Energy
8. Decent Work and Economic Growth
9. Industry, Innovation and Infrastructure
10. Reduced Inequalities
11. Sustainable Cities and Communities
12. Responsible Consumption and Production
13. Climate Action
14. Life Below Water
15. Life On Land
16. Peace, Justice and Strong Institutions
17. Partnership For the Goals

At first glance, these goals may be seen as unrelated to the duties of an architect. However, as exemplified by several cases in the guide, the interaction between humans and the built environment is the foundation of each development goal. As noted at the beginning of this chapter, the paradigm shift towards a new worldview coincides with these development goals based on their holistic understanding of the earth.

3.3.1.3 Previous thesis on the sustainability in architectural education

Initially, a literature review regarding sustainability in architectural education is conducted at the preparation phase of the study. Thus, the first overview of the field that contained the information about dissertations, books, articles, and reviews guided the study in terms of exhibiting the research gaps in the field. After the determination of the field of study, the methodology founded upon the bibliometric analysis and timeline was developed. However, as the methodology of this study suggested another literature review was conducted via exploiting bibliometric analysis tools. Since the data documentation of the literature is required, Web of Science' databases were scanned for both sustainability in architecture and sustainability in architectural education.

However, as it turns out, the number of research output in the field of education remained low for attaining a larger perspective in the field. To enlarge the documentation, the study conducted a survey on the masters' theses and dissertations found in two databases as well: the Thesis Center by the Council of Higher Education (Turkey) and ProQuest Dissertations & Theses Global. The research criteria were carefully determined since they required the uttermost resemblance as the criteria used for the Web of Science. These research outputs will also be visualized in the timeline.

Thesis Center by the Council of Higher Education:

Based on the legislations of the Council of Higher Education, the language of the dissertations and theses may vary based on the corresponding institutions' language of education. Therefore, the database of Thesis Center must be scanned in both Turkish and English for a reliable outcome.

- Language: Turkish

  Keywords: sürdürülebilir, mimarlık, eğitim

  Search Field: All

  Result: 84

Theses on which the above criteria appear to be a total number of 84. However, a further manual elimination is required since some of the findings' titles and subjects turned out irrelevant. So, after eliminating the theses by filtering their subjects such as interior design/industrial design education, 74 theses appeared to be the result. Furthermore, the rest of the findings are manually eliminated according to their content. The following table illustrates the final research input for this study to utilize through its methodology and timeline:

Table 3-6: Thesis on the topic (retrieved from Thesis Center by the Council of Higher Education with keywords in Turkish)

Title	Author/Year	Thesis Type	Details
A sustainable model proposal for architectural education	Elif Tatar (2015)	Ph.D.	The dissertation aims to propose a sustainable education model for architectural studio environment in the light of contemporary developments and policies related to the field.
A modal proposal in the scope of construction project course for bettering sustainable building envelope design education, ITU case	Elif Sarpaşar (2017)	Master	Thesis proposes an educational model after the examination of construction project studio for three semesters.
A model proposal for integrating energy efficient/sustainable design principles with architectural education in Turkey	Salih Ceylan (2016)	Ph.D.	The dissertation proposes an undergraduate architectural education model that derives from the contrasts between the current models in Turkey and the certain institutions in developed countries that are managed to adopt a successful program in terms of sustainability and energy efficiency.
Development of BIM learning scenarios for architectural education	Hatidza Çapkin (2020)	Ph.D.	A strategy for BIM integration in the architectural curricula of ITU's graduate program in architecture is developed in this thesis.

- Language: English

Keywords: sustainability, architecture, education

Search Field: All

Result: 112

Theses on which the above criteria appear to be a total number of 112. However, a further manual elimination is required since some of the findings' titles and subjects turned out irrelevant. So, after eliminating the theses by filtering their subjects, 95 theses appeared to be the final result. After the final manual elimination of theses regarding their titles and abstracts, the results are summarized on the following table:

Table 3-7: Thesis on the topic (retrieved from Thesis Center by the Council of Higher Education with keywords in English)

Title	Author/Year	Thesis Type	Details
Integration of building energy performance assessment into architectural design studio	Derya Güleç (2007)	Master	Thesis share research findings based on an experimental study carried out in an architectural studio. The studio is separated into two groups where one is testing their

			projects' environmental performance addition to the conventional design process.
Sustainability in architectural education: the impact of education on perceptions of sustainability	Ayça Nilüfer Çalikuşu (2019)	Master	The study examines the architectural studios in context of sustainability by two case studies. Thus, it aims to clarify the role of architectural studios in terms of sustainability.
A study on integration of sustainability principles into architectural education	Sine İbrahimgil (2019)	Ph.D.	Various curricula alternatives concerning the integration of sustainability were investigated, and national higher education institutions were categorized based on their program and student surveys were conducted.

- Language: English

Keywords: sustainability, architectural, education

Search Field: All

Result: 53

Table 3-8: Thesis on the topic (retrieved from Thesis Center by the Council of Higher Education with keywords in English)

Title	Author/Year	Thesis Type	Details
Integrating sustainability principles into architectural design studio	Kamal Eldin Mohamed (2018)	Master	The study creates an integration method that could be validated through the junior students' work in the innovative Sustainable Architecture Design Studio at Izmir Institute of Technology. The study reports on three experimental sustainable architecture studios.

ProQuest Dissertations & Theses Global:

Keywords: sustainable, sustainability, architecture, education

Command Line Search with Codes: ab(sustainab*) AND ab(architecture) AND ab(education)

Language: English

Source Type: Dissertations & Theses

Results: 71

As methodology of this study requires, the final 71 studies were manually eliminated by reviewing the titles and their contexts. The relevant results related to this study were listed above:

Table 3-9: Thesis on the topic (retrieved from ProQuest Dissertations & Theses Global)

Title	Author/Year	Thesis Type	Details
The role of built environment education programs in environmental education	Julia L. Morlacci (2002)	Master	This study compares five programs of built environment education to represent different multidisciplinary education techniques incorporate environmental and urban education.
Sustainability and architectural education: transforming the culture of architectural education in the United States	Amanda S. Woodward (2007)	Ph.D.	The thesis analyzes richly complex cases and clarifies the ways in which sustainability efforts are understood and advanced. These efforts encounter resistance and constraints as well. Using cultural factors as a lens through which to analyze architectural education, the study offers an argument emphasizing the role of culture in explaining change and resistance to change. Various data sources were employed including interviews and artifacts.
Environmental architecture education: a comparative study between the curricula of Kuwait university and Newcastle university with reflection on policy making and end users	Al-Hassan, Ameera (2010)	Ph.D.	The study proposes a new teaching environment including curriculum recommendations, and new teaching, learning, and assessment methods with a focus on policy makers and multidisciplinary nature of architecture.
Exploring the Integration of Sustainability and Green Building Themes within Formal Architectural Education	Traci Rose Rider (2010)	Ph.D.	This study focuses on two main themes that derived from the interviews with thought leaders in the related area, student engagement at the instructional methods level, and revisioning of the field at the philosophical level. It deeply explores the implications of these concepts.
Liberating architectural education for sustainable development: practitioners' perspectives in Hong Kong	Julie, Kwok Wah (2013)	Master	This study explores the possible improvements for the current architectural education to support sustainable development that derive from the insights of architectural practitioners via interviews.
Thinking smart: incorporating smart buildings design theory, building information modeling, and integrated project delivery into architecture design school curriculum	Aaron J. Gonzales (2014)	Ph.D.	This study suggests a shift in the curriculum framework by adapting modifications to architectural education such as BIM and IPD.

3.3.2 An overview of the challenges in architectural education

Architectural education is replete with diverse challenges stemming from existing curricula, course contents, duration, and place of learning (Ruhi-Sipahioğlu & Alanlı, 2020; Tzonis, 2014a, 2014b). In the last few decades, the expectation for more specialized work towards a disciplinary and/or sub-disciplinary field of study/practice has grown tremendously. The primary reason for this is that most of the inherited curriculum is discipline-based. In architectural education, the specialization of topics stands out as the separation of the practice and theory in the curricula. To be specific, theoretical and design courses are taught in separate courses where there is little or no effort to intersect their paths in formal architectural education. William Keenan points out the discussion of the underlying concern about the subject of boundness whether the restricted modernist path to knowledge expertise is the best road to take for the academic education of students as global actors (Keenan, 2020). Since architecture itself requires multidisciplinary knowledge and its integration with one another, architectural education shouldn't approach different contexts separately.

On the other hand, considering the necessity of equipping problem-solving skills on various subjects is crucial in architectural practice, especially while focusing on sustainable and anti-climate change design. It is clear that the interdisciplinary interactions and collaborative learning skills are not developed through architectural education. Because most of the disciplines which work alongside architecture are missing in the curricula. From a theoretical point of view, William Keenan states that "merging, melting, meandering may all be appropriate conceptions for the shifting and drifting that occurs around problems and issues that defy fixed categorization and final classification (2020, p. 68)."

Nowadays, bureaucracy stands out as an inhibitor in the way of the information age. It is not capable of keeping up with the pace of the current information network resulting from advancements. The rigidness of the system holds back these advancements in terms of time management and contemporariness. The same problem occurs also in universities. In higher education formal learning environments are defined strictly as curriculums. It is very challenging to change the content of the curriculums because of the administrative barriers. On the other hand, in the 21st century the disciplines are somehow more integrated and/or specialized that a small advancement in a field can affect the related topics. Formal learning environments have to be flexible and changeable enough to stay contemporary.

From a holistic point of view, thinking through all the scales and their transitions from one another in terms of socially, economically and politically is the key aspect of understanding the world as a whole. In a globalized world architecture professionals work not only from discrete locations but also worldwide. In terms of architectural education, this discussion is furthered by Tzonis and asked as if architectural education should focus on a generalist or specialist approach:

> "The dichotomy between a curriculum that focuses on 'global', 'universal' or 'core' architectural knowledge and 'local', 'regional' one. There are not only philosophical, moral, and political issues associated with this question but also practical ones about educating for 'global practitioners' as opposed to one for designer that would serve regional communities towards safeguarding environmental and socio-cultural resources and diversity (2014b, p. 77)."

Nowadays, architecture is facing a problem which is briefly defined by Tzonis (2014); an explosion of differentiation and specialization of architectural knowledge and division of labor in architectural practice caused by technological, epistemological, economic, and social forces demanding a place in the curriculum (as well as equivalent quantities of people and spaces). The enormous requirements to provide a necessary physical environment is somehow impossible but also is one of the missing pieces between theory and practice.

In the contemporary world, equality in education is one of the main political discussions throughout the developed countries. However, in most universities the required physical competences to further or lead the research relating to a specific field are generally insufficient. Regarding the current direction that architecture is oriented, technological tools must have requirements to design buildings that can sustain. So, most of the tools such as robotics, CNCs, laser cutters, 3D printers, digital programs etc. need to be integrated both physically and theoretically into architectural curricula.

3.4 Summary

The beginning of this chapter provides a brief overview of sustainability discourse and illustrates how the field has evolved over the past thirty years into an essential concept for this new era. Thus, sustainability has become one of the most researched topics for academics, as a result, approaches to the concept have diversified significantly. Through several studies that utilize the timeline methodology, this chapter explored how sustainability is reflected in both architectural research and practice. On the other hand, political agendas developed by the policy-makers serve as a basis for a discussion of how research, education, and practice regarding sustainability have evolved.

The last part of this chapter overviewed the milestones affecting architectural education about the sustainability paradigm and the significant challenges in architectural education concerning sustainability. This chapter pointed out the multiple definitions derived from the research fields of architectural sustainability. The figure below illustrates the multiplicity in these definitions. This thesis aims to reveal how the multiplicity in sustainability in architecture reflects on architectural education.

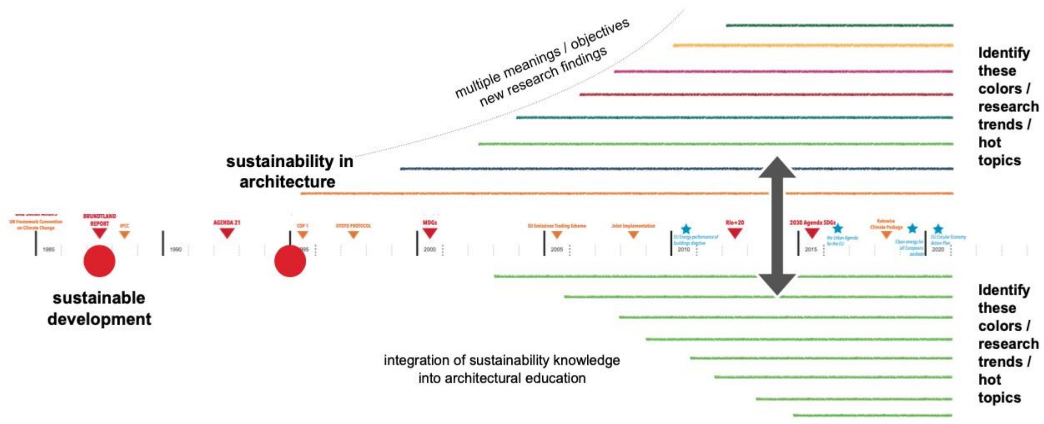


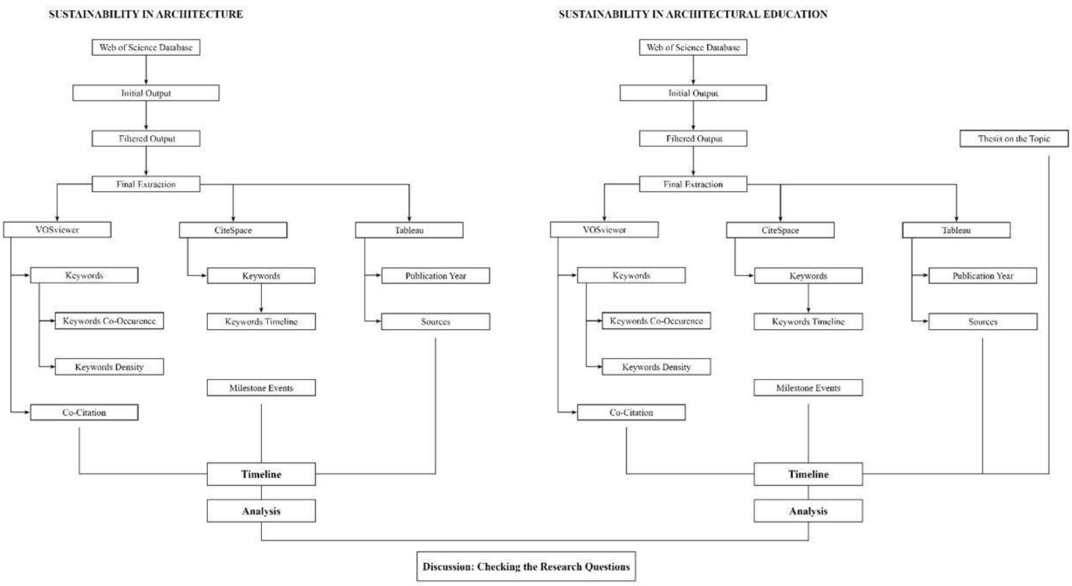
Figure 3-5: A figurative representation of the thesis objective in creating timelines for these fields

This study intends to reveal the discrepancies by utilizing bibliometric analysis of research and education fields of architectural sustainability as the color-coded representation in the figure. Through bibliometric analysis tools and the production of a timeline, it is aimed to present a clear picture of the status quo regarding sustainability in architecture and the integration of sustainability knowledge into architectural education.

4 CREATING THE TIMELINES

This thesis aims to provide a general understanding of the evolution of sustainability in architecture concerning its interaction with education using bibliometric data analysis.

Chapter 2 overlays the logic behind the development of a research field's timeline. Chapter 3 provides what this study calls the cornerstone events/publications interacting the two research fields. This chapter creates the two timelines by superimposing the accumulated charts/analysis from the bibliometric data: (1) A timeline of sustainability in architecture; (2) A timeline of sustainability in architectural education. The following figure illustrates the methodology leading to these timelines.



Finally, chapter 5 will overlap these timelines to compare/contrast the key trends in both fields to illuminate how the research fields relate to one another.

4.1 Terminology

This study aims to identify which documents are the most influential when analyzing the intersection of sustainability, architecture, and education and to determine the intellectual structure of the field through various analyses accordingly to the data provided by Web of Science (WoS). To achieve the presented goal, after the collection of the data from the WoS databases (SCI-EXPANDED, SSCI, A&HCI, ESCI), the information is processed through bibliometric analysis tools for information visualization. There is numerous bibliometric analysis software. This study utilized VOSviewer, and CiteSpace as its core structure for the methodology. Initially, a free software called the VOSviewer, developed by Van Eck and Waltman from Leiden University, was used since it has a beneficial mapping algorithm that unfolds existing bibliometric networks. Moreover, it constructs and visualizes the bibliometric data that forms upon the bibliographic coupling, citations, and authorship (Van Eck & Waltman, 2021). Thus, it also includes text mining function that illustrates the relationship between the most occurred terms indicating the influential topics of related research field. Overall, there are various advantages of using this software ranging from easy visualization to numeric influence of a source (coded as the *total link strength*). On the other hand, CiteSpace developed by Chaomei Chen, is also a freely available software to visualize and analyze the trends of a scientific field where its primary source is WoS. The primary focus of this program is to point out the cornerstones of a research field (Chen, 2016). So, its primary advantage is to detect emerging trends both for development, and contemporary status of a research field without spending tremendous hours in reviewing the literature. This study utilizes CiteSpace to illustrate the bursts of research topics and co-occurrence of these topics in a chronological context where it can be represented in the final timeline.

The table below details the terminology used in the analysis programs.

Table 4-1: Main terms in VOSviewer (Van Eck & Waltman, 2021)

Software	Term	Description
VOSviewer	Items	Objects of interest (e.g., publications, researchers, or terms)
VOSviewer	Link	Connection or relation between two items (e.g., bibliographic coupling links between publications, co- authorship links between researchers, and co-occurrence links between terms)

VOSviewer	Link strength	"Represented by a positive numerical value. The higher this value, the stronger the link. The strength of a link may for example indicate the number of cited references two publications have in common (in the case of bibliographic coupling links), the number of publications two researchers have co-authored (in the case of co-authorship links), or the number of publications in which two terms occur together (in the case of co- occurrence links)."
VOSviewer	Network	Set of items connected by their links.[1]
VOSviewer	Cluster	"Sets of items included in a map. Clusters are non-overlapping in VOSviewer… an item may belong to only one cluster. Clusters do not need to exhaustively cover all items in a map. Hence, there may be items that do not belong to any cluster. Clusters are labeled using cluster numbers."
VOSviewer	Weight attribute: number of links	The number of links of an item with other items.
VOSviewer	Weight attribute: total link strength	The cumulative strength of the links of an item with other items.

Table 4-2: Main terms in Gephi and Citespace

Gephi	Degree Centrality	Defined as the number of links incident upon a node. The term, degree centrality has the same meaning as the weight attribute used in the VOSviewer. A node that has 10 links (connections) would therefore has a degree centrality of 10.
Gephi/CiteSpace	Betweenness Centrality	An indicator of a node's centrality in the network. It is equal to the number of shortest paths from all nodes other nodes that pass through that node.
Gephi	Modularity	Modularity is one measure of the structure of networks or graphs. It was designed to measure the strength of division of a network into modules (also called groups, clusters or communities).

The study employs diverse criteria for selecting the nodes in the co-citation and co-occurrence networks in VOSviewer and Citespace. In Citespace, the study starts with the default g-index and generates the network visualization. Second, it looks at the modularity of the network, the number of clusters, and average silhouette scores. If the network had only a couple of clusters, such as three or five, it would not be able to show a detailed breakdown of the field. Yet hundreds of clusters wouldn't provide a comprehensive view either.

[1] In terms of the terminology, Van Eck and Waltman draws on the terminologies used in the field as follows: "In the literature, a network is sometimes referred to as a graph. Likewise, an item is sometimes called a node or a vertex, a link is sometimes called an edge, and the strength of a link is sometimes called an edge weight. These terms are not used by VOSviewer, but they may be used by other software tools for network analysis and network visualization (2021, p. 5).

According to the literature, “a good range of the number of clusters would be about 7~10 major clusters with 10 or more members and each of the clusters has high silhouette values (e.g. > 0.70) (Chen, 2021).” To be considered within acceptable range, modularity should be higher than 0.3 (Newman, 2004). The silhouette score should be above 0.4 for representing a reasonable division (Rousseeuw & Kaufman, 1990). As a rule of thumb, the more frequent a keyword is cited, the greater its influence is, and keywords with a centrality value exceeding 0.1 have the most influence. In the co-occurrence analysis, nodes with a high frequency and centrality are considered key nodes since they possess a high influence across the entire network (Su et al., 2019). It is possible to gain valuable information about these nodes by examining these key nodes.

VOSviewer does not have any specific criteria for selecting nodes. Therefore, the study analyzes the data in terms of the cluster number as well as the number of elements in each cluster.

4.2 The timeline of the sustainability in architecture

4.2.1 Data collection and analysis methods

In this study, literature data were collected from the Web of Science (WoS). For this bibliometric analysis, it was planned to use both Scopus and Web of Science, but a close comparison of the results revealed that most of the publications matched. The number of publications from WoS was sufficient to overlay the evolution of sustainability in architecture. Moreover, the reliability and extensity of the databases in WoS were led to more scientific and credible publications since it contains the two of the most frequently-used; the Science Citation Index Expanded (SCIE) and the Social Science Citation Index (SSCI) (Liao et al., 2018). An article’s bibliometric data includes information about its author(s), title, abstract, keywords, references, year of publication, source type, issue number, volume number, and DOI, and others.

In the beginning, the citations displayed by Web of Science according to the search criteria as shown below were exported to store all the results as a single document. An online bibliography management tool called Zotero was used to store all citations. The data was then transferred to other programs using the necessary import formats (VOSviewer, CiteSpace, Gephi, etc.).

To identify the relevant studies that lie at the intersection between "sustainability" and "architecture" the following approach is used to query the online database WoS (Table 1-3).

Table 4-3: Number of records per database

Database	Search query	Number of records
Web of Science	TS= (sustainab*) AND TS=(architect* or building) Refined by: Document Types: Articles; Web of Science Categories: Architecture or Construction Building Technology or Urban Studies Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, ESCI. Date Received: 08 September 2021 Query Link: https://www.webofscience.com/wos/woscc/summary/3a1c597f-a123-414a-883e-c02112aca002-07680412/times-cited-descending/1	6602

Table 4-4: Number of records per database categorized based on document type

Article	Article/Book Chapter	Article/Proceedings Paper	Article/Book
6150	354	97	1

The following table illustrates the utilized methods with reference to their goals alongside the matched bibliometric analysis tools.

Table 4-5: The tools and methods leading to the timeline visualization

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
Text mining			
Word co-occurrence analysis (All years)	To analyze the co-occurrence of keywords and to identify relationships and interactions between the subjects and emerging research trends (All years)	VOSviewer	Gephi & VOSviewer
Word co-occurrence analysis (4 years interval)	To analyze the co-occurrence of keywords and to identify relationships and interactions between the subjects and emerging research trends (5 years interval)	CiteSpace	CiteSpace

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; to determine key references in the field	VOSviewer	VOSviewer
Co-citation burst analysis	To identify the burst interval of co-cited publication for detecting publications in a particular period.	CiteSpace	CiteSpace
The timeline	To visualize the timeline based on the results of the previous analysis	Analysis results from previous steps	Adobe Illustrator

As a result of the process, the required dataset and method were obtained. Finally, a timeline is ready to be generated for sustainability in architecture. As for the timeline, the study includes key policy documents as well as milestones derived from Chapter 3.

4.2.2 Results from the analytical analysis

The study inserted the number of publications with their source in the tableau program to determine the number of publications across years.

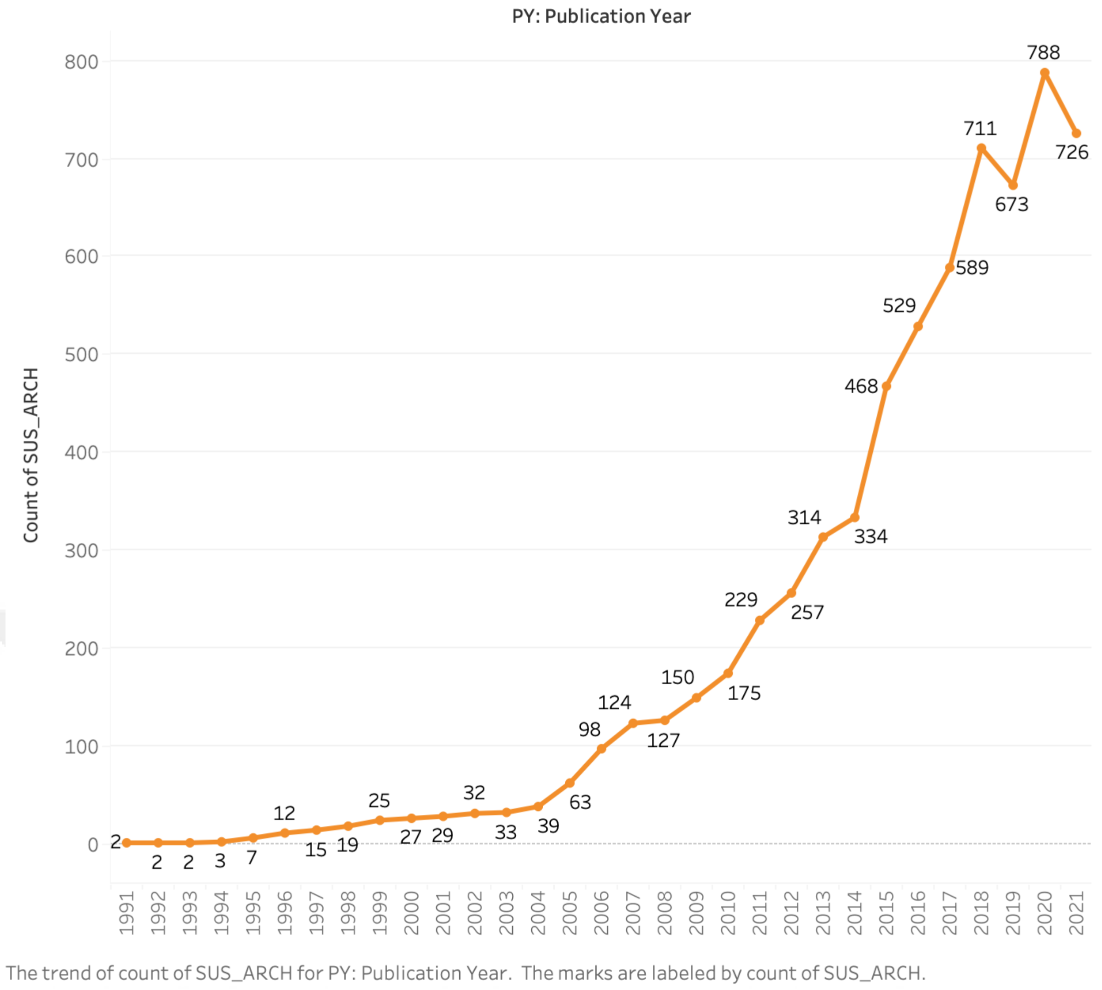


Figure 4-1: Number of publications across years

Number of publications increases exponentially after 2006 which indicates a constant growing interest towards architectural sustainability.

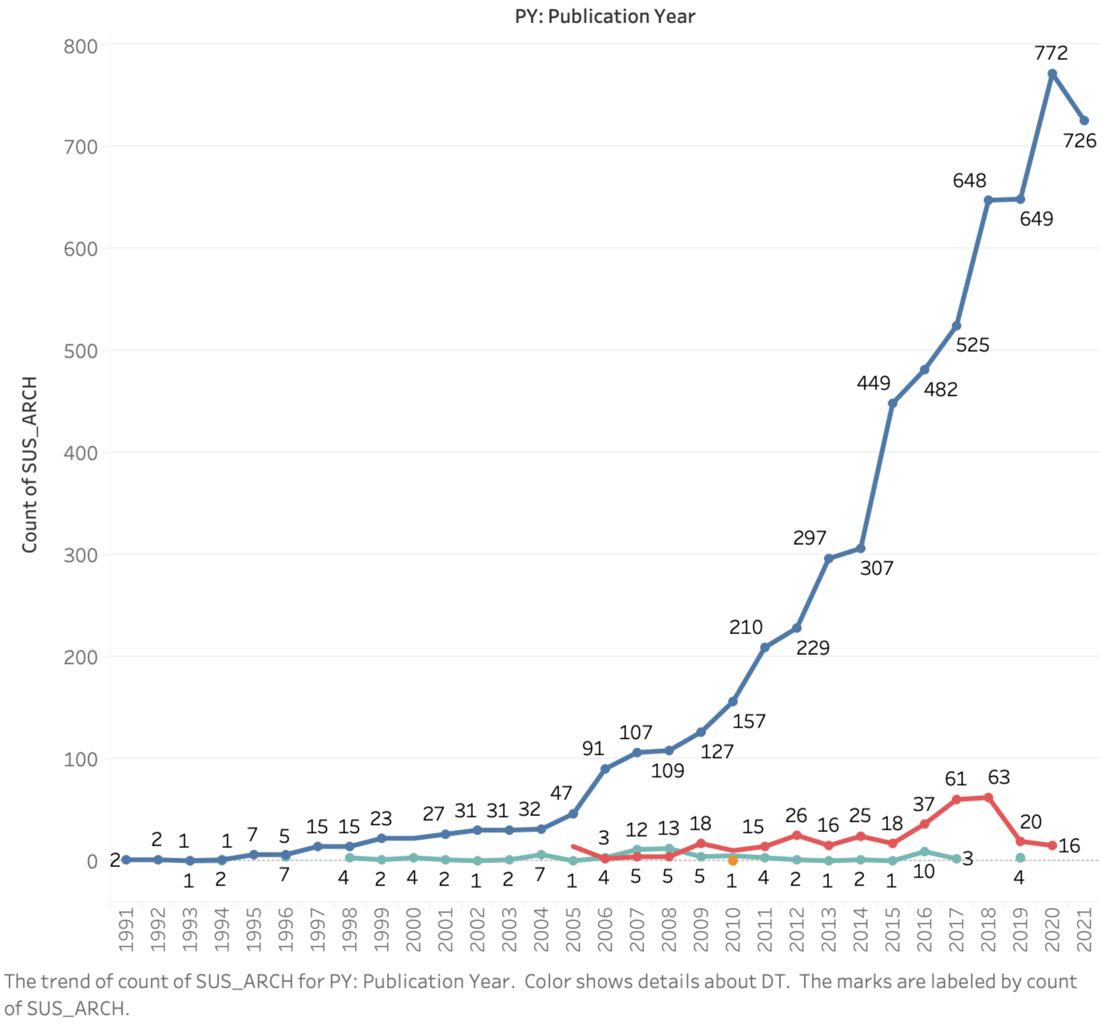


Figure 4-2: Number of publications according to their document types

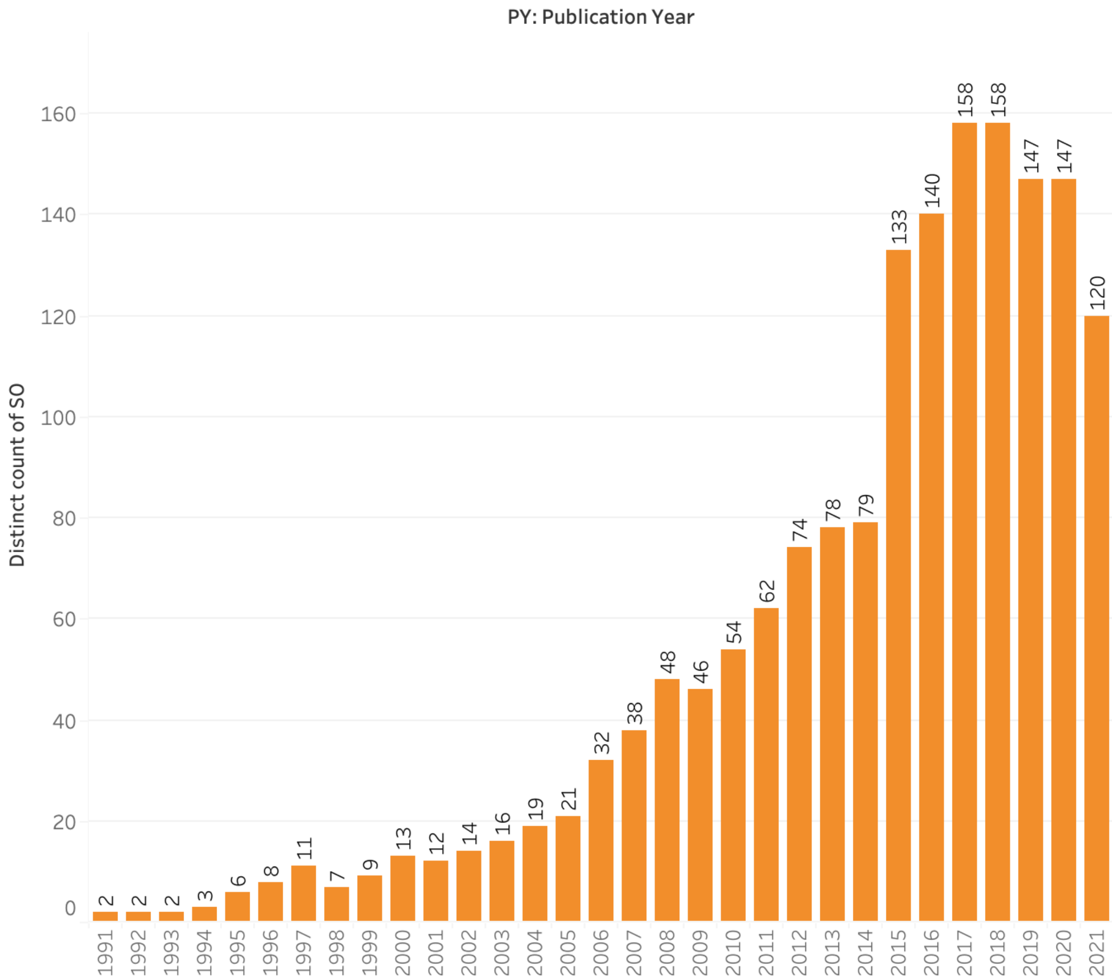


Figure 4-3: Number of research outlets (sources) across years

As the figure indicates, there is a leap between 2014 and 2015 in terms of the journal count that are available for scientific publication. Also, as 2021 unfolds, a significant decrease occurs approximately 20% which might be related to the global covid pandemic.

TI	DT	PY: Publicat..	
Urban green space, public health, and environmental justice: The challenge of making..	Article	2014	1.256
Adaptive thermal comfort and sustainable thermal standards for buildings	Article; Proceedings Paper	2002	858
Sustainability in the construction industry: A review of recent developments based o..	Article; Proceedings Paper	2009	642
The greening of the concrete industry	Article; Proceedings Paper	2009	624
Sustainable development and climate change initiatives	Article; Proceedings Paper	2008	538
A review of the present and future utilisation of FRP composites in the civil infrastru..	Article; Proceedings Paper	2010	531
From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world	Article	2011	421
Stainless steel in construction: A review of research, applications, challenges and op..	Article; Proceedings Paper	2008	392
Role of informal sector recycling in waste management in developing countries	Article	2006	378
User behavior in whole building simulation	Article	2009	352
Dynamic daylight performance metrics for sustainable building design	Article	2006	344
Multicriteria planning of post-earthquake sustainable reconstruction	Article	2002	333
Modeling the environmental impacts of urban land use and land cover change - a stud..	Article	2005	308
Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-..	Article	2018	303
The changing role of life cycle phases, subsystems and materials in the LCA of low en..	Article	2010	302
Assessing the environmental performance of land cover types for urban planning	Article	2000	283
Three challenges for the compact city as a sustainable urban form: Household consu..	Article	2005	279
Application of life-cycle assessment to early stage building design for reduced embo..	Article	2013	276
On the history of indoor air quality and health	Article	2004	275
Impacts of urbanization on urban structures and energy demand: What can we learn ..	Article	2011	273
Influence of mineral additions on the performance of 100% recycled aggregate concr..	Article	2009	270
Developing a green building assessment tool for developing countries - Case of Jordan	Article	2009	269
Multi-objective optimization for building retrofit strategies: A model and an applicati..	Article	2012	262
Life cycle of buildings, demolition and recycling potential: A case study in Turin, Italy	Article	2009	262
Building information modeling for sustainable design and LEED (R) rating analysis	Article	2011	251
The behavior of self-compacting concrete containing micro-encapsulated Phase Chan..	Article	2009	249
Spatial distribution of urban building energy consumption by end use	Article	2012	246
Construction waste: Quantification and source evaluation	Article; Proceedings Paper	1996	244
Debating the future of comfort: environmental sustainability, energy consumption a..	Article	2005	243
Barriers and drivers for sustainable building	Article	2011	241
Are users more tolerant of 'green' buildings?	Article; Proceedings Paper	2007	237
Built cultural heritage and sustainable urban development	Article	2007	236
Use of recycled concrete aggregate in fly-ash concrete	Article	2012	228
Comprehensive concept planning of urban greening based on ecological principles: a ..	Article	2005	228
Towards an integrated understanding of green space in the European built environm..	Article	2009	222
The effect of material choice on the total energy need and recycling potential of a bui..	Article	2006	220
Technology adoption in the BIM implementation for lean architectural practice	Article	2011	217
Acoustic characterization of natural fibers for sound absorption applications	Article	2015	217
Building environmental assessment methods: redefining intentions and roles	Article	2005	215

Figure 4-4: Publications sorted based on the number of citations received in WoS

This study will utilize clusters in terms of categorizing the related publication. However, as can be deduced from the figure, few of the most cited publications are studies that their main focus are sustainability on an urban scale.

4.2.3 Text mining analysis in VOSviewer

The analysis assessed the distribution of the most frequent keywords, examining their cooccurrence (keywords occurring together within the same paper). Using only the author keywords that appear below the abstract, the study attempts to highlight the most relevant research topics in the field of SUS-ARCH. The analysis determined **16476** keywords The minimum number of occurrences is set at 15, VOSviewer allows users to specify a minimum threshold number for keywords to be include on the map. **194** keywords met the threshold. **13120** keywords appeared only once (79,63 %).

Table 4-6: Top 10 keywords between 1991-2021 (sorted based on total link strength)

Rank	Label	Frequency/ occurrences	Total Link Strength
1	sustainability	962	1324
2	energy efficiency	235	342
3	sustainable development	245	321
4	buildings	104	239
5	life cycle assessment	142	233
6	built environment	126	223
7	climate change	110	206
8	energy	78	176
9	green building	98	165
10	housing	85	147

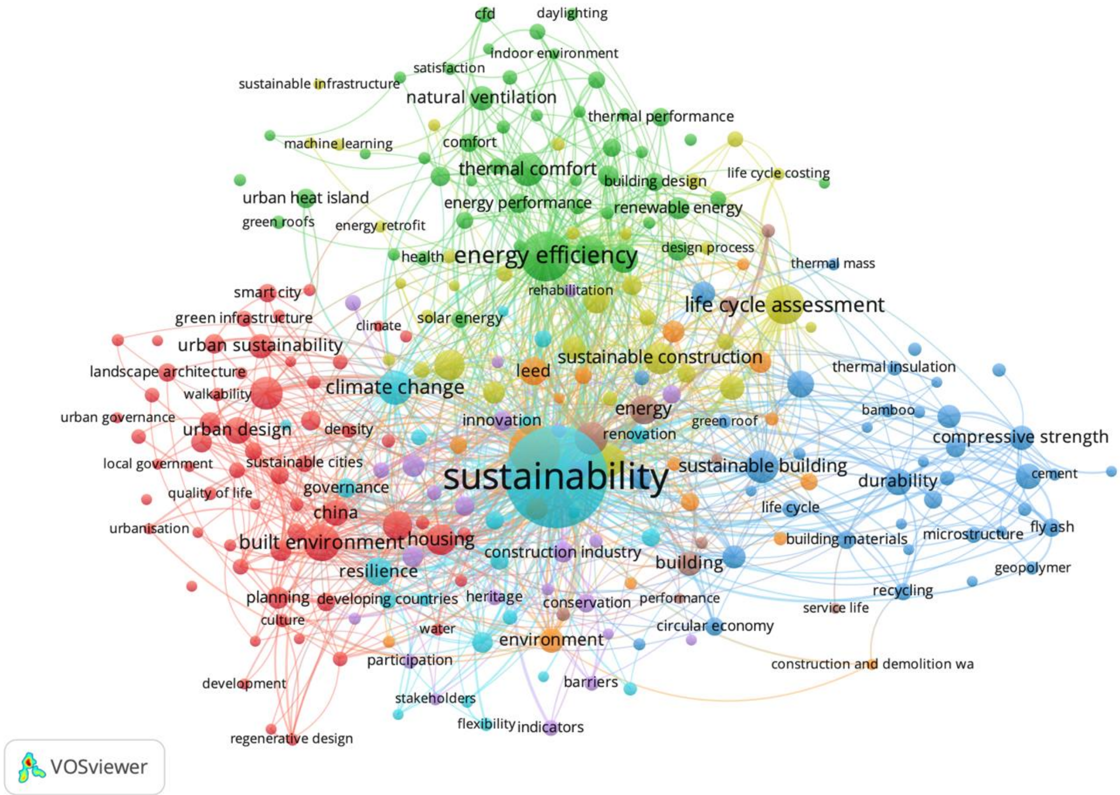


Figure 4-5: Keyword co-occurrence visualization.

The size of nodes indicates the frequency of occurrence. The curves between the nodes represents their co-occurrence in the same publication. The shorter the distance between two nodes, the larger the number of co-occurrences of the two keywords. The minimum number of occurrences of a keyword was set as 12. Of the 16479 keywords that were involved in SA research, 257 keywords met the threshold. Clustering resolution 1.2 yields 8 clusters.

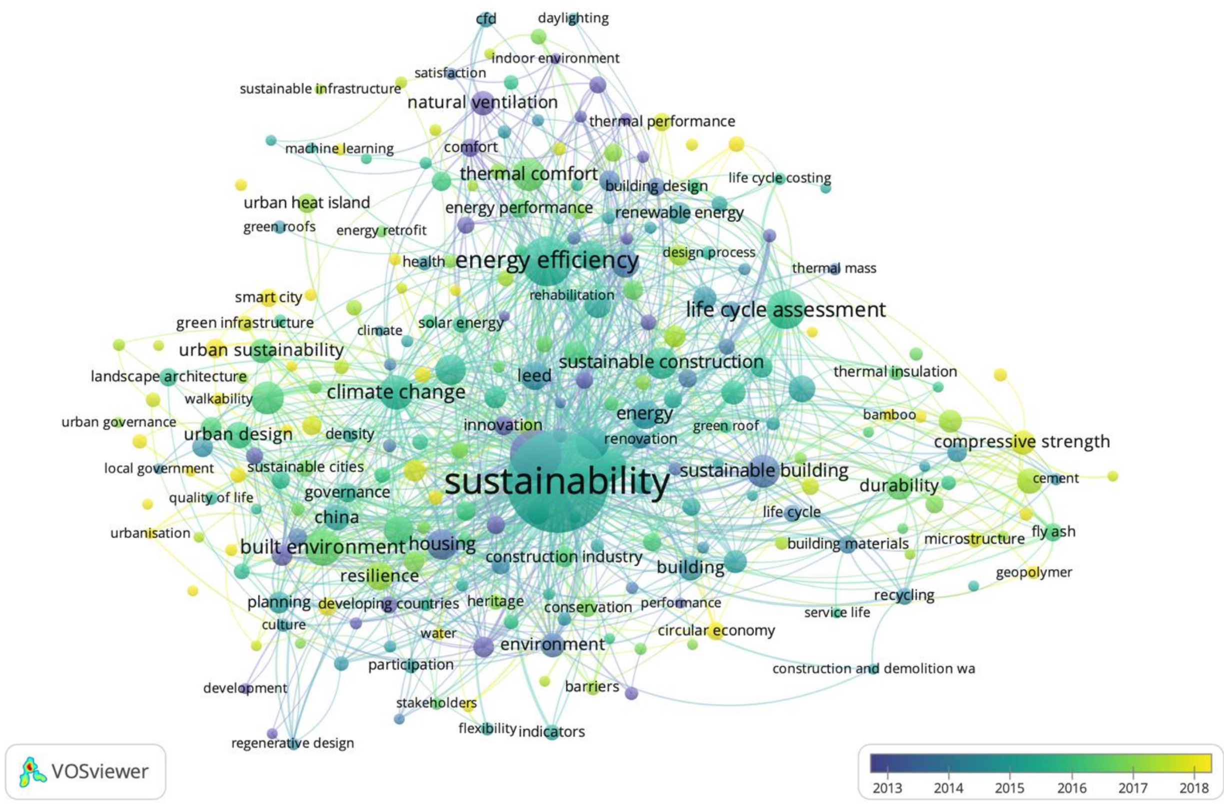


Figure 4-6: Overlay visualization of keyword co-occurrence visualization of SA

Table 4-7: Co-occurrence analysis of keywords. Top 10 keywords in the 8 clusters (The numbers in the brackets indicate the frequency of keywords based on the co-occurrence analysis)

Cluster ID	Cluster 1 (red)	Cluster 2 (green)	Cluster 3 (blue)	Cluster 4 (yellow)	Cluster 5 (purple)	Cluster 6 (cyan)	Cluster 7 (orange)	Cluster 8 (brown)
Size	60	48	40	33	25	23	18	10
Average year	2016,2	2005,4	2016,1	2016	2015,7	2014,57	2014,72	2014,35
Cluster Label	Urban planning and sustainability	Building energy performance	Sustainable building materials	LCA and BIM	Urban regeneration / heritage-Stakeholders	Resilience/ adaptation /climate change	Building environmental assessment	Building performance and maintenance
1	built environment (126)	energy efficiency (235)	sustainable building (103)	life cycle assessment (142)	social sustainability (44)	sustainability	sustainable development (245)	Buildings (261)
2	urban planning (98)	thermal comfort (100)	embodied energy (70)	green building (98)	urban regeneration (43)	climate change	Leed (71)	Energy (78)

3	Housing (83)	energy consumption (80)	Durability (65)	sustainable construction (92)	construction industry (39)	resilience	Environment (57)	Building (55)
4	Architecture (78)	green buildings (75)	mechanical properties (59)	sustainable design (90)	Innovation (38)	public policy	Bim (47)	Efficiency (24)
5	urban design (70)	natural ventilation (54)	compressive strength (54)	sustainable buildings (65)	adaptive reuse (37)	social housing	Lca (47)	Assessment (19)
6	China (60)	renewable energy (47)	thermal conductivity (53)	environmental impact (56)	Conservation (33)	governance	Design (46)	Exergy (18)
7	urban sustainability (56)	building performance (41)	Construction (50)	residential buildings (52)	vernacular architecture (33)	adaptation	Prefabrication (30)	Maintenance (15)
8	Planning (47)	Optimization (40)	sustainable architecture (49)	environmental sustainability (48)	Simulation (30)	renovation	architectural design (28)	Residential (13)
9	Cities (43)	urban heat island (38)	Sustainable (49)	life cycle assessment (lca) (38)	Heritage (26)	building stock	building information modeling (27)	service life (12)
10	Gis (40)	energy saving (37)	Concrete (38)	life cycle analysis (33)	Indicators (25)	refurbishment	environmental assessment (27)	Performance (12)
Keywords appeared in recent publications (the years in brackets indicate the average year of the keyword)								
1	socially and culturally sustainable architecture and urban design (30) (2020,51)	covid-19 (14) (2020,53)	circular economy (34) (2019,9)	machine learning (15) (2020)	affordable housing (20) (2018,23)	Regeneration (12) (2018)	building information modeling (27)	
2	sustainable development goals (13) (2019,7)	outdoor thermal comfort (15) (2018,46)	sustainable building materials (15) (2018,86)	building information modelling (25) (2019,37)	social sustainability (44) (2017,7)	Adaptability (14) (2107,85)	Carbon emission (17) (2017,29)	
3	smart cities (37) (2019,29)	Building sustainability (14) (2017,85)	Bamboo (18) (2018,22)	rating systems (13) (2018,41)	cultural heritage (24) (2017,13)	analytic hierarchy process (12) (2017,33)	Bim (47) (2017,20)	
4	internet of things (15) (2018,86)	thermal performance (31) (2017,61)	thermal properties (17) (2018,17)	building information modeling (bim) (23) (2018,04)	Barriers (21) (2017,1)	Resilience (75) (2017,07)		

5	smart city (32) (2018,46)	building energy simulation (16) (2017,37)	geopolymer (19) (2018,15)	economic sustainability (12) (2017,83)	Heritage (26) (2016,88)	social housing (38) (2017,08)		

The study extracted keywords from recent publications (based on the average publication year) to determine the forefront of the research field. These keywords will be correlated with the analysis of the four-year interval studies in the following section.

4.2.4 Text mining analysis in CiteSpace

The study uses CiteSpace for three types of analysis: (1) the timeline view of the co-occurred keywords, (2) the citation burst analysis of these keywords, (3) the analysis of these keywords in four years range.

4.2.4.1 Citation burst analysis of keywords

The citation burst analysis enables the study to determine the keywords that were highly cited in a certain period. To analyze word co-occurrence in CiteSpace, the study set the number of years per slice to 1 and then selects the top 100 levels in a slice (Table 4-8). Co-citated keywords are determined based on the g-index (k=10) of keywords in 1 year slice. CiteSpace uses Kleinberg's burst detection algorithm to analyze the subject categories with the strongest citation bursts and identify new front concepts emerging in a research field. The figure below sorts the 46 Keywords with the Strongest Citation Bursts chronologically. The study then maps these keywords in the timeline of sustainable architecture.

Table 4-8: Details of the selection criteria and results (1991-2021)

Timespan	1991-2021 (Slice Length=1)
Selection Criteria	G index K=10 ; LRF = -1; LB Y= -1
Network	N=365, E=1053 (Density=0.00159)

Keywords	Year	Strength	Begin	End
building stock	1991	13.55	**1999**	2009
public policy	1991	8.61	**1999**	2009
green building challenge	1991	4.11	**1999**	1999
building performance	1991	3.71	**2001**	2010
sustainable development	1991	9.67	**2004**	2011
sustainable building	1991	10.52	**2005**	2012
natural ventilation	1991	5.06	**2005**	2013
green building	1991	5	**2008**	2009
sustainable architecture	1991	5.42	**2009**	2012
embodied energy	1991	4.32	**2010**	2016
co2 emission	1991	3.94	**2010**	2014
sustainable design	1991	5.04	**2012**	2012
regenerative design	1991	4.56	**2012**	2012
ecosystem service	1991	3.48	**2012**	2014
life cycle analysis	1991	3.68	**2013**	2015
thermal conductivity	1991	4.35	**2014**	2016
life cycle assessment	1991	3.99	**2014**	2014
urban sustainability	1991	8.78	**2015**	2017
energy performance	1991	4.3	**2015**	2018
urban resilience	1991	3.62	**2015**	2017
architectural design	1991	4.57	**2016**	2016
energy retrofit	1991	4.26	**2016**	2019
sensitivity analysis	1991	3.53	**2016**	2017
social sustainability	1991	4.86	**2017**	2019
urban form	1991	4.83	**2017**	2021
urban development	1991	4.43	**2017**	2019
smart city	1991	8.51	**2018**	2021
sustainable city	1991	5.14	**2018**	2021
internet of thing	1991	4.57	**2018**	2021
urban morphology	1991	4.48	**2018**	2019
green infrastructure	1991	4.39	**2018**	2021
social housing	1991	4.07	**2018**	2021
economic sustainability	1991	3.48	**2018**	2019
environmental performance	1991	3.48	**2018**	2019
life cycle costing	1991	3.48	**2018**	2019
building information modelling	1991	5.49	**2019**	2021
life cycle assessment (lca)	1991	5.1	**2019**	2021
affordable housing	1991	4.76	**2019**	2021
cultural heritage	1991	3.92	**2019**	2021
building envelope	1991	3.8	**2019**	2019
circular economy	1991	8.68	**2020**	2021
compressive strength	1991	5.9	**2020**	2021

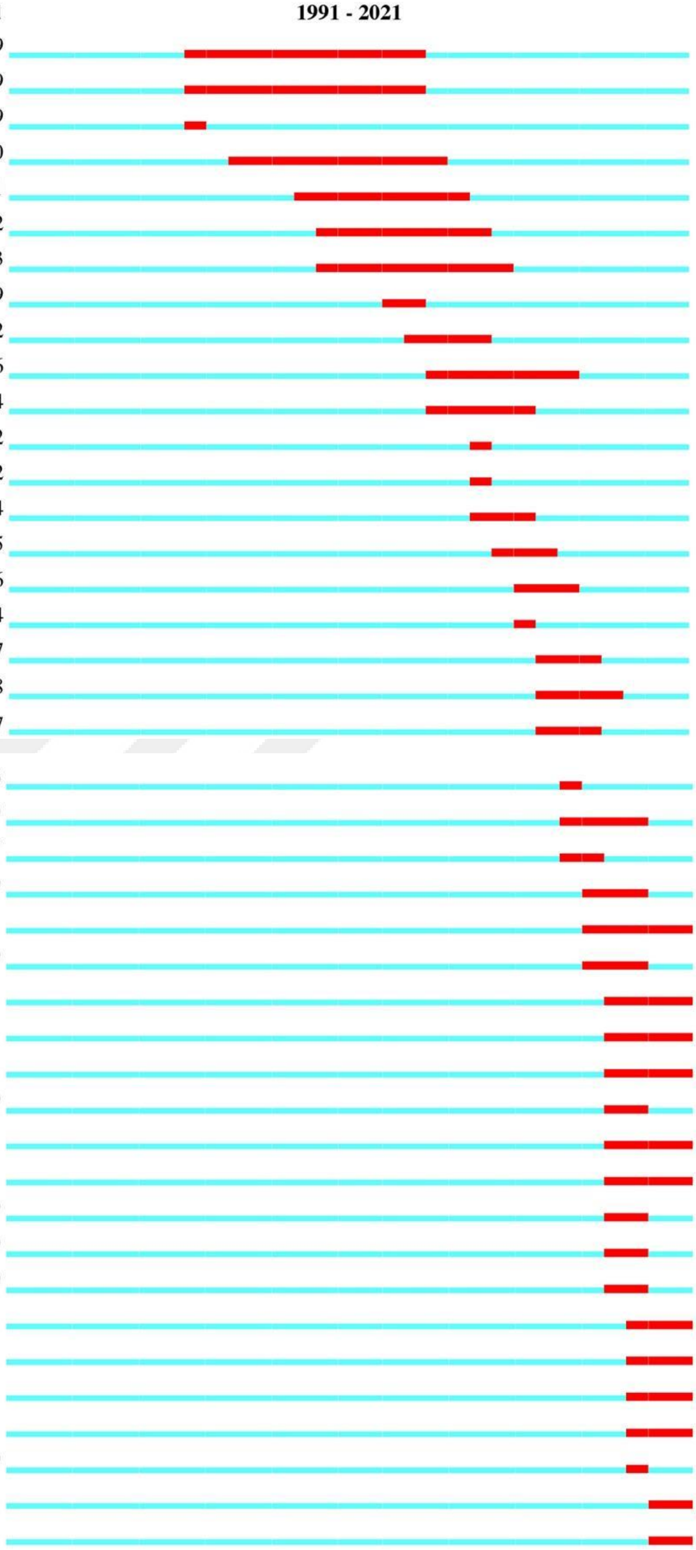


Figure 4-7: Keyword citation burst across years taken from Citespace

These keywords will be grouped and shown in the timeline with their affiliated clusters' colors.

4.2.4.2 The timeline of the keyword co-occurrence

To analyze word co-occurrence in CiteSpace, the study set the number of years per slice to 4 and then selects top 50 levels in a slice (Table 4-9). For the timeline analysis the study excludes the keywords appearing in the publications between 1991-1997 because in total there were only 37 keywords. The keyword analysis divided the total length into 4 years for easing the analysis process.

Table 4-9: Details of the selection criteria and results (1998-2021)

Timespan	1998-2021 (Slice Length=1)
Selection Criteria	Top 50 per slice; LRF = -1; LB Y= -1
Network	N=382, E=2193 (Density=0.0301)
Modularity	0.495
Weighted Mean Silhouette (S)	0.7829

Table 4-10: Number of keywords per year (1991-2021)

Year	Number of keywords	Year	Number of keywords
1991	0	2007	352
1992	0	2008	382
1993	0	2009	465
1994	0	2010	664
1995	8	2011	837
1996	9	2012	947
1997	20	2013	1198
1998	65	2014	1249
1999	70	2015	1702
2000	100	2016	1994
2001	92	2017	2337
2002	119	2018	2713
2003	102	2019	2534
2004	144	2020	3001
2005	205	2021	2791
2006	305		

Analysis based on the top 50 levels of most occurred items from each slice (4 years) in CiteSpace. Following table illustrates the number of retrieved keywords (nodes) from each 4 years slice.

Table 4-11: The number of retrieved keywords (sus-arch)

Years	Space (total number of keywords)	Keywords (nodes)
1998-2001	272	272
2002-2005	488	100
2006-2009	1286	51
2010-2013	3065	54
2014-2017	6071	56
2018-2021	9347	56

The study represents the timeline view of these keywords.

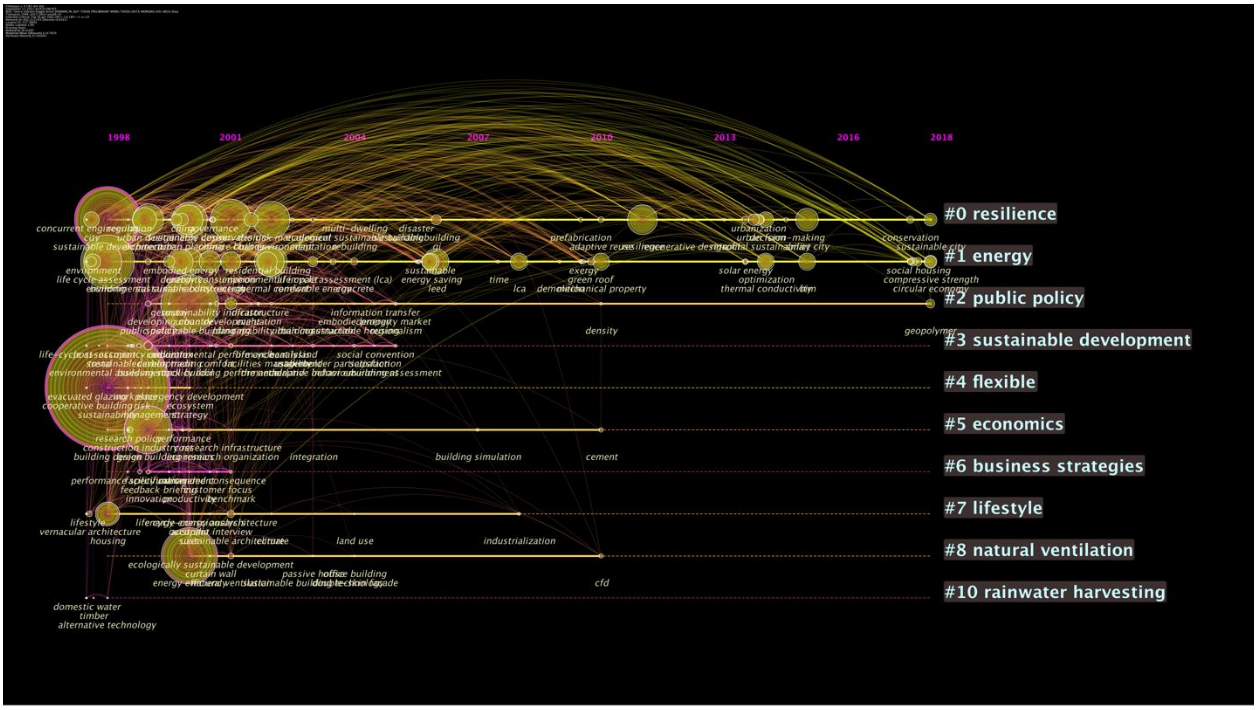


Figure 4-8: Keyword co-occurrence analysis overlaid as a timeline in CiteSpace

1.1.1.1. Word co-occurrence analysis (1998-2001)

For each slice (4 years) the study pursues diverse selection criteria, because the number of keywords increases exponentially till 2021.

Table 4-12: Details of the selection criteria and results (1998-2001)

Timespan	1998-2001 (Slice Length=4)
Selection Criteria	g-index (k=5); LRF = -1; LB Y= -1
Network	N=28, E=74 (Density=0.1958)
Modularity	0.4357
Weighted Mean Silhouette (S)	0.7967

Table 4-13: Top 10 keywords between 1998-2001 (Left ranking based on frequency; right ranking based on degree centrality)

Rank	Label	year	frequency	Degree centrality	Rank	Label	Betweenness centrality	frequency	Degree centrality
1	sustainability	1998	27	15	1	green building	127.092177	27	23
2	green building	1999	10	23	2	sustainable development	70.197318	9	19
3	sustainable development	1998	9	19	3	innovation	100.472393	6	18
4	innovation	1999	6	18	4	regulation	44.314586	5	17
5	public policy	1999	6	16	5	public policy	53.085278	6	16
6	green building challenge	1999	6	13	6	sustainability	102.304767	27	15
7	environment	1998	6	12	7	trend	34.978055	5	15
8	feedback	1999	6	12	8	Energy efficiency	32.866901	4	15
9	regulation	1999	5	17	9	green building challenge	41.561894	6	13
10	trend	1999	5	15	10	economics	21.692115	4	13

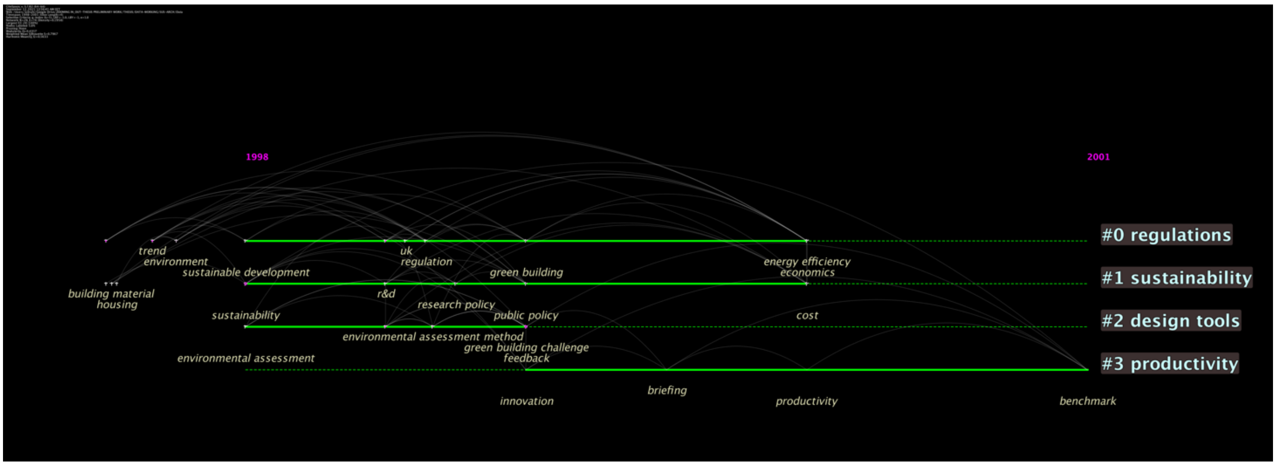


Figure 4-8: Timeline view of the years 1998-2001

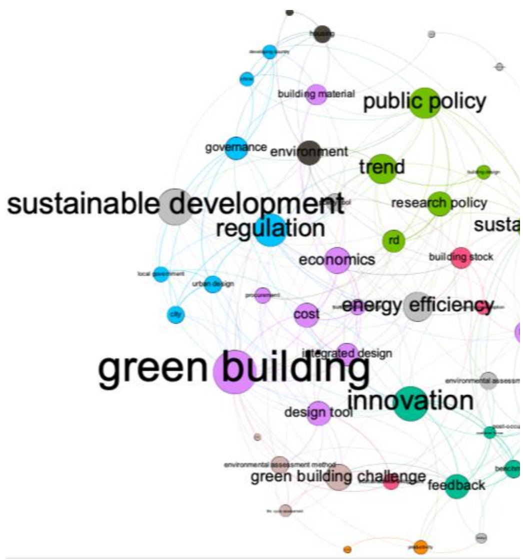


Figure 4-9: For the years between 1998-2001, Keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their frequency)

Figure 4-10: For the years between, keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their centrality)

4.2.4.3 Word co-occurrence analysis (2002-2005)

Table 4-14: Details of the selection criteria and results (2002-2005)

Timespan	2002-2005 (Slice Length=1)
Selection Criteria	g-index (k=15); LRF = -1; LB Y= -1
Network	N=108, E=299 (Density=0.0517)
Modularity	0.6243
Weighted Mean Silhouette (S)	0.7291

Table 4-15: Top 10 keywords between 2005-2009 (Left ranking based on frequency; right ranking based on degree centrality)

Rank	Label	year	frequency	Degree centrality	Rank	Label	Betweenness centrality	frequency	Degree centrality
1	sustainability	2002	23	27	1	sustainability	1330.133699	23	27
2	building	2003	11	18	2	Building	780.816067	11	18
3	sustainable development	2004	9	13	3	Construction	714.138153	6	18
4	public policy	2002	8	16	4	public policy	509.066817	8	16
5	city	2002	7	8	5	building stock	473.382091	7	14
6	building stock	2002	7	14	6	comfort	212.987076	5	14

7	design	2003	6	9	7	trend	34.978055	5	15
8	sustainable building	2005	6	10	8	adaptive behaviour	212.98707 6	4	14
9	construction	2003	6	18	9	building performan ce	531.48860 6	4	13
10	capability building	2005	5	10	10	sustainable developme nt	509.67199 8	9	13

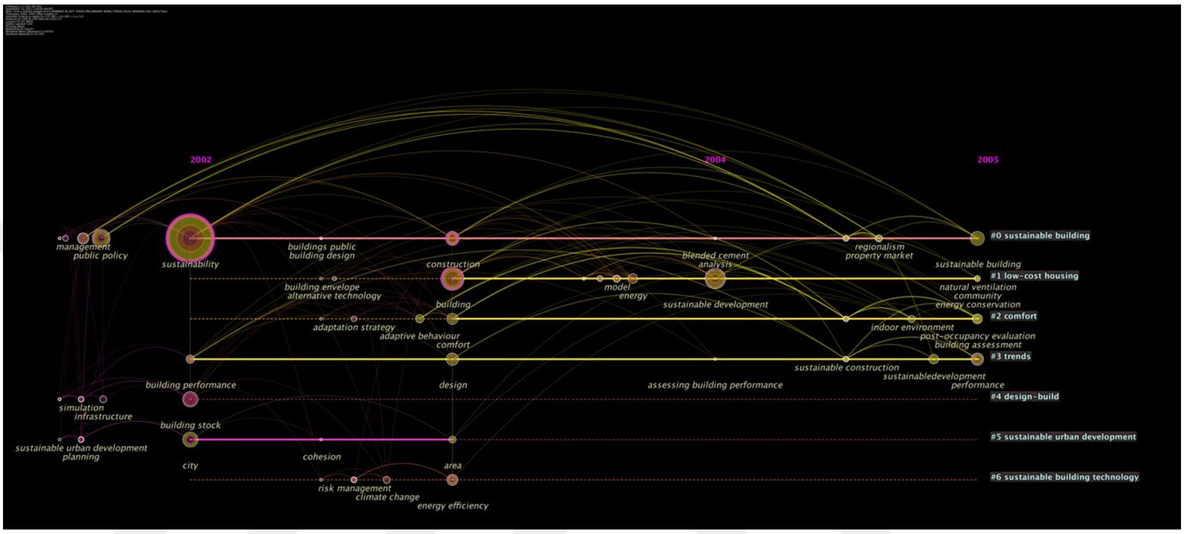


Figure 4-11: Timeline view of the years 2002-2005

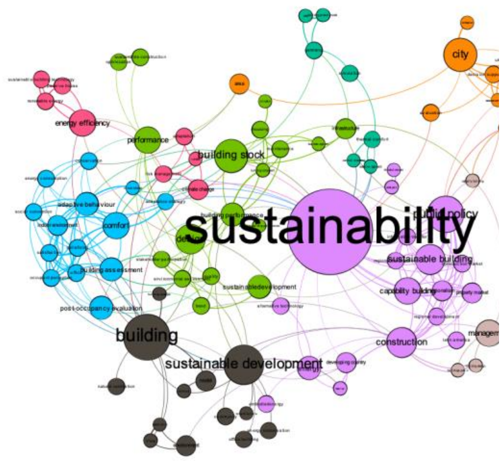


Figure 4-12: For the years between 2002-2005, Keyword co-occurrence visualization (keyword and nodes

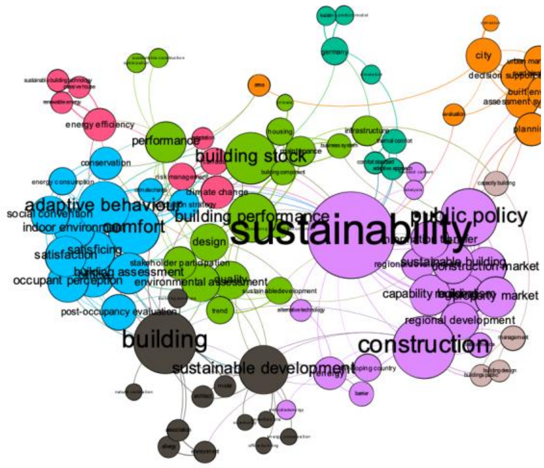


Figure 4-13: For the years between 2002-2005, keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their centrality)

dimensions are ranked based on their frequency)

4.2.4.4 Word co-occurrence analysis (2006-2009)

Table 4-16: Details of the selection criteria and results (2006-2009)

Timespan	2006-2009 (Slice Length=1)
Selection Criteria	g-index (k=10); LRF = -1; LBY= -1
Network	N=98, E=347 (Density=0.073)
Modularity	0.4176
Weighted Mean Silhouette (S)	0.7594

Table 4-17: Top 10 keywords between 2006-2009 (Left ranking based on frequency; right ranking based on degree centrality)

Rank	Label	year	frequency	Degree centrality	Rank	Label	Betweenness centrality	frequency	Degree centrality
1	sustainability	2006	75	27	1	sustainability	165.685507	75	27
2	sustainable development	2006	28	23	2	performance	143.046806	20	26
3	energy	2007	25	21	3	sustainable development	94.469275	28	23
4	building	2006	21	21	4	construction	101.984068	17	23
5	performance	2007	20	26	5	building stock	473.382091	14	23
6	green building	2006	19	16	6	Energy	70.663467	25	21
7	construction	2006	17	23	7	building	183.515063	21	21
8	sustainable building	2006	15	14	8	Management	101.883232	11	20
9	city	2006	14	15	9	green building	22.326852	19	16
10	building stock	2006	14	23	10	Design	43.913602	13	16

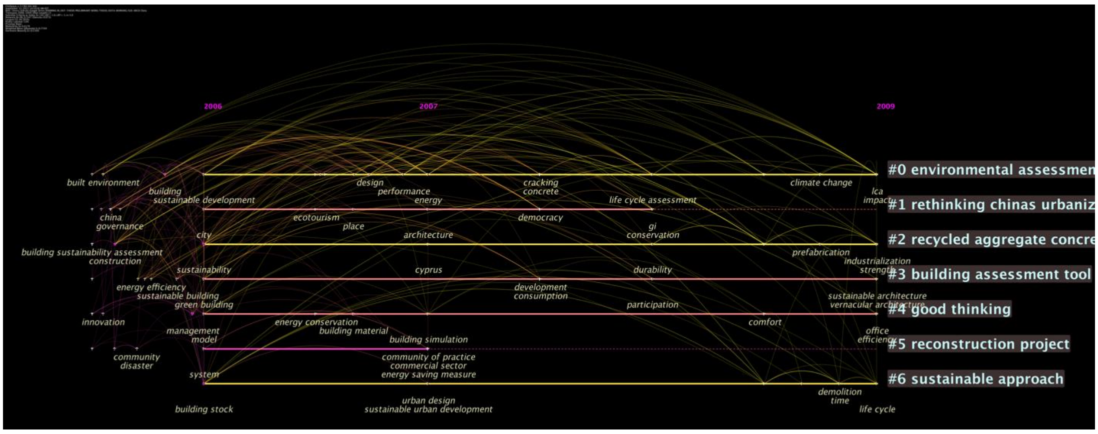
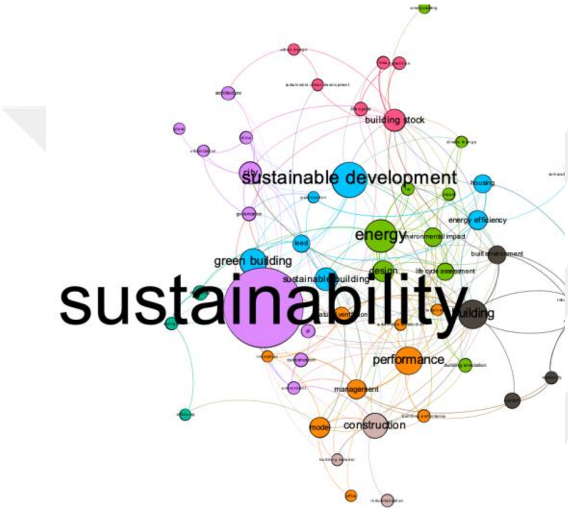


Figure 4-14: Timeline view of the years 2006-2009



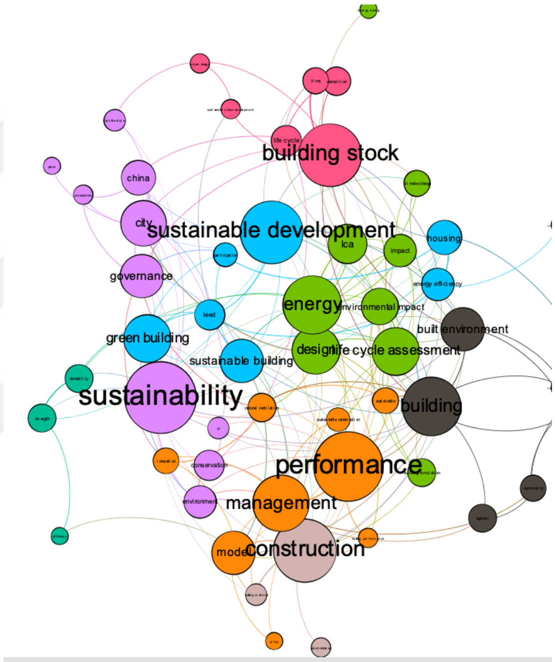


Figure 4-15: For the years between 2006-2009, Keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their frequency)

Figure 4-16: For the years between 2006-2009, keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their centrality)

4.2.4.5 Word co-occurrence analysis (2010-2013)

Table 4-18: Details of the selection criteria and results (2010-2013)

Timespan	2010-2013 (Slice Length=1)
Selection Criteria	g-index (k=10); LRF = 2; LBY= 8
Network	N=137, E=509 (Density=0.0546)
Modularity	0.43

Weighted Mean Silhouette (S)	0.7663

Table 4-19: Top 10 keywords between 2010-2013 (Left ranking based on frequency; right ranking based on degree centrality)

Rank	Label	year	frequency	Degree centrality	Rank	Label	Betweenness centrality	frequency	Degree centrality
1	sustainability	2010	197	12	1	Performance	1383.172736	197	30
2	building	2010	80	25	2	Construction	650.160018	36	29
3	energy	2010	63	20	3	Building	804.853149	80	25
4	performance	2010	58	30	4	Impact	559.422004	34	21
5	Sustainable development	2010	52	6	5	Energy	387.64195	63	20
6	City	2010	50	16	6	Model	463.879083	41	18
7	Energy efficiency	2010	46	6	7	built environment	567.950857	27	18
8	Model	2010	41	18	8	co2 emission	432.372385	11	17
9	Design	2010	40	13	9	Methodology	245.832008	8	17
10	Sustainable building	2010	39	2	10	City	377.464025	50	16

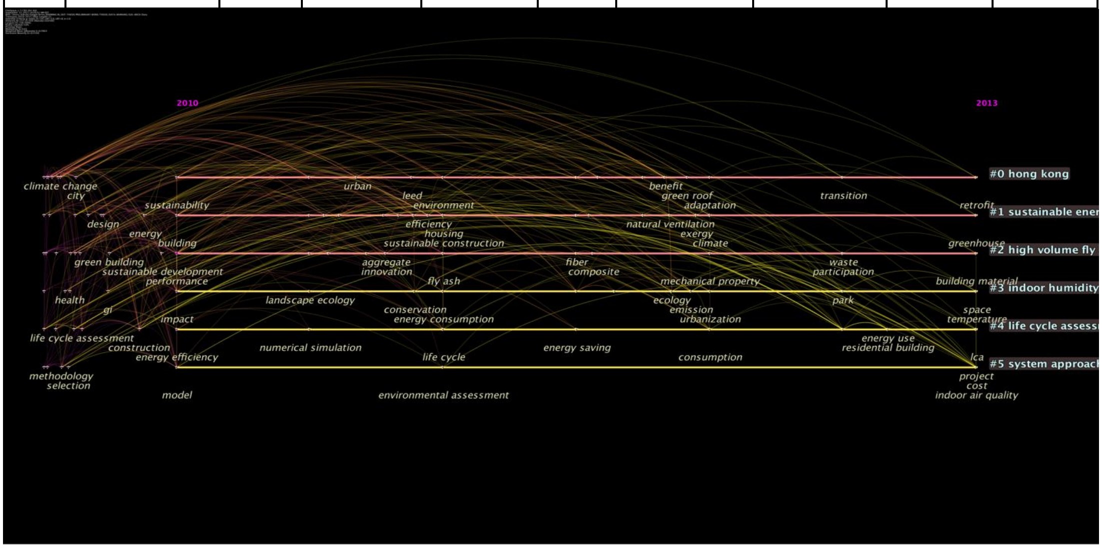


Figure 4-17: Timeline view of the years 2010-2013

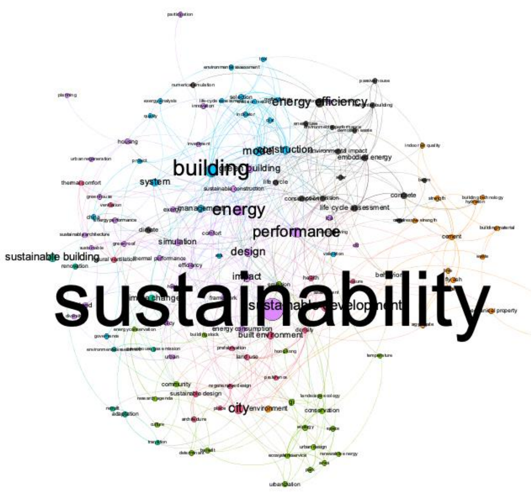


Figure 4-18: For the years between 2010-2013, Keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their frequency)

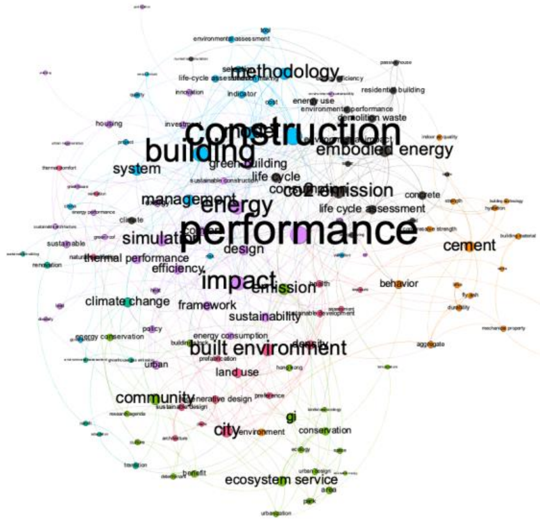


Figure 4-19: For the years between 2010-2013, keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their centrality)

4.2.4.6 Word co-occurrence analysis (2014-2017)

Table 4-20: Details of the selection criteria and results (2014-2017)

Timespan	2014-2017 (Slice Length=1)
Selection Criteria	g-index (k=20); LRF = 2; LBY= 8
Network	N=314, E=1286 (Density=0.0262)
Modularity	0.5002
Weighted Mean Silhouette (S)	0.7678

Table 4-21: Top 10 keywords between 2014-2017 (Left ranking based on frequency; right ranking based on degree centrality)

Rank	Label	year	frequency	Degree centrality	Rank	Label	Betweenness centrality	frequency	Degree centrality
1	sustainability	2014	378	2	1	Biodiversity	2231.319179	13	27
2	performance	2014	184	16	2	Barrier	1380.176087	21	26
3	Building	2014	181	11	3	Climate	946.613721	36	22
4	Design	2014	143	9	4	Embodied energy	996.364394	43	21

5	City	2014	119	14	5	Temperature	872.969543	16	21
6	Energy	2014	119	10	6	Demand	1083.563603	16	21
7	System	2014	114	4	7	Project	849.333245	14	21
8	Impact	2014	109	17	8	life cycle assessment	686.511452	73	20
9	Construction	2014	104	18	9	Conservation	868.199187	23	20
10	Energy efficiency	2014	81	9	10	heat island	902.361753	21	20

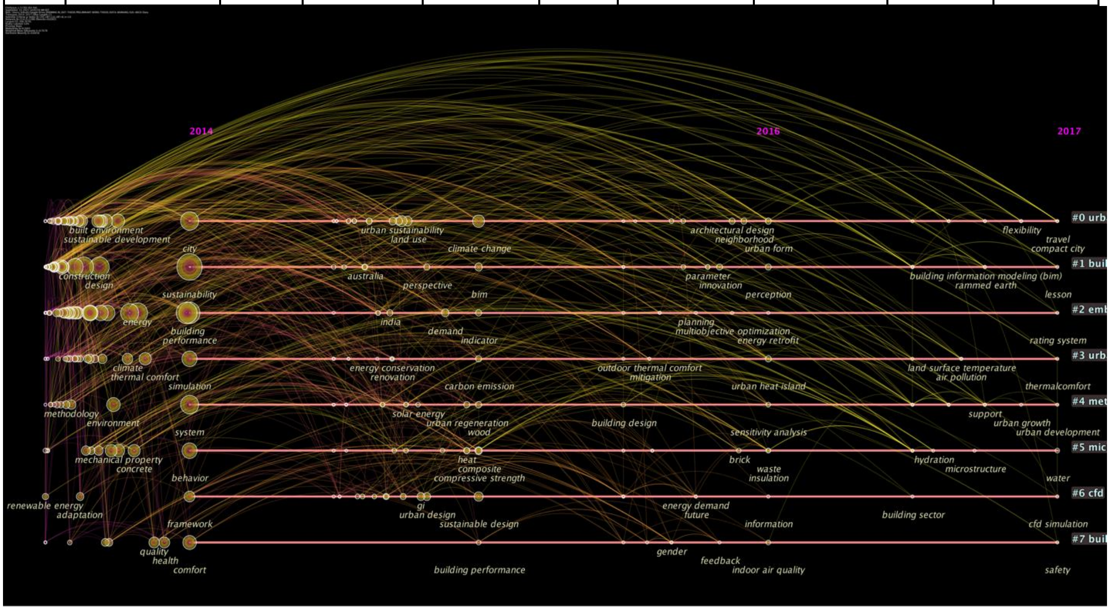
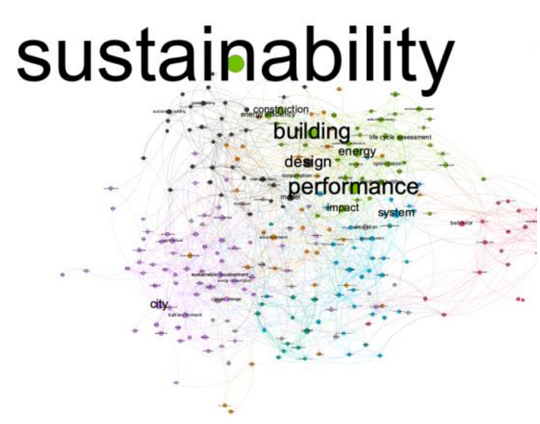


Figure 4-20: Timeline view of the years 2014-2017



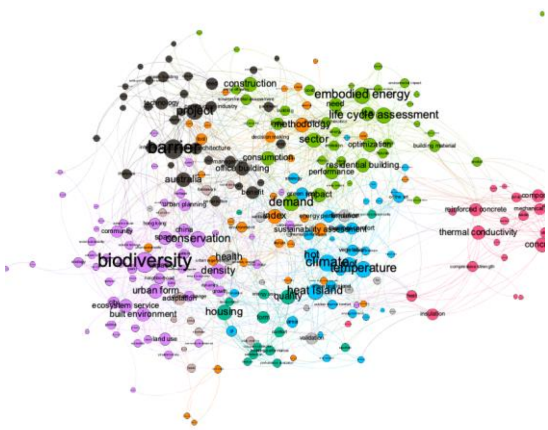


Figure 4-21: For the years between 2014-2017, Keyword co-occurrence visualization (keyword and nodes

Figure 4-22: For the years between 2014-2017, keyword co-occurrence visualization (keyword and nodes

dimensions are ranked based on their frequency)	dimensions are ranked based on their centrality)

4.2.4.7 Word co-occurrence analysis (2018-2021)

Table 4-22: Details of the selection criteria and results (2018-2021)

Timespan	2018-2021 (Slice Length=1)
Selection Criteria	g-index (k=15); LRF = 2; LBY= 8
Network	N=316, E=1362 (Density=0.0274)
Modularity	0.5274
Weighted Mean Silhouette (S)	0.7607

Table 4-23: Top 10 keywords between 2018-2021 (Left ranking based on frequency; right ranking based on degree centrality)

Rank	Label	year	frequency	Degree centrality	Rank	Label	Betweenness centrality	frequency	Degree centrality
1	sustainability	2018	554	10	1	residential building	1468.998172	95	28
2	performance	2018	327	24	2	Concrete	1781.222445	99	27
3	Design	2018	268	18	3	City	2179.559877	235	26
4	City	2018	235	26	4	Performance	2088.471293	327	24
5	Impact	2018	220	15	5	mechanical property	978.574693	96	24
6	Building	2018	216	13	6	Lca (life-cycle-assessment)	885.109614	63	24
7	Energy	2018	181	21	7	life cycle assessment	507.109422	137	22
8	System	2018	179	14	8	Energy	955.71824	181	21
9	Construction	2018	167	21	9	construction	1643.972549	167	21
10	Model	2018	166	14	10	Durability	428.453536	71	20

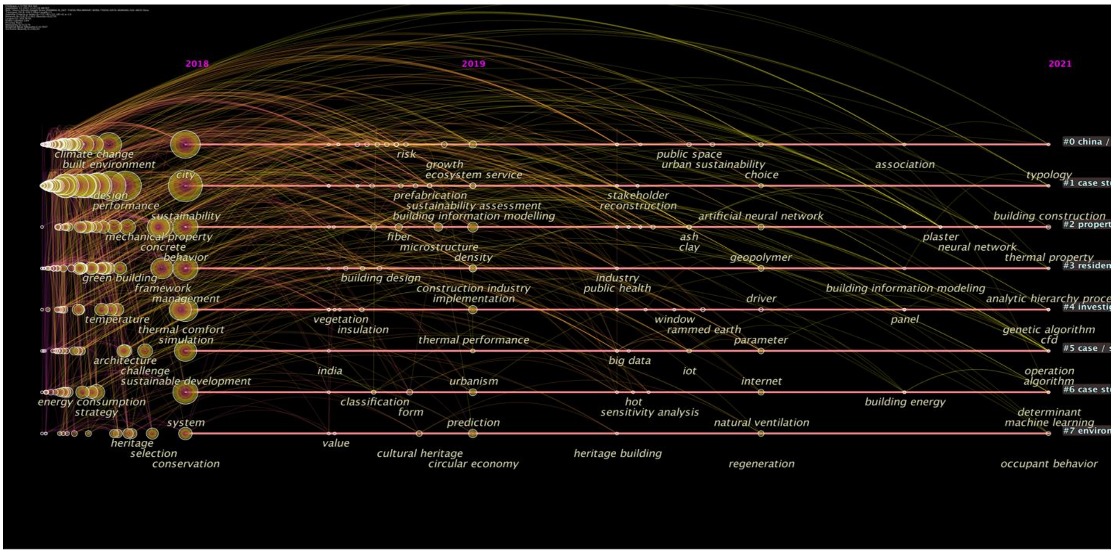
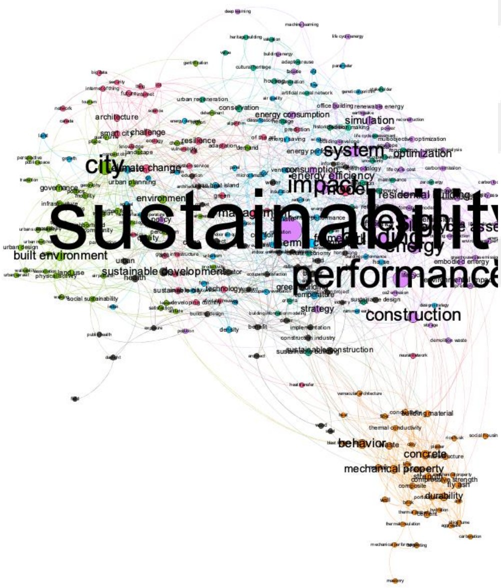


Figure 4-23: Timeline view of the years 2018-2021



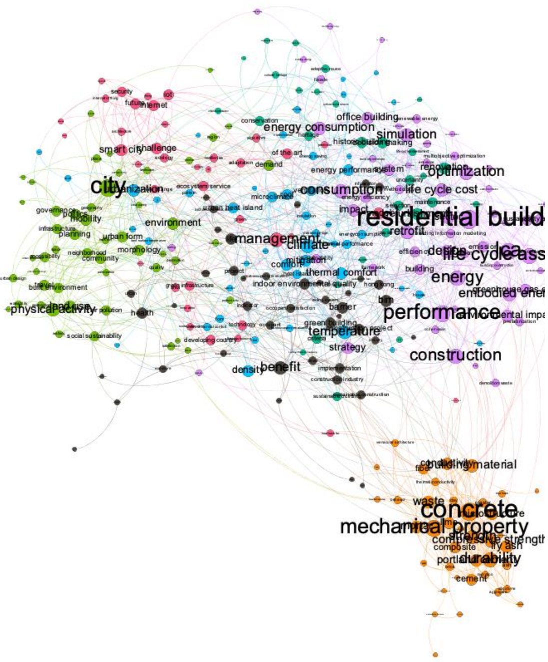


Figure 4-24: For the years between 2018-2021, Keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their frequency)

Figure 4-25: For the years between 2018-2021, keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their centrality)

4.2.5 Bibliometric Analysis

4.2.5.1 Co-citation analysis in VOSviewer

Analyzing co-citations in cited references is an efficient way to determine a study's intellectual basis. The study uses VOSviewer for creating the co-citation network. The minimum number of citations for a cited reference is 15. Out of 202937 references, 418 meet this threshold. Every node in Figure 4-27 represents a document, with the first author, publication year, and abbreviation of the source. Node sizes reflect the number of co-citations for each document. The links between the nodes represent the co-citation relationships between the two documents. 6602 bibliographic records provide information about documents contained within these nodes, but these documents may not be listed in 6602 bibliographic records.

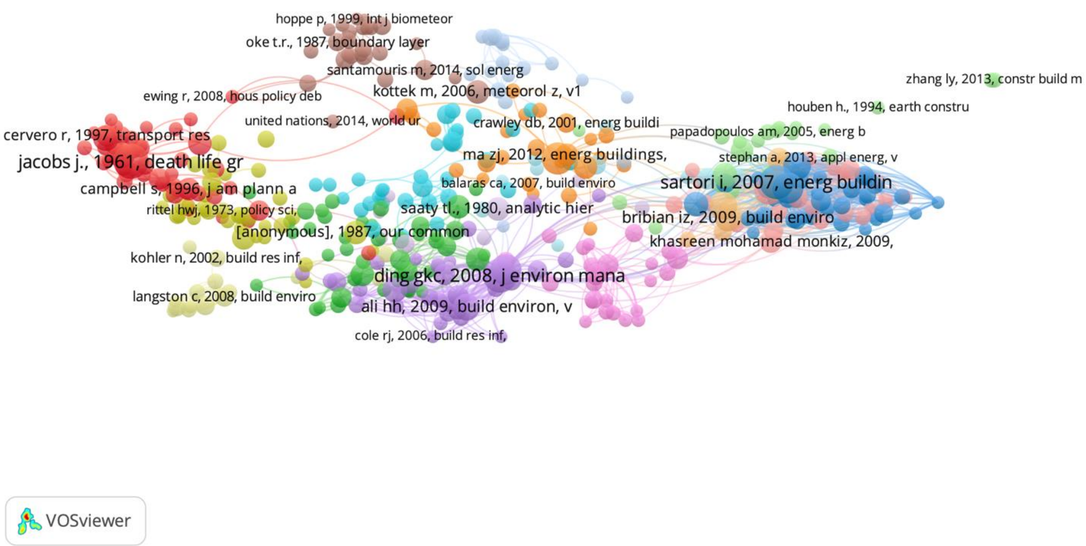


Figure 4-26: Visualization of the co-citation analysis network (threshold: 15, clustering resolution 2)

The network created though VOSviewer further analyzed in Gephi for calculating the modularity of the network.

Table 4-24: Top 10 co-cited references between 1991-2021

Rank	label	cluster	Weight <Links> (Degree centrality)	Weight <Total link strength>	Weight <Citations>	Betweenness centrality
1	Death and Life of Great American Cities (Jacobs, 1961)	1	58	212	104	338,531161
2	Sustainable construction--the role of environmental assessment tools (Ding, 2008)	4	141	573	100	610.159109
3	Energy use in the life cycle of conventional and low-energy buildings: A review article (Sartori & Hestnes, 2007)	2	120	677	97	310,40491
4	A review on buildings energy consumption information (Pérez-Lombard et al., 2008)	3	130	297	90	493,868072
5	Life cycle energy analysis of buildings: An overview (Ramesh et al., 2010)	2	110	611	83	228.983998
6	A critical review of building environmental assessment tools (Haapio & Viitaniemi, 2008)	4	123	465	80	407.892131
7	ISO 14040:1997, Environmental management — Life cycle assessment — Principles and framework	2	90	388	78	119.916107
8	Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review (Cabeza et al., 2014)	2	106	411	72	204.918908
9	Sustainability in the construction industry: A review of recent developments based on LCA (Ortiz et al., 2009)	2	124	491	68	335.850186
10	A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential (Thormark, 2002)	2	113	491	65	240.482884

VOSviewer determined 16 co-citation clusters (resolution at 2) according to the co-citation of these references. The number of member documents determines the cluster size. The study extracted the co-citation network into an excel sheet to list these clusters in order of size. Based on the analysis of the abstracts, it named these clusters.

Cluster #1 ‘urban sustainability (54 members) was the largest one, followed by ‘barriers and drivers’ (43 members) and ‘life-cycle energy analysis’ (37 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 #1 was formed by older documents than any other ones. Additionally, the representative document of each cluster was the one that was most co-cited in the respective cluster.

Table 4-25: Clusters determined in the co-citation analysis

ID	Cluster Label	Color	Size	Mean Year	Representative Documents	Explanation about the cluster members
1	Urban sustainability	Red	54	2001,2	(Dempsey et al., 2011; Jabareen, 2006; Lynch, 1960)	Research on sustainability assessment of neighborhoods and cities; smart cities; urban planning
2	Barriers and drivers	Green	43	2007,4	(Eichholtz et al., 2010; Häkkinen & Belloni, 2011; Newsham et al., 2009; Zuo & Zhao, 2014)	Decision makers, market demand, adoption of green technology, feasibility Member of this cluster make research on the evaluation of certified buildings and the correlation between user satisfaction and building energy savings. Moreover, a focus is also on the drivers and barriers for sustainable buildings.
3	Life cycle energy analysis	Blue	37	2005,9	(Ramesh et al., 2010; Sartori & Hestnes, 2007; Thormark, 2006)	Life cycle energy analysis, focus on embodied energy
4	Regenerative Design	Yellow	36	1998,5	(Cole, 2012; du Plessis & Cole, 2011; Reed, 2007)	Resilience, regenerative paradigm, The document ‘Our common future’ is in this cluster.
5	Building environmental assessment tools	Purple	34	2007,6	(Ali & Al Nsairat, 2009; Ding, 2008; Haapio & Viitaniemi, 2008)	Building environmental assessment tools; comparative studies on rating tools
6	Post-occupancy, Thermal Comfort	Cyan	33	2003,7	(Leaman & Bordass, 2007; Paul & Taylor, 2008)	Research on occupant comfort and satisfaction in terms of indoor environmental qualities; post-occupancy evaluations
7	Building optimization/prediction based on simulation	Orange	26	2009,8	(Pérez-Lombard et al., 2008; Wang et al., 2005)	Building optimization/prediction based on simulation; focused mainly on building renovation and residential building stock
8	Cooling the cities	Brown	26	2001,6	(Akbari et al., 2001; Kottek et al., 2006; Santamouris, 2014)	Climate knowledge and urban planning; urban heat island Research on the relationship among the urban texture (green area, building form) and the energy consumption and outdoor comfort
9	Building Information Modelling/Early decision making	Pink	24	2013	(Azhar et al., 2011; Basbagill et al., 2013; J. K. W. Wong & Zhou, 2015)	Research on building information modelling and decision-making models for reducing both embodied energy and in-use energy LCA and LEED integration with BIM
10	Life Cycle Assessment	Light red	22	2010,6	(Blengini & Di Carlo, 2010; Cabeza et al.,	LCA reviews

					2014; Khasreen et al., 2009)	
11	Building materials with a low impact	Light green	21	2007,5	(Flower & Sanjayan, 2007; Venkatarama Reddy & Jagadish, 2003; Zabalza Bribián et al., 2011)	Traditional, state-of-the-art, and future thermal building insulation materials and solutions – Properties, requirements and possibilities Research on building materials with respect to life-cycle analysis / impact of concrete production on environment / local materials
12	Green/building envelope and roofs	Light blue	18	2008,3	(Alexandri & Jones, 2008; Saiz et al., 2006; N. H. Wong et al., 2010)	Research on green roof, green walls
13	Building adaptation/reuse	Light yellow	15	2005,2	(Bullen, 2007; Langston et al., 2008)	Research on adaptive reuse, industrial heritage
14	Complex decision making	Light purple	11	1999,1	(Hill & Bowen, 1997)	AHP a conceptual framework aimed at implementing sustainability principles in the building industry
15	Zero energy buildings	Light cyan	10	2008,1	(Hernandez & Kenny, 2010; Marszal et al., 2011)	Net zero energy buildings: A consistent definition framework
16	LCA (methodology development)	Light orange	8	2006,5	(Ortiz et al., 2009; Zabalza Bribián et al., 2009)	Generic LCA-methodology applicable for buildings

The next step in this analysis involves the examination of the betweenness centrality of these nodes hence they overlay correlation between diverse clusters.

4.2.5.2 Co-citation burst analysis by CiteSpace

A citation burst indicates that the scientific community has paid or is paying particular attention to these articles. Co-citated references are determined based on the g-index (k=10) of cited references in 1 year slice. If a certain citation receives burst this means a growing number of publications are referring to these articles at that period. The burst must last at least 1 years in this analysis. The analysis yields 155 publications.

References	Year	Strength	Begin	End	1991 - 2021
**WorldCommissiononEnvironmentandDevelopment, 1987, OUR COMM FUT, V0, P0	1987	8.96	**1999**	2012	
Wackernagel M, 1996, OUR ECOLOGICAL FOOTP, V0, P0	1996	7.72	**1999**	2013	
Cole RJ, 1999, BUILD RES INF, V27, P230, DOI	1999	6.76	**1999**	2008	
Kohler N, 1999, BUILD RES INF, V27, P309, DOI	1999	6.68	**1999**	2002	
WCED, 1987, REPORT WORLD COMMISS, V0, P0, DOI	1987	12.08	**2004**	2012	
Egan J, 1998, RETHINKING CONSTRUCT, V0, P0	1998	6.82	**2005**	2010	
Turner RK, 2006, BUILD RES INF, V34, P197, DOI	2006	3.96	**2006**	2008	
Pearce D, 2006, BUILD RES INF, V34, P201, DOI	2006	3.96	**2006**	2008	
Kohler N, 2002, BUILD RES INF, V30, P226, DOI	2002	5.25	**2007**	2009	
Kaatz E, 2006, BUILD RES INF, V34, P308, DOI	2006	4.38	**2008**	2011	
Thormark C, 2002, BUILD ENVIRON, V37, P429, DOI	2002	10.3	**2009**	2016	
Scheuer C, 2003, ENERG BUILDINGS, V35, P1049, DOI	2003	5.85	**2009**	2014	
Turner C, 2008, ENERGY PERFORMANCE L, V0, P0	2008	4.25	**2009**	2012	
Kats G, 2003, COSTS FINANCIAL BENE, V0, P0	2003	4.64	**2010**	2013	
Adalberth K, 1997, BUILD ENVIRON, V32, P321, DOI	1997	4.06	**2010**	2013	
Forsberg A, 2004, BUILD ENVIRON, V39, P223, DOI	2004	6.43	**2011**	2016	
Rosen MA, 2008, ENERG POLICY, V36, P128, DOI	2008	5.08	**2011**	2012	
Hoffman AJ, 2008, ORGAN ENVIRON, V21, P390, DOI	2008	4.63	**2011**	2014	
Newsham GR, 2009, ENERG BUILDINGS, V41, P897, DOI	2009	11.33	**2012**	2016	
Marszal AJ, 2011, ENERG BUILDINGS, V43, P971, DOI	2011	6.01	**2012**	2014	
**OrganizationIS, 1997, STANDARD ISO 14040 E, V0, P0	1997	5.32	**2012**	2016	
Sartori I, 2007, ENERG BUILDINGS, V39, P249, DOI	2007	9.18	**2013**	2016	
Ortiz O, 2009, CONSTR BUILD MATER, V23, P28, DOI	2009	8.47	**2013**	2014	
[Anonymous], 1987, OUR COMMON FUTURE, V0, P0	1987	7.57	**2013**	2017	
Haapio A, 2008, ENVIRON IMPACT ASSES, V28, P469, DOI	2008	7.3	**2013**	2016	
Kibert CJ, 2008, SUSTAINABLE CONSTRUC, V0, P0	2008	5.75	**2013**	2014	
Standardization IO, 2006, 140402006 ISO, V0, P0	2006	10.18	**2014**	2016	
Hernandez P, 2010, ENERG BUILDINGS, V42, P815, DOI	2010	9.71	**2014**	2016	
Ramesh T, 2010, ENERG BUILDINGS, V42, P1592, DOI	2010	7.9	**2014**	2015	
Asif M, 2007, BUILD ENVIRON, V42, P1391, DOI	2007	6.44	**2014**	2015	
Classen M, 2014, BAUINGENIEUR-GERMANY, V89, P125	2014	5.9	**2014**	2015	
Dixit MK, 2010, ENERG BUILDINGS, V42, P1238, DOI	2010	6.61	**2015**	2016	
Eichholtz P, 2010, AM ECON REV, V100, P2492, DOI	2010	5.91	**2015**	2018	
Perez-Lombard L, 2008, ENERG BUILDINGS, V40, P394, DOI	2008	4.55	**2015**	2017	
Sharma A, 2011, RENEW SUST ENERG REV, V15, P871, DOI	2011	4.26	**2015**	2018	
Fuerst F, 2011, REAL ESTATE ECON, V39, P45,	2011	4.26	**2015**	2018	
Ma ZJ, 2012, ENERG BUILDINGS, V55, P889, DOI	2012	6.78	**2016**	2018	
Campbell S, 1996, J AM PLANN ASSOC, V62, P296, DOI	1996	5.99	**2016**	2019	
Gustavsson L, 2010, ENERG BUILDINGS, V42, P210, DOI	2010	5.33	**2016**	2018	
Blengini GA, 2010, ENERG BUILDINGS, V42, P869, DOI	2010	5.33	**2016**	2018	
Wang WM, 2005, BUILD ENVIRON, V40, P1512, DOI	2005	4.53	**2016**	2019	
Sharifi A, 2013, ENVIRON IMPACT ASSES, V38, P73, DOI	2013	3.68	**2016**	2019	
Ewing R, 2010, J AM PLANN ASSOC, V76, P265, DOI	2010	7.13	**2017**	2021	
Azhar S, 2011, AUTOMAT CONSTR, V20, P217, DOI	2011	6.65	**2017**	2021	
Cervero R, 1997, TRANSPORT RES D-TR E, V2, P199, DOI	1997	4.48	**2017**	2019	

Figure 4-27: Citation burst analysis of co-citated articles taken from Citespace

4.2.6 The timeline of sustainability in architecture

This section will describe the process of creating the timeline of sustainability in architecture by explaining how the outputs of the bibliometric analysis and milestones in Chapter 3 are assembled. Following the timeline, the final product will also be presented at the end of this section.

The study used several datasets that are layered throughout to create the timeline. The study first created the date bar. The Brundtland Report published by the United Nations in 1987 was originally selected as the beginning year of the date bar since it is widely accepted as the origin of the sustainability domain and sustainability development. The timeline stops at 2021, where bibliometric data for this year are collected. The study will also discuss new research fields that will stand out in the upcoming years. A one-year interval is used for the date bar, just as the bibliometric data analysis outcomes are presented in one-year intervals. Additionally, five-year intervals are also referenced to provide readers with a more refined basis for discussion. The final intervention to the date bar is the vertically spanning dotted lines located with intervals of four years. They stand for the results of the co-cited network analysis at four-year intervals. The vertical dotted lines begin in 1998 since the results of bibliometric analysis became more reliable after that date.

Upon finalizing the date bar, milestones including political agendas, scientific declarations, and activities that could affect the research field were added to the timeline.

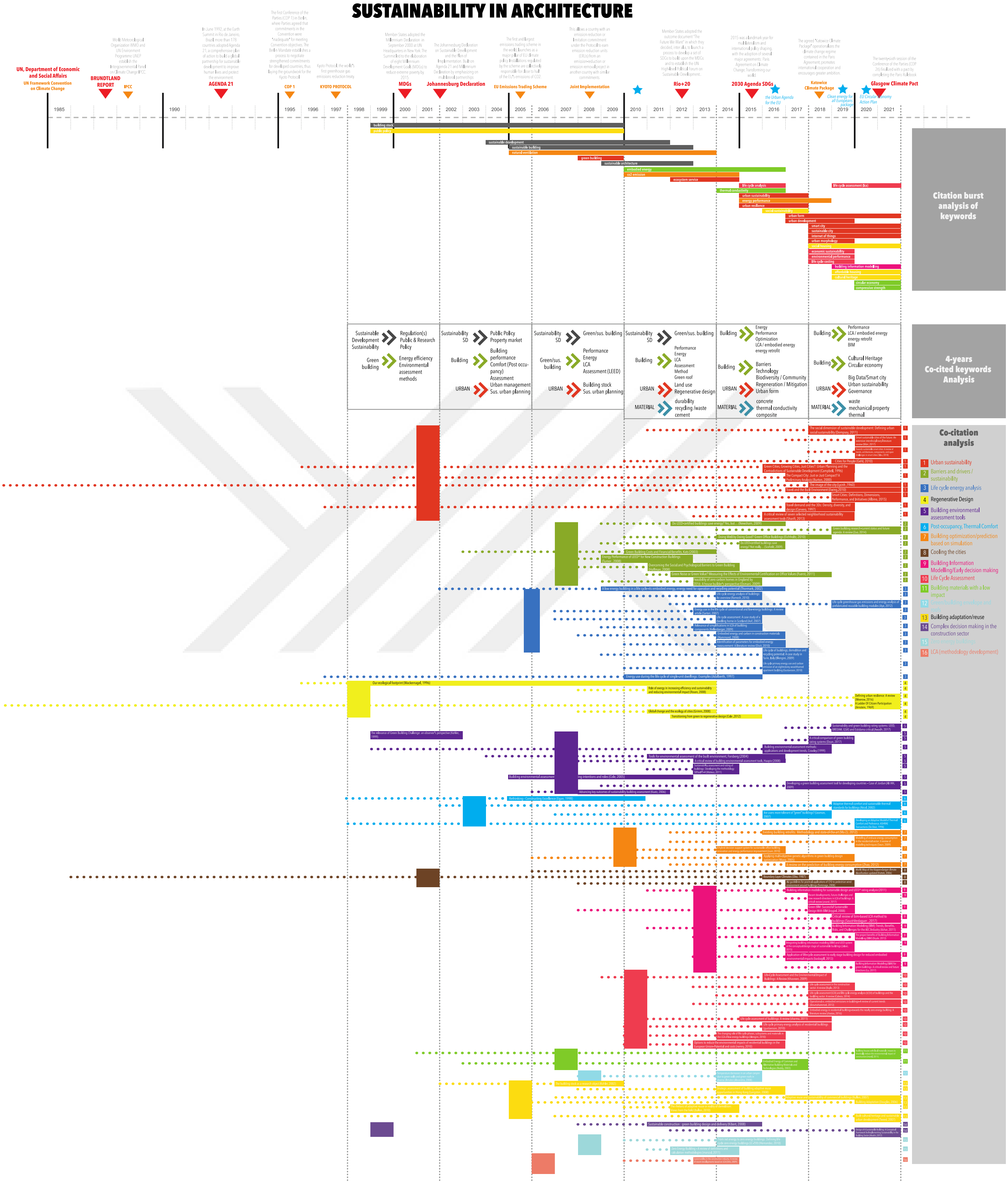
So, the timeline renders it possible for the readers to analyze how the research field has been affected by the decision maker’s actions. Next, the sixteen clusters resulting from the co-citation analysis are included. These clusters allow the categorization of each specific research field. They are also individually named and color-coded according to their content. The colors derive from the VOSviewer network color and are consistent throughout the timeline.

Citation bursts of keywords were placed under the date bar, colored according to the cluster research field they belong to. Despite this, the co-occurrence analysis recommended eight clusters for the keyword analysis, which were manually distributed to previously conceived sixteen clusters in order to improve the level of correlation between the keywords and publications. These keywords correspond to the most trending topics of sustainability in architecture.

An analysis of the keywords within a four years interval was next shared in order to visualize the trends and patterns in the literature regarding political factors on a larger scale. The four-year intervals are necessary because the bibliometric data visualization program shares results that are difficult to evaluate for readers. In addition, the number of publications increases exponentially, so the results are also no longer coherent in terms of the co-occurrences of the keywords related to these years. The keyword analysis is also colored in harmony with the clustering.

Citation bursts of co-cited publications appear in colored boxes beneath the timeline. They are sorted by their burst strength, so they are considered the most influential studies during the indicated years. Each study's dotted line extends backward into its publication year at the tail. The vertically oriented rectangles represent the average publication year for each cluster.

TIMELINE
SUSTAINABILITY IN ARCHITECTURE



4.3 The timeline of sustainability in architectural education

4.3.1 Data collection and analysis methods

In this study, literature data were collected from the Web of Science (WoS). Initially, Scopus and WoS were scanned, and the results were compared, since the majority of the reliable databases are matched, it was decided only to utilize WoS. Moreover, the reliability and extensity of the databases in WoS were led to more scientific and credible publications since it contains the two of the most frequently-used; the Science Citation Index Expanded (SCIE) and the Social Science Citation Index (SSCI) (Liao et al., 2018). The number of publications from WoS was insufficient to overlay the evolution of sustainability in architectural education. Hence, enlarging the data required manual modification for the bibliometric analysis that includes the related theses and dissertations reviews. Therefore, the timeline of sustainability in architecture will be updated after the bibliometric analysis outcomes were inserted. The bibliometric data includes information about its author(s), title, abstract, keywords, references, year of publication, source type, issue number, volume number, and DOI, and others.

In the beginning, the citations displayed by Web of Science according to the search criteria as shown below were exported to store all the results as a single document. An online bibliography management tool called Zotero was used to store all citations. The data was then transferred to other programs using the necessary import formats (VOSviewer, CiteSpace, Gephi, Tableau).

To identify the relevant studies that lie at the intersection between "sustainability", "architecture", and "education" the following approach is used to query the online database WoS (Table 1-26).

Table 4-26: Number of records per database

Database	Search query	Number of records

Web of Science	**Fields and Keywords:** TS=(architectur* AND sustainab* AND education) **Refined by:** NOT Document Types: Corrections or Book Reviews or News Items or Retracted PublicationsNOT Web of Science Categories: Toxicology or Spectroscopy or Respiratory System or Nursing or Medical EthicsNOT Web of Science Categories: Medical InformaticsNOT Web of Science Categories: Computer Science Theory MethodsNOT Web of Science Categories: Hospitality Leisure Sport TourismNOT Web of Science Categories: Thermodynamics or Sociology or RoboticsNOT Web of Science Categories: Psychology Applied or Plant Sciences or Philosophy or Optics or Mining Mineral Processing or MicrobiologyNOT Web of Science Categories: Mathematics Interdisciplinary Applications or Mathematics or Materials Science Textiles or Materials Science Coatings Films or Materials Science Characterization Testing or Marine Freshwater BiologyNOT Web of Science Categories: Linguistics or Language Linguistics or International Relations or Horticulture or Health Policy Services or Folklore or Ergonomics or Engineering BiomedicalNOT Web of Science Categories: Transportation Science Technology or Health Care Sciences Services or Demography or Chemistry Multidisciplinary or Business Finance or Biology or Biochemistry Molecular Biology or Agriculture MultidisciplinaryNOT Web of Science Categories: Rehabilitation or Women S Studies or Social Work or Psychology MultidisciplinaryNOT Web of Science Categories: Social Issues or Public Administration or Psychology Educational or Physics Applied or Nutrition Dietetics or Meteorology Atmospheric Sciences or Information Science Library ScienceNOT Web of Science Categories: History Philosophy Of Science or Ethics or Political Science or Imaging Science Photographic Technology or HistoryNOT Web of Science Categories: Remote Sensing or Food Science Technology or Engineering GeologicalNOT Web of Science Categories: Geography Physical or Engineering Aerospace or Computer Science CyberneticsNOT Web of Science Categories: Automation Control Systems or Astronomy Astrophysics or Agricultural Economics PolicyNOT Web of Science Categories: Water Resources or Operations Research Management Science or Geography or Economics or Nanoscience Nanotechnology or Geosciences MultidisciplinaryNOT Web of Science Categories: Computer Science Software Engineering or Computer Science Hardware ArchitectureNOT Web of Science Categories: TelecommunicationsNOT Web of Science Categories: Public Environmental Occupational HealthNOT Web of Science Categories: Area StudiesNOT Web of Science Categories: Development Studies Timespan: All **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI Languages: All To Access the search results: https://www.webofscience.com/wos/woscc/summary/237d20ac-ebc1-49b7-8be1-02ddf5c30a60-06902224/relevance/1 **Date Received:** 02 September 2021	633[2]

Table 4-27: Number of records per database categorized based on document type

Article	Article/Book Chapter	Article grouped in Proceeding Papers (7) and proceeding papers (297)	Editorial Material	Review
291	17	306	4	14

The purpose of this study is to retrieve research directly related to integrating sustainability into architectural education, and as such it searched WoS by inserting three keywords: architectur*, sustainab*, and education. The title survey, however,

[2] 1 paper deleted given to its similarity among each other: Same paper published twice in different publications. The book chapter is deleted. Zeiler, W; Savanovic, P; van Houten, R MULTIDISCIPLINARY MASTER DESIGN PROJECTS BASED ON WORKSHOPS FOR PROFESSIONALS
Zeiler, W; Savanovic, P Integral design pedagogy: Representation and process in multidisciplinary master student projects based on workshops for professionals

revealed a confusing picture because many of the research outputs dealt with the sustainability of education buildings.

To this end, to attain a coherent picture of the research field, the study manually reviewed six hundred and two (632) papers. This manual elimination process was crucial for the outcome to be consistent and coherent. According to the research criteria, the total number of records was reduced to two hundred and seventy-nine (279) papers.

Table 4-28: Number of records based on the selection phases

Selection Phase	**Number of publications**
Phase 1 (based on publication titles)	77 selected
Phase 2 (based on publication abstracts)	165 selected (316 publications not related to the topic; 71 left for reading full texts; 3 publications without access to neither abstract nor full text)
Phase 3 (based on full texts)	37 selected (34 publications not related to the topic)
Total	279 publications

Table 4-29: Number of selected records categorized based on document type

Total Number of records				
Article	Article/Book Chapter	Article grouped in Proceeding Papers (7) and proceeding papers (297)	Editorial Material	Review
116	5	155	-	3

4.3.2 Results from the analytical analysis

The number of publications included in the analysis are inserted into the tableau program.

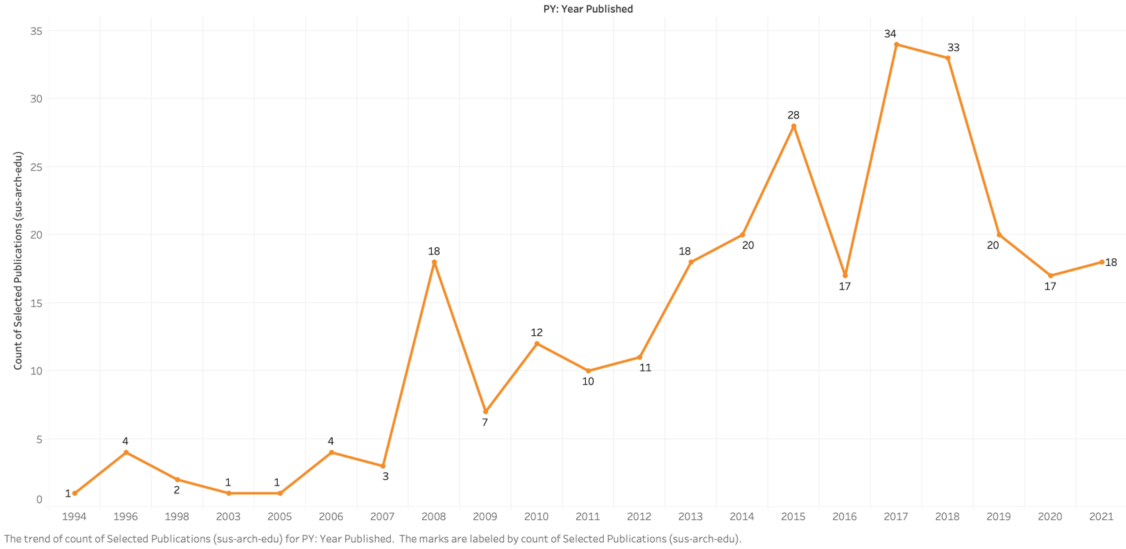
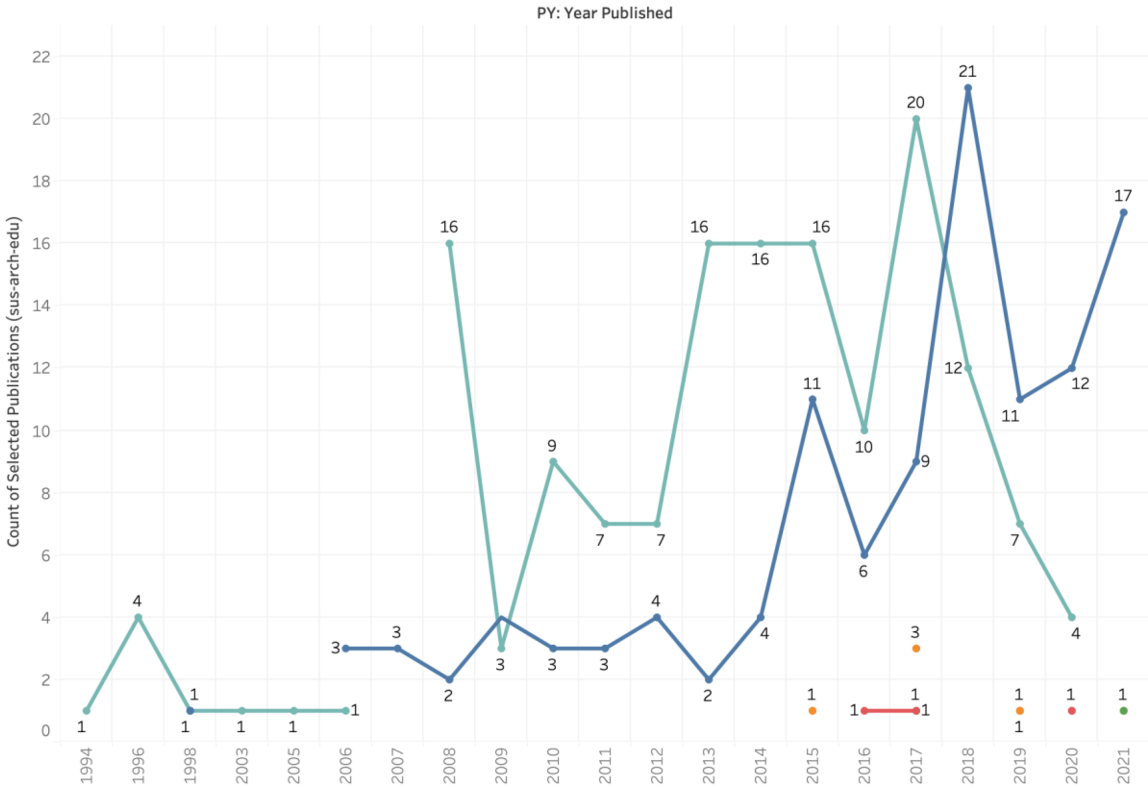


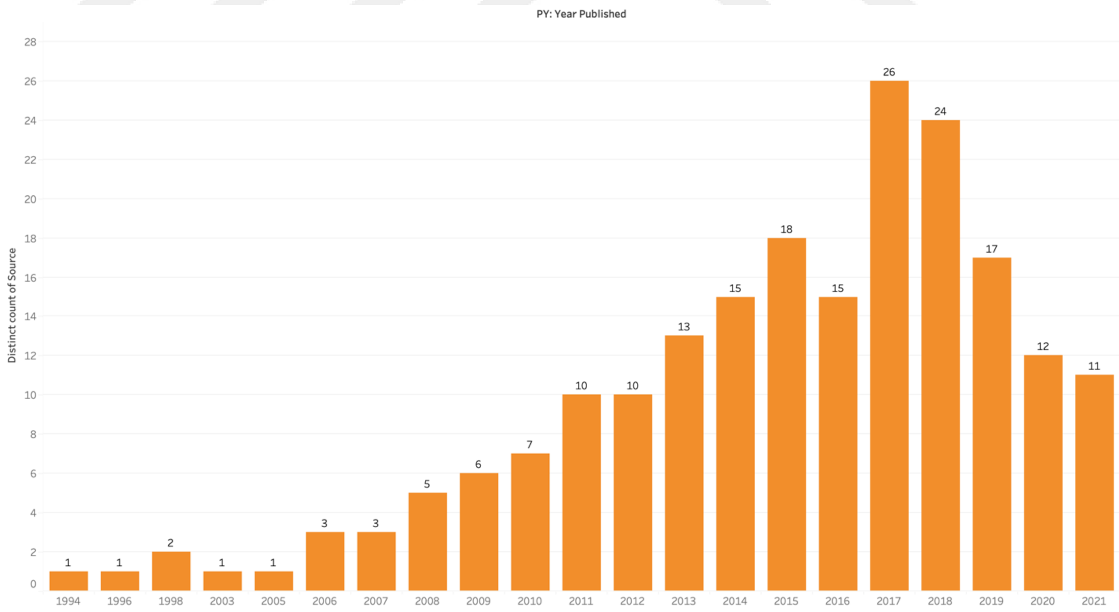
Figure 11: Number of publications across years

From the overall perspective, the number of publications is very low, until 2007 the most articles published in 1994 and 2006 and it counts 4. The number of publications peak at the 2017, but a significant decrease occurred after 2018.



The trend of count of Selected Publications (sus-arch-edu) for PY: Year Published. Color shows details about DT: Document Type. The marks are labeled by count of Selected Publications (sus-arch-edu).

Figure 4-28: Number of publications according to their document types



Distinct count of Source for each PY: Year Published. The marks are labeled by distinct count of Source.

Number of research outlets (source) across years

The number of journals that are available for the scientific publication are in parallel with the number of publications across the years.

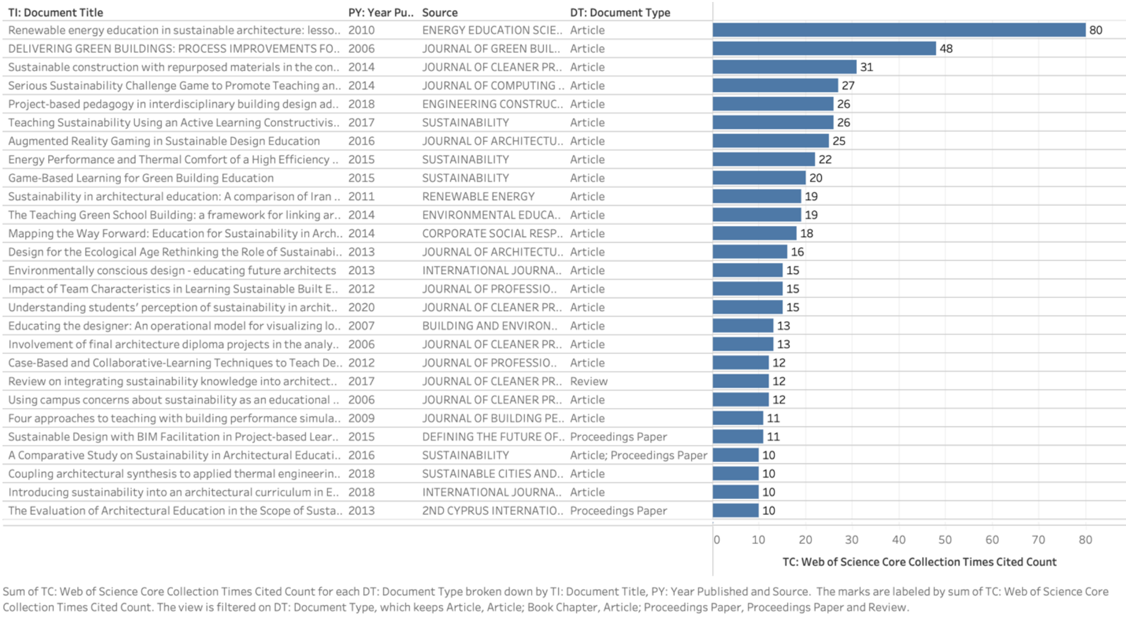


Figure 4-29: Publications sorted based on the number of citations received in WoS

4.3.3 Text Mining Analysis in VOSviewer

The analysis assessed the distribution of the most frequent keywords, examining their cooccurrence (keywords occurring together within the same paper). Using only the author keywords that appear below the abstract, the study attempts to highlight the most relevant research topics in the field of SUS-ARCH. The analysis determined **740** keywords The minimum number of occurrences is set at 3, VOSviewer allows users to specify a minimum threshold number for keywords to be include on the map. **50** keywords met the threshold. **624** keywords appeared only once (83,19 %). Upon detailed analysis however, the study determined that keywords like “architecture education” “architectural education” repeatedly hence it is not possible to separate clusters.

Table 4-30: Top 10 keywords between 1991-2021 (sorted based on total link strength)

Rank	Label	Frequency/ occurrences	Total Link Strength
1	sustainability	53	93
2	architecture	29	65
	education	34	53
3	architectural education	45	49
4	sustainable design	18	28
5	sustainable architecture	16	21
6	design studio	9	16
7	design	6	15
8	higher education	8	15
9	built environment	9	12
10	curriculum	5	12

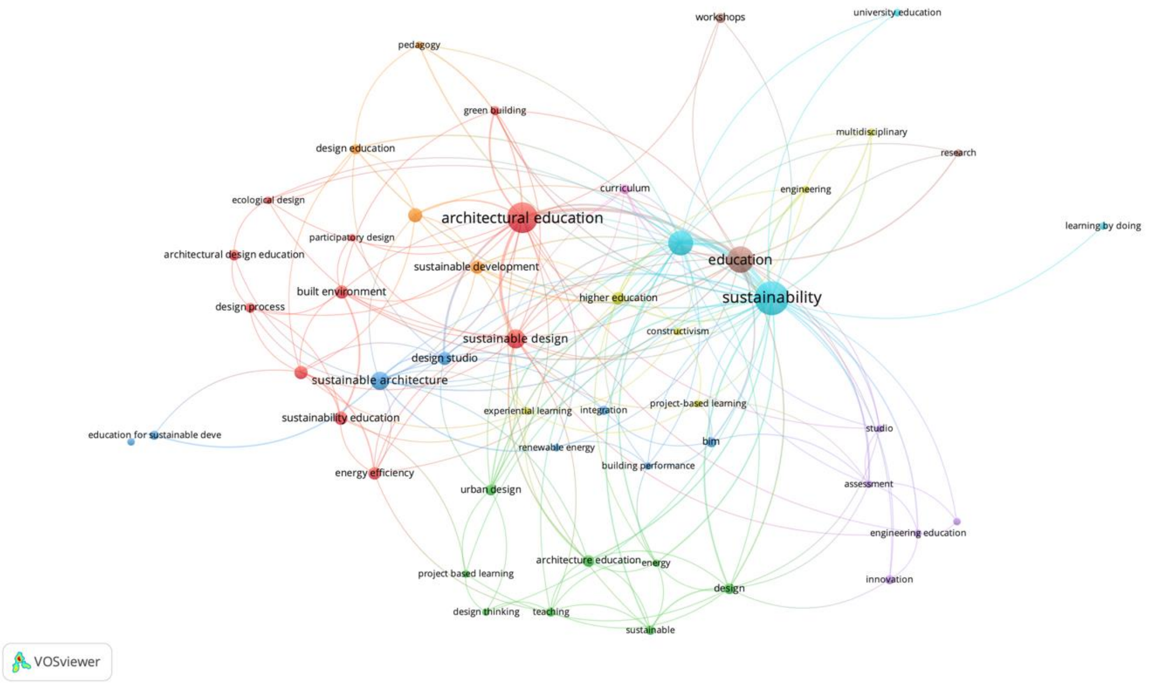


Figure 4-30: Graphic representing the keyword co-occurrence

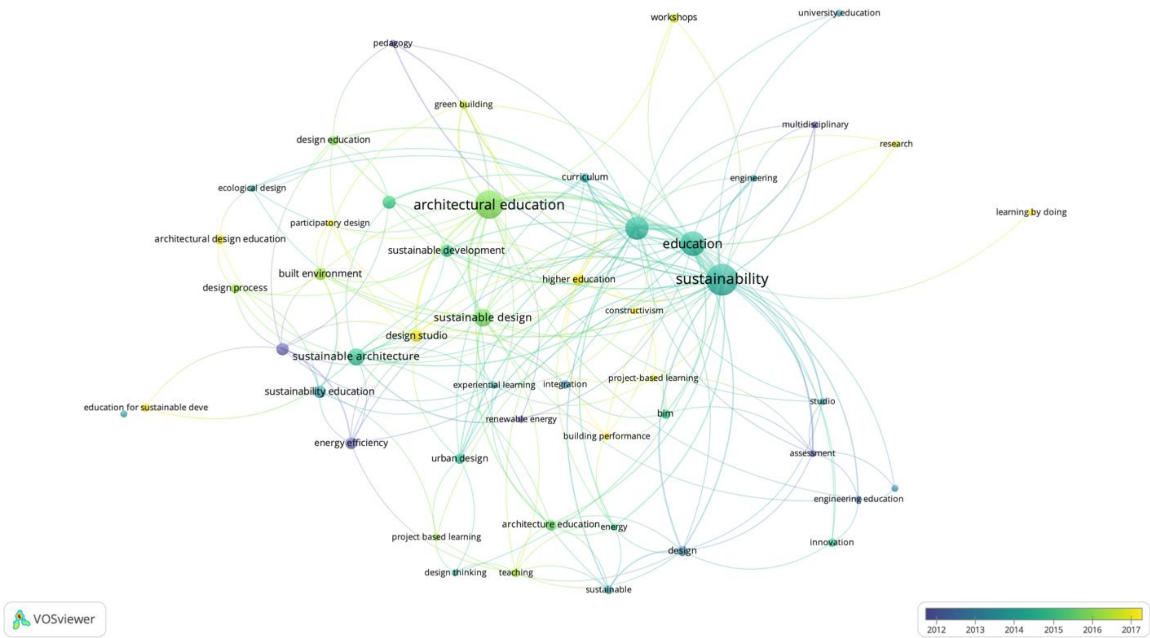


Figure 4-31: Overlay visualization of the keywords

4.3.4 Text mining analysis in CiteSpace

The study uses CiteSpace for three types of analysis: (1) the timeline view of the co-occurred keywords, (2) the analysis of these keywords in four years range.

Citation burst analysis does not identify any specific emerging research in the field. Comparatively to the first group, the analyzed number of documents is limited, and numerous keywords are used interchangeably, therefore, to analyze the sustainability in architectural education, another mapping technique is used.

4.3.4.1 The timeline of the word co-occurrence

To analyze word co-occurrence in CiteSpace, the study set the number of years per slice to 4 and then selects top 50 levels in a slice. For the timeline analysis the study excludes the keywords appearing in the publications between 1994-2005 because in total there were only 9 publications on the topic and there no keywords till 2006 (Table -4-31).

Table 4-31: Number of keywords per year (1991-2021)

Year	Number of keywords	Year	Number of keywords
1994	0	2008	70
1995	0	2009	20
1996	0	2010	43
1997	0	2011	35
1998	4	2012	40
1999	0	2013	61
2000	0	2014	65
2001	0	2015	101
2002	0	2016	65
2003	0	2017	106
2004	0	2018	128
2005	0	2019	80
2006	14	2020	67
2007	11	2021	78

Table 4-32: Details of the selection criteria and results (2006-2021)

Timespan	2006-2021 (Slice Length=4)
Selection Criteria	g-index (k=20); LRF = -1; LB Y= -1
Network	N=150, E=317 (Density=0.0284)
Modularity	0.568
Weighted Mean Silhouette (S)	0.8662

Following table illustrates the number of retrieved keywords (nodes) from each 4 years slice.

Table 4-33: The number of retrieved keywords (sus-arch-edu)

Years	**Space (total number of keywords)**	**Keywords (nodes)**
2006-2009	107	38
2010-2013	149	43
2014-2017	292	60
2018-2021	323	54

The study represents the timeline view of these keywords.

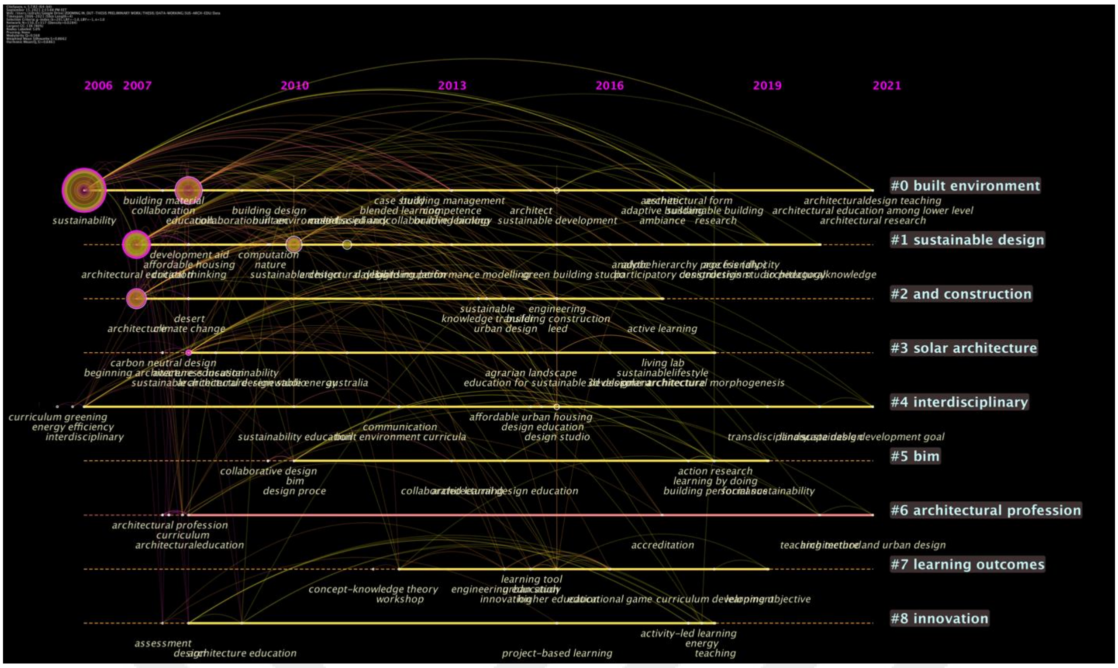


Figure 4-32: Timeline view of keyword co-occurrence in CiteSpace

4.3.4.2 Word co-occurrence analysis (2006-2009)

Table 4-34: Details of the selection criteria and results (2006-2009)

Timespan	2006-2009 (Slice Length=1)
Selection Criteria	top 50 per slice; LRF = -1; LBY= -1
Network	N=107, E=251 (Density=0.044)
Modularity	0.8031
Weighted Mean Silhouette (S)	0.8775

Table 4-35: Top 10 keywords between 2006-2009 (Left ranking based on frequency; right ranking based on degree centrality)

Rank	Label	frequency	Degree centrality	Rank	Label	Betweenness centrality	frequency	Degree centrality
1	sustainability	12	22	1	Sustainability	1201,221569	12	22
2	Architecture	5	16	2	architecture	800,831046	5	16
3	Education	5	14	3	Architectural education	653	4	14
4	Architectural education	4	14	4	education	149,311111	5	14
5	sustainable architecture	3	8	5	architecturaleducation	111,478431	2	12

6	Energy efficiency	3	4	6	architectural profession	180	2	11
7	design	2	6	7	council of architecture	90,580392	1	9
8	interdisciplinary	2	2	8	curriculum	90,580392	1	9
9	development	2	7	9	environmental performance	90,580392	1	9
10	architectural profession	2	11	10	consultancy cell	90,580392	1	9

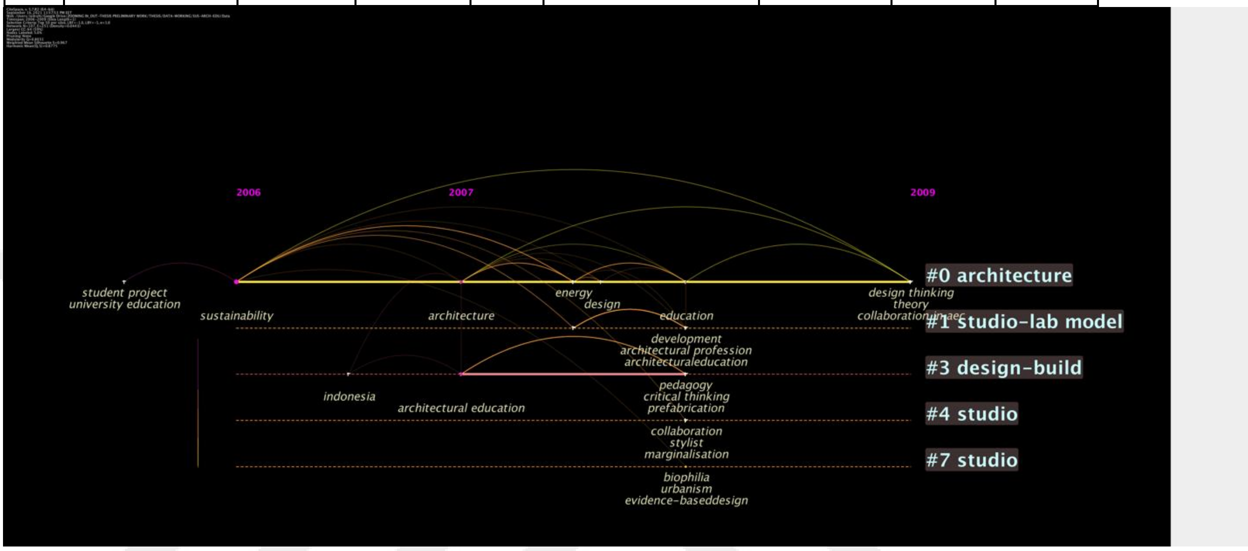
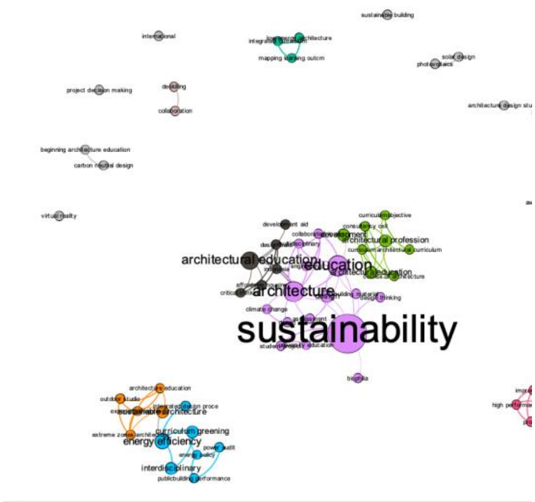


Figure 4-33: Timeline view of the years 2006-2009



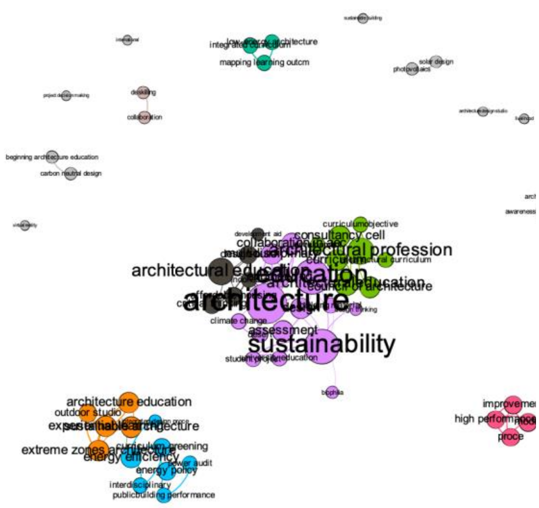


Figure 4-34: For the years between 2006-2009, Keyword co-occurrence visualization (keyword and nodes

Figure 4-35: For the years between 2006-2009, keyword co-occurrence visualization (keyword and nodes

dimensions are ranked based on their frequency)	dimensions are ranked based on their centrality)

4.3.4.3 Word co-occurrence analysis (2010-2013)

Table 4-36: Details of the selection criteria and results (2010-2013)

Timespan	2010-2013 (Slice Length=1)
Selection Criteria	top 50 per slice; LRF = -1; LBY= -1
Network	N=149, E=364 (Density=0,033)
Modularity	0.7779

Table 4-37: Top 10 keywords between 2010-2013 (Left ranking based on frequency; right ranking based on degree centrality)

Rank	Label	frequency	Degree centrality	Rank	Label	Betweenness centrality	frequency	Degree centrality
1	education	10	11	1	education	483	10	11
2	architectural education	6	9	2	architectural education	237,5	6	9
3	sustainability	5	9	3	sustainability	275,25	5	9
4	built environment	3	7	4	built environment	144,75	3	7
5	architecture	3	6	5	architecture	329	3	6
6	sustainable design	2	5	6	sustainable design	33,5	2	5
7	interdisciplinary	2	2	7	interdisciplinary	49	2	2
8	bim	2	4	8	bim	125,25	2	4
9	collaborative design	2	4	9	collaborative design	85,75	2	4
10	design process	2	4	10	design process	58,25	2	4

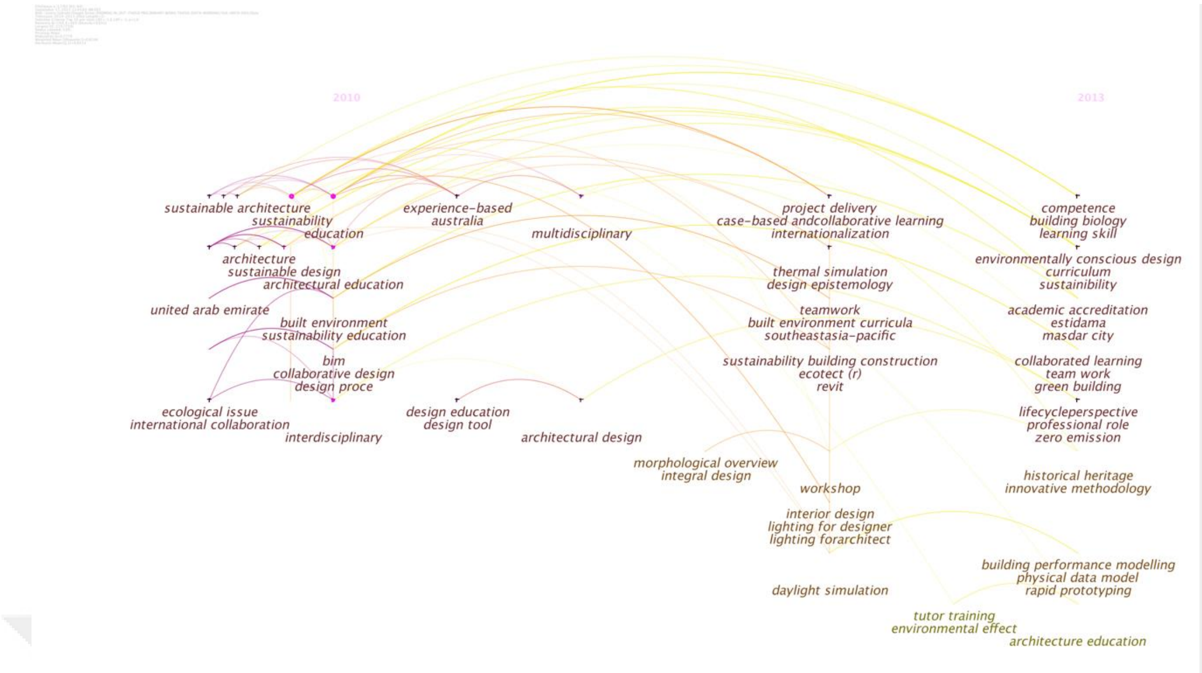


Figure 4-36: Timeline view of the years 2010-2013

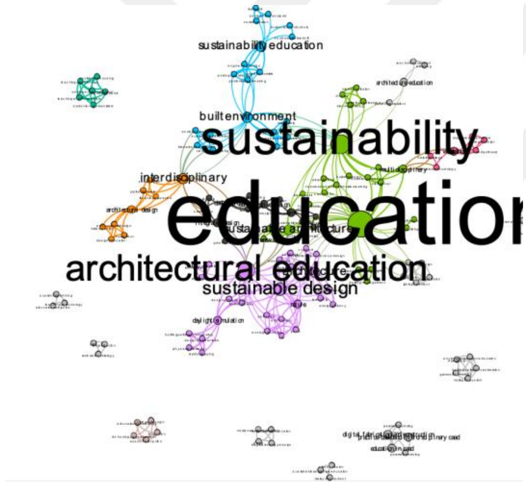


Figure 4-37: For the years between 2010-2013, Keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their frequency)

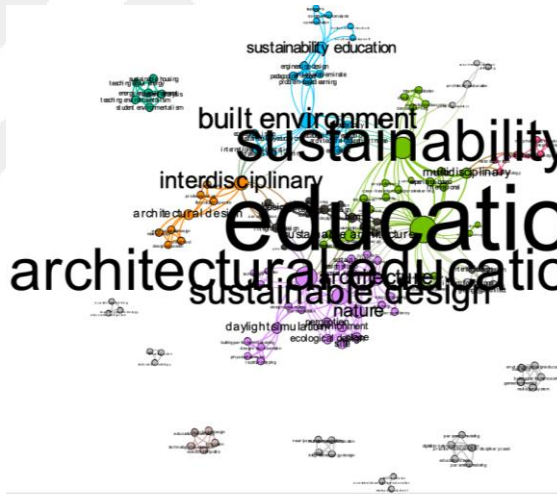


Figure 4-38: For the years between 2010-2013, keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their centrality)

4.3.4.4 Word co-occurrence analysis (2014-2017)

Table 4-38: Details of the selection criteria and results (2014-2017)

Timespan	2014-2017 (Slice Length=1)

Selection Criteria	top 50 per slice; LRF = -1; LBY= -1
Network	N=292, E=844 (Density=0.0199)
Modularity	0.7809
Weighted Mean Silhouette (S)	0.9193

Table 4-39: Top 10 keywords between 2014-2017 (Left ranking based on frequency; right ranking based on degree centrality)

Rank	Label	frequency	Degree centrality	Rank	Label	Betweenness centrality	frequency	Degree centrality
1	sustainability	17	52	1	architecture	5809,025491	16	53
2	architecture	16	53	2	sustainability	7482,564187	17	52
3	architectural education	13	35	3	education	4477,956441	12	37
4	education	12	37	4	architectural education	4712,775242	13	35
5	sustainable design	6	18	5	architectural design	2576,684802	6	20
6	architectural design	6	20	6	design studio	2948,161936	6	20
7	design studio	6	20	7	sustainable architecture	3811,019641	6	19
8	sustainable architecture	6	19	8	higher education	1479,54773	4	19
9	sustainable development	4	12	9	sustainable design	1295,483208	6	18
10	sustainability	17	52	10	architecture	5809,025491	16	53

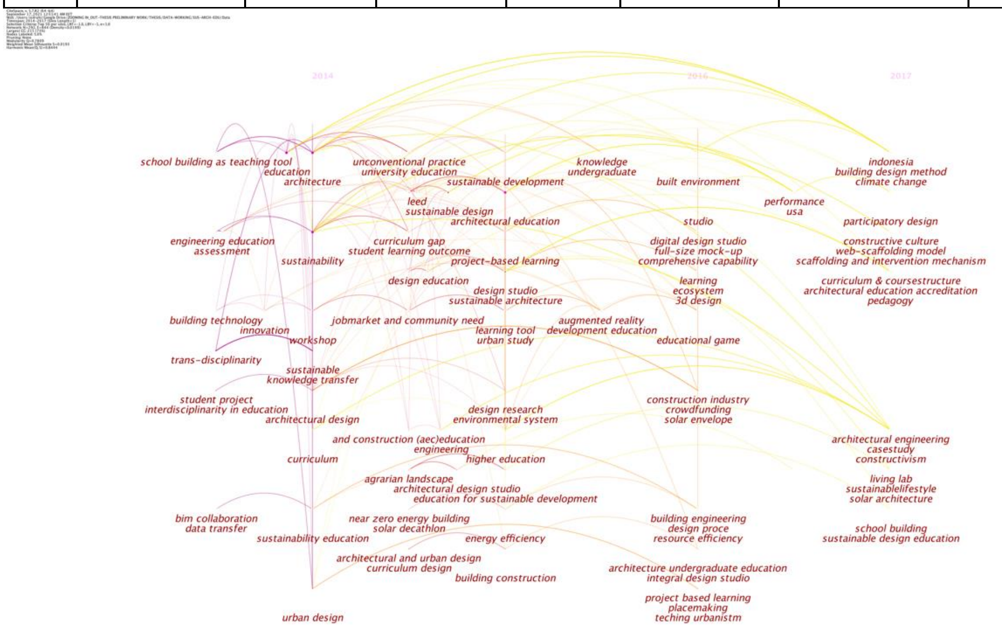
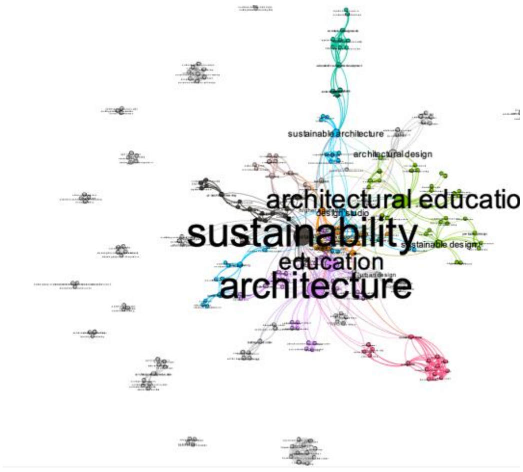


Figure 4-39: Timeline view of the years 2014-2017



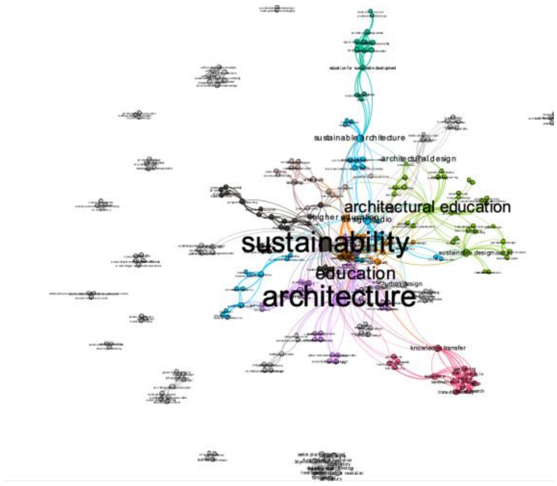


Figure 4-40: For the years between 2014-2017, Keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their frequency)

Figure 4-41: For the years between 2014-2017, keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their centrality)

4.3.4.5 Word co-occurrence analysis (2018-2021)

Table 4-40: Details of the selection criteria and results (2018-2021)

Timespan	2018-2021 (Slice Length=1)
Top 50	Top 50 per slice (k=15); LRF = -1; LBY= -1
Network	N=316, E=935 (Density=0.0188)
Modularity	0.8201
Weighted Mean Silhouette (S)	0.9563

Table 4-41: Top 10 keywords between 2018-2021 (Left ranking based on frequency; right ranking based on degree centrality)

Rank	Label	frequency	Degree centrality	Rank	Label	Betweenness centrality	frequency	Degree centrality
1	architectural education	17	52	1	sustainability	18183,32619	16	55
2	sustainability	16	55	2	architectural education	12822,766667	17	52
3	education	8	32	3	education	4999,788095	8	32
4	sustainable design	7	27	4	sustainable design	6791,269048	7	27
5	architecture	5	24	5	built environment	5679	4	26

6	built environment	4	26	6	architecture	7934,304762	5	24
7	sustainable development	4	18	7	sustainable development	7579,6	4	18
8	higher education	3	17	8	higher education	3899,304762	3	17
9	sustainable architecture	3	17	9	sustainable architecture	7076,407143	3	17
10	architecturaleducation	3	14	10	architecturaleducation	1027,62381	3	14

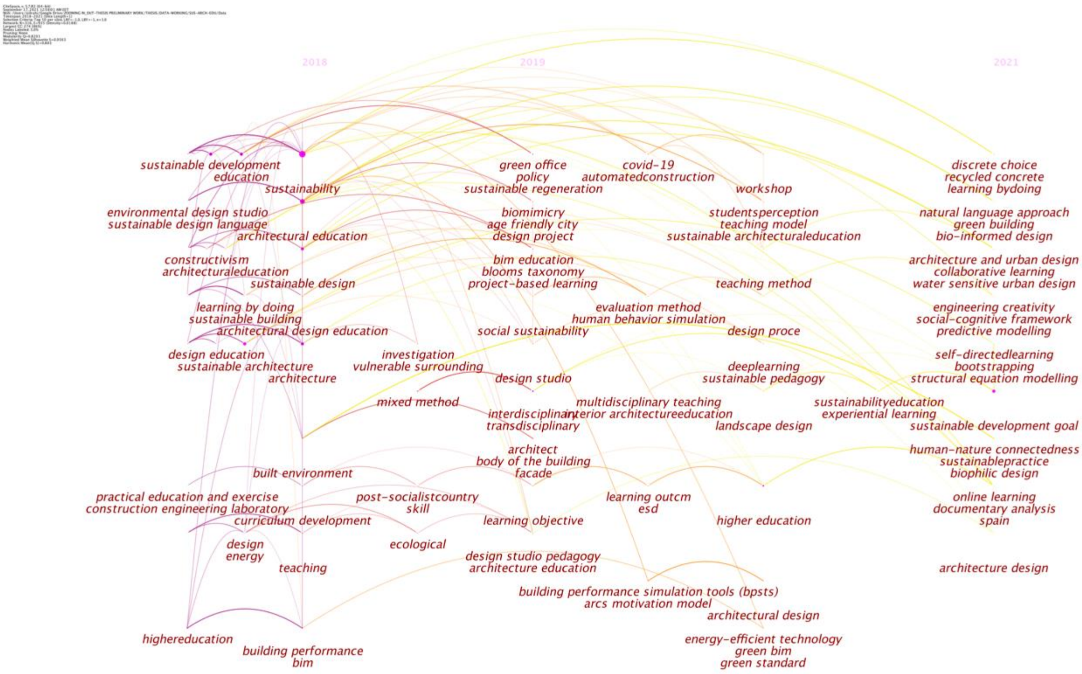


Figure 4-42: Timeline view of the years 2018-2021

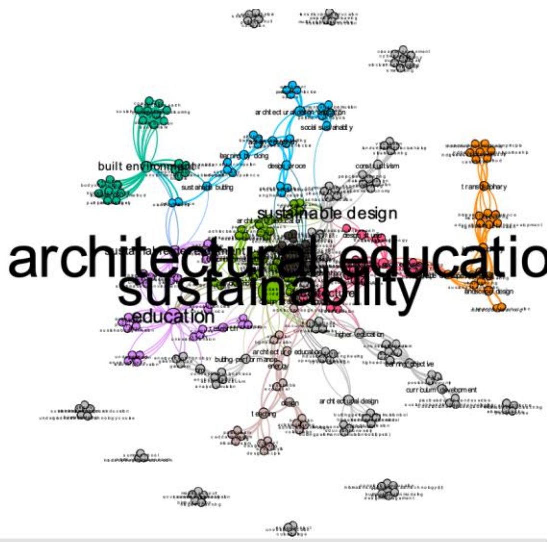


Figure 4-43: For the years between 2018-2021, Keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their frequency)

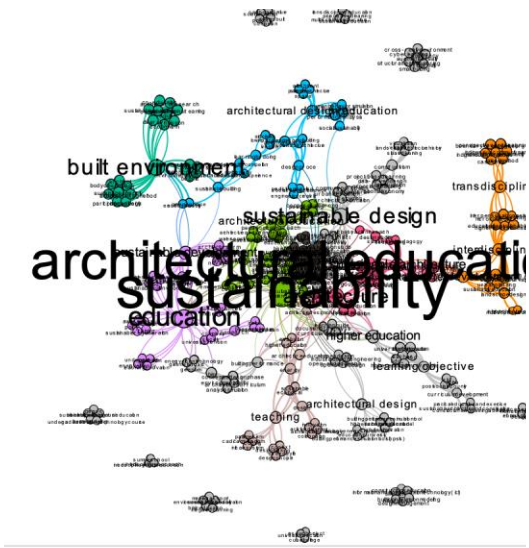


Figure 4-44: For the years between 2018-2021, keyword co-occurrence visualization (keyword and nodes dimensions are ranked based on their centrality)

4.3.5 Bibliometric analysis

4.3.5.1 Co-citation analysis in VOSviewer

The study uses VOSviewer for creating the co-citation network. The minimum number of citations for a cited reference is **3**. Out of 5482 references, 95 meet this threshold.

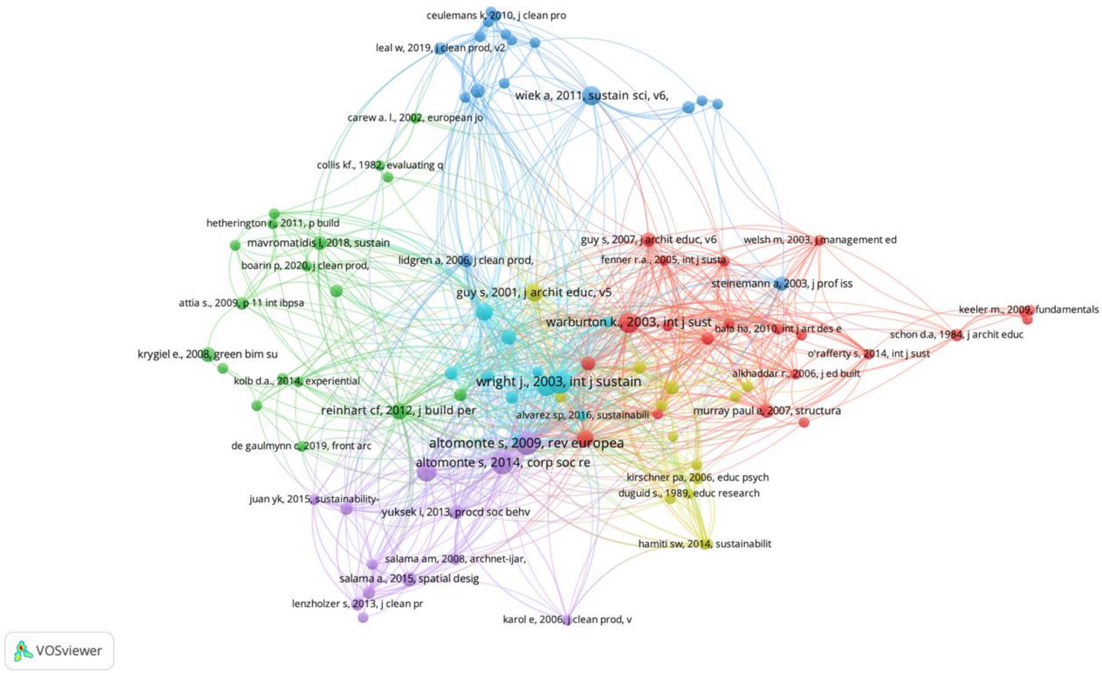


Figure 4-45: Co-citation analysis (threshold: 6)

Table 4-42: Top 10 co-cited references between 1991-2021 (sorted based on the number of citations)

Rank	label	cluster	Weight <Links> (Degree centrality)	Weight <Total link strength>	Weight <Citations>
2	Environmental Education for Sustainable Architecture (Altomonte, 2009)	5	49	77	14
1	Introducing sustainability into the architecture curriculum in the United States (Wright James, 2003)	6	58	108	14
3	Education for Sustainability in Architecture and Urban Design (Altomonte et al., 2014a)	5	48	93	13
4	Deep learning and education for sustainability (Warburton, 2003)	1	46	74	11
5	Sustainability in architectural education: A comparison of Iran and Australia (Taleghani et al., 2011)	5	37	61	10
6	Design for the Ecological Age: Rethinking the Role of Sustainability in Architectural Education (Khan et al., 2013)	6	52	78	9
7	Key competencies in sustainability: a reference framework for academic program development (Wiek et al., 2011)	3	21	25	9
8	Reinterpreting Sustainable Architecture: The Place of Technology (Guy & Farmer, 2001)	4	32	38	8

9	Environmentally conscious design – educating future architects (Domenica Iulo Lisa et al., 2013)	6	44	68	8
10	Review on integrating sustainability knowledge into architectural education: Practice in the UK and the USA (Ismail et al., 2017)	1	44	63	7

Altomonte (2009), Wright (2003), and Altomonte et. al. (2014b) are at the top three and attached 14, 14, and 13 co-citations, respectively. Altomonte's papers emerge from the EDUCATE Action, which was funded by the European Agency for Competitiveness and Innovation (EACI) of the European Commission, under the 'Intelligent Energy Europe' Programme 2008. Hence the results of this project have an important impact in the field.

Table 4-43: Cluster identified in the co-citation analysis

ID	Cluster Label	Color	Size	Mean Year	Representative Documents	Explanation about the cluster members
1	Central cluster (consisting of the clusters 2-3-4-5-6)	Red	21	2005, 3	(Ismail et al., 2017; Warburton, 2003)	Research on integrating sustainability knowledge into architectural curricula (detailed analysis of courses) The cluster include two major research output on the multiple meaning of sustainable architecture
2	Energy performance simulation BIM collaboration	Green	18	2010, 8[3]	(Mavromatidis, 2018; Reinhart et al., 2012)	Games; BIM
3	Incorporation of sustainability into university courses and curricula	Blue	17	2009, 5	(Wiek et al., 2011)	Articles on the incorporation of sustainability in universities' curricula
4	The design studio	Yellow	14	2000, 2	(Guy & Farmer, 2001; Schön, 1983)	Reflections on the design studio; theoretical approach to the sustainable architecture
5	Integration of sustainability into studio practice	Purple	13	2008, 6	(Altomonte, 2009; Taleghani et al., 2011)	Diverse strategies for the integration (studio)
6	Integration of sustainability into architectural curricula	Cyan	11	2011, 7	(Khan et al., 2013; Wright James, 2003)	Introducing sustainability into an architectural curriculum. Two publications provide an overview of the sustainability in the built environment.

[3] Publication date of three research were omitted to calculate the mean year, bloom b, 1956, taxonomy ed objectiv; collis kf., 1982, evaluating quality l; rittel hwj, 1973, policy sci, v4, p155, doi 10.1007/bf01405730.

Future research will make the analysis bibliographic coupling to determine existing research tracks in the field. Co-citation analysis proved to be valuable in overlaying a certain timeline for this study.

4.3.5.2 Co-citation burst analysis by CiteSpace

Co-citated references are determined based on the g-index (k=25) of cited references in 1 year slice. If a certain citation receives burst this means a growing number of publications are referring to these articles at that period.

Table 4-44: Details of the selection criteria and results (1994-2021)

Timespan	1994-2021 (Slice Length=1)
Selection Criteria	g-index (k=25); LRF = -1; LB Y= -1
Network	N=491, E=1680 (Density=0.014)

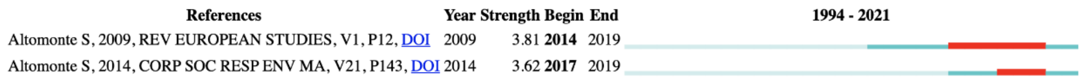


Figure 4-46: Citation burst results from Citespace

4.3.6 The timeline of sustainability in architectural education

The part describes the process of building the timeline of sustainability in architectural education. The timeline method is mainly parallel with that of sustainability in architecture, but there are a few additions that arise from the differences in the bibliometric analysis results. This part will end with the presentation of the final product.

The date bar is directly drawn from the first timeline. Besides the milestones from the previous timeline, influential charters, declarations, conferences, and meetings regarding the educational field of sustainability in architecture have been included as well. Consequently, the timeline enables the readers to be able to evaluate how the research field has been affected by/or has affected the institutions' and civil society organizations' (CSO's) political actions.

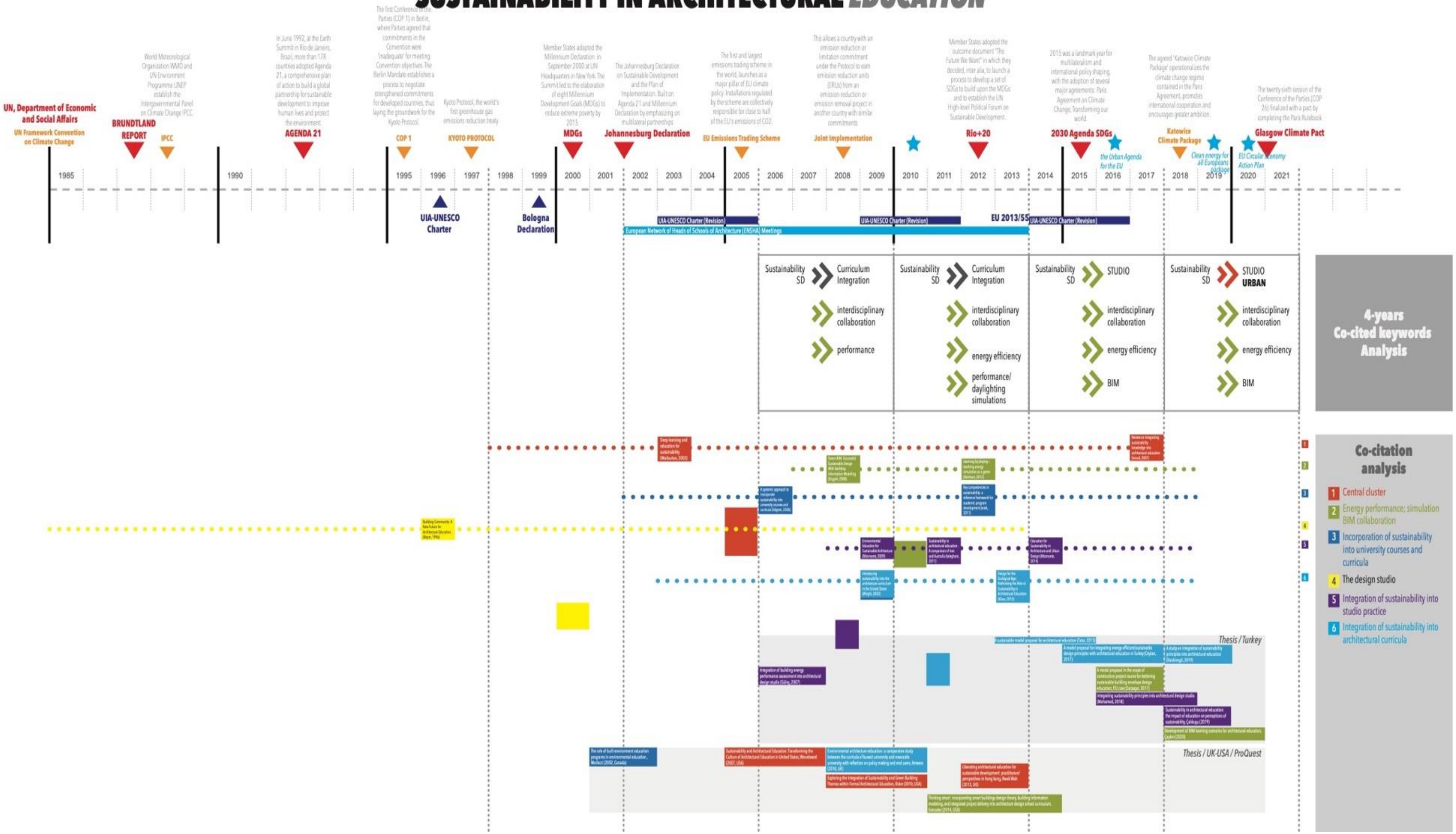
Next, the clusters that allow categorization of each specific research field, are attached to the timeline. Comparatively to the previous timeline, the number of clusters has decreased, to six. The clusters are determined by the co-citation analysis and they are individually named and color-coded according to their content. The colors are coherent in terms of the content throughout the timeline.

Moreover, an analysis of the keywords within 4 years intervals were shared to better illustrate the trends and patterns in the literature regarding the political factors on a larger scale. The outcomes start from 2006 which is the date where a suitable number of studies were started to publish for the bibliometric analysis tools to properly yield results. Below the timeline, the most co-cited publications are located in color with reference to the clusters. These publications indicate that they are the most influential studies in the shown years and they are sorted based on their co-citation numbers. The dotted lines that stretch to both sides of the boxes represent the beginning and the end of the publication dates concerning each of the clusters. Also, the vertically oriented rectangles illustrate the average publication year per cluster.

Finally, two more layers were inserted since the collected data was found insufficient in terms of presenting a clear picture of the tendencies from the beginning. So, as presented in the previous chapters, the analyses of existing theses on the topic were placed below the journal publication in two contexts. First, the thesis framed with the gray box on top illustrates the related thesis published in Turkey collected from Thesis Center of Council of Higher Education. Second, the analyses of the theses collected from ProQuest's databases were placed in a light gray frame beneath the theses published in Turkey. Thus, they both are also color-coded according to the co-citation analysis.

TIMELINE

SUSTAINABILITY IN ARCHITECTURAL *EDUCATION*



4.4 Summary

A detailed discussion of the timeline methodology and the bibliometric analysis and information visualization tools employed to construct the timeline was provided in this chapter. The chapter introduced the databases used in the data collection processes and the number of the papers published in credible indexes. The results derived from analytical analysis were also shared for both SUS-ARCH, and SUS-ARCH-EDU. Finally, the chapter finalized with the two different timelines of the research topics to present the outcome of the timeline methodology.

5 DISCUSSION AND CONCLUSION

The thesis embarked on developing a methodology for creating a timeline of a research field based on bibliometric methods. The overall aim is to present a non-representational visual expression that enables readers to generate knowledge and discuss the status quo of a research field. As the primary source of information originates from the bibliometric analysis of a research area, numerous complex network visualizations needed to be unified into a timeline in a short time.

The thesis carried out a case study to illustrate the use of this methodology. It intends to provide a general understanding of the evolution of sustainability in architecture in pursuit of its interaction with architectural education. This section explains how research fields relate to one another by analyzing the timeline and comparing the key trends. The timeline's chronological structure paves the way for many different interpretations. The growth rate of data inputs means that timelines cannot predict outcomes. Yet, the study's multilayer structure and retrospective background generate speculative discussions within a historical context. Based on the period covered by this study, timelines may provide insight for future research in the case study field.

5.1 General remarks on the research field

This study's literature review on sustainability and sustainability in architecture revealed that the sustainability paradigm has evolved continuously since its emergence.

This study argued that the predominant paradigm of sustainability is classificatory in a way to diversify the conceptualizations of sustainability in the field of sustainable architecture. Thus, a more comprehensive understanding of sustainability is required to resolve the complex set of relationships as a result of the holistic sense of nature. Apart from the multiple meanings and understandings of the concept, it is referred to as the mechanistic worldview that aims to reach a level of efficiency in consumption. Mechanistic worldview has gained significant attention to reach a point where the overall aim is to harm the nature as less as possible.

During the last decade, there has been another call for shifting the paradigm that advocates changing the underlying worldview. The transition from a mechanistic worldview to an ecological one is deemed essential by recent precursor research. As a result, this sustainability paradigm shift demands an entirely new conception of reality and life.

Architectural education has been incorporating the concept of sustainability for many years. Consequently, the sustainability field has been incorporated into many formal and non-formal learning environments. But the question is how these learning environments and architectural education have adapted to the dynamic nature of sustainability. As discussed in Chapter 3, architectural sustainability has acquired multiple meanings and objectives through the years in both research and professional practice. Sustainability gains multiple meanings in architecture with the help of new research findings. As the knowledge of sustainability and sustainability in architecture grows, its integration into architecture education becomes more and more challenging. It is likely that the foundational and structural differences between the fields of research and education account for the difficulty of integrating knowledge into education.

In higher education, the burden of bureaucracy has outpaced the speed of the information network. Consequently, curriculums have become very rigid to the point where changes are hard to implement. In this era, most architectural design processes require knowledge from multiple disciplines thus interdisciplinary interactions and collaborative learning environments are vital for the education of architects. The existing curricula and learning environments of most architectural schools are unable to merge and melt that disciplinary knowledge. Yet, such a discussion on the reasons causing these difficulties is beyond the scope of this thesis.

5.2 Reading the timelines

This part analyzes the timelines to generate discussions about the past, present, and possibly the future of sustainability in the research fields of sustainability in architecture and architectural education. To do so, initially, the two timelines will be separately shared and discussed. This separation of timelines paves the way for comparing the two timelines not only contextually but also the differences in their applicability, and quality. In the second phase, upon these discussions, a comparative analysis will be presented to reveal the status quo of integration of sustainability knowledge into architectural education. The chapter finalizes with a general discussion on the timeline methodology.

The independence of the timeline methodology from the subject clears the path for future research and development of the method. In Chapter 2, the thesis discussed how these timeline interpretations depend on the reader's perspective. Accordingly, the reader may reinterpret the timelines in this chapter, as they contain insights that are relatively subjective.

5.2.1 Sustainability in architecture

With the advancement in communication technologies and consequently globalization in the second half of the 20th century, concerns and awareness about anthropogenic global warming grew across the globe. Thus, the debates about this rising topic took a step forward in the international arena with the involvement of policymakers. After a few conventions and reports, in 1992, at Earth Summit in Rio de Janeiro, a comprehensive development plan called Agenda 21 was introduced and adopted by more than 178 countries. In 1997, following the first meeting of the *Conference of the Parties (COP 1)* in Berlin, the *Kyoto Protocol* was signed by all participants, becoming the first global treaty to reduce greenhouse gas emissions. According to the timeline, the Kyoto Protocol was a turning point for sustainability in architecture research since the following year, the co-occurrence of keywords increased drastically, indicating that academic research had focused on specific topics. Bibliometric data analysis shows that the first keywords that burst in the research field are public policy and building stock. The four-year analysis of co-cited keywords highlighted regulations, public, and research policies as hot research topics. The study also determined that under the roof of green buildings, research on building scale in this period centered on energy efficiency and environmental assessment. The timeline also exhibits the book entitled "Our Ecological Footprint: Reducing Impact on the Earth" by Mathis Wackernagel and William E. Rees was one of the most influential publications in the field of regenerative sustainability. Surprisingly, the average publication year of regenerative design also dates back to 1998. Next year, the publications related to building environmental assessment tools, are co-cited in the paper called The Relevance of Green Building Challenge: An Observer’s Perspective by Niklaus Kohler. In the following years, the citation bursts of keywords did not change in number until 2004, but from 2002 urban scale started to get attention specifically for urban management and sustainable urban planning.

After the burst of sustainable development in 2004, the first and largest emissions trading scheme in the world was launched as a major pillar of European Union climate policy. These regulations for EU countries seem to affect academic research thus such keywords as sustainable building, and natural ventilation start to burst alongside sustainable development. Moreover, in the next four years, performance, energy, Life Cycle Assessment (LCA), and LEED frequently occurred in bibliometric data. In 2008 green building, and in 2009 sustainable architecture keywords burst can be observed in the literature.

Research on sustainability at the building scale has continued to expand from 2010 to 2014 with the directive of Energy Performance of Buildings by the EU. The terms embodied energy and CO2 emission became more of an issue and most of the papers that are related to barriers and drivers of sustainability were highly cited. In contrast, the regenerative paradigm and land use gained importance as presented in the analysis of the co-cited keywords that may result from the UN Rio+20 where the member states adopted the outcome document "The Future We Want". Besides, durability and recycling of materials came into prominence.

The following four years are crucial for climate change actions and research in architectural sustainability since the political actions were highly influential and concentrated. Thus, 2015 was a landmark year for multilateralism and international policy shaping, with the adoption of several major agreements. From 2015 onwards, the approach towards sustainability in architecture drastically changed. The timeline illustrates that the focus of the researchers has shifted from building scale to urban scale based on the Sustainable Development Goals introduced at the Paris Conference in 2015. Contextually, SDGs cover a variety of headings that at first glance may seem unrelated to architecture, yet from a holistic perspective, each goal is relevant to sustainable development. Therefore, the timeline shows that urban sustainability, urban resilience, social sustainability, urban development, and urban form are keywords that burst between 2015 and 2017. In terms of research on building materials, concrete, thermal conductivity, and composite have gained importance. Also, co-citation analysis displays the influential publications related to life cycle analysis were mostly cited in these years, yet their average publication year dates back to 2005.

From 2017 to 2021, the overall tendency of academic literature towards urban scale continues to grow. Alongside the advancements in technology, the keywords; smart city, sustainable city, internet of things, and urban morphology start to burst concerning big data, on the other hand, urban sustainability, and urban resilience have lost favor. Surprisingly, the average publication year of the citations related to urban scale dates back to 2001. Besides, life cycle assessment, building information modeling, and energy retrofit are also among the co-cited keywords in these years. Furthermore, social housing, affordable housing, cultural heritage, and circular economy are some of the keywords that started their burst, yet they may continue to be the most researched topics among the researchers.

From a wider perspective, timeline indicates the following conclusions:

- There are three milestones for sustainability in architecture. First, the Kyoto protocol in 1997 has become the driving force for the increase in research. Policies related to public and research are the prevailing topics. Second, the Johannesburg

Declaration and EU regulations on emissions trading demonstrate a defining moment in the field, given the high number of publications and preferred research areas. The primary focus shifts from public policies to sustainable building technology. Third will be the Paris Conference in 2015 with the introduction of the SDGs. 2015 saw a big increase in the number of publications and outlets for research. As a result, the research shifts from the building scale to the urban scale.

- Public policy and governance have been the subject of extensive research from the late 1990s into the late 2000s. This focus may imply that the field aims at creating ground for governing the new policy decisions and guiding new research funding.
- Topics like urban resilience and sustainability are getting an increased focus in the field as of 2016s. Their main references run back to the early 1960s, specifically Jacobs (1961) and Lynch (1960).
- Another hot topic within the same research scale is smart cities integrated with big data analytics. In parallel to this topic, the study determined that big data analytics and the internet of things have mean years of 2017 and 2019, respectively.
- Contemporary research in material sciences focuses on reducing the environmental impact of building materials, exemplified by extensive research on concrete and recycled content.
- Parallel to the research on materials, research on the life cycle assessment/analysis has gained considerable attention.
- Even though the mean publication year of papers on BIM dates to 2011, citation bursts of the keyword start at 2017. The papers' keywords indicate increased attention is paid to BIM use mainly in building design processes guided with building environmental assessment tools.
- Over the last five years, the term ‘green building’ is seen to have decreased in frequency, while leaving its place to ‘sustainable building’.

5.2.2 Sustainability in architectural education

Through the review of the timeline of sustainability in architectural education, this study discusses how sustainability has found its place in architectural education. The number of publications on sustainability in architectural education is less than four before 2008, as shown in the figure below. It was impossible to embed bibliometric analyses of keywords until 2006 since they did not yield accurate results. Therefore, the four-year review of co-cited keywords illustrates the trending research topics related to the subject beginning from 2006. Sustainable development integration into architectural education was a hot research topic between 2006-2010. Since the beginning of 2014, however, the focus of researchers has shifted toward the integration of sustainability into design studios.

Figure 5-1: Number of publications according to their document types.

Alongside sustainability's integration to curriculum and studio practices, the research community focuses on the necessary skills for the digital design tools as of 2014. Building Information Modeling (BIM) appears to be a highly anticipated architectural education input. From the beginning, interdisciplinary collaboration in architectural design has been indicated as a must for attaining sustainability in the built environment. Gaining skills in interdisciplinary design processes is one of the notable qualifications of graduates must possess as indicated in the UIA-UNESCO Charter.

Besides the articles, the theses in the timeline indicate that the majority of studies conducted in Turkey proposed a model for integrating sustainability into the design studio or the architecture curriculum. On the other hand, theses that are published in the UK and USA focus on a variety of topics. These different approaches include architectural education relationship with professional practice, socio-cultural underpinnings of sustainability in architectural education and so on.

5.2.3 Reflecting on the timeline methodology

The study developed a methodology to create a readily available source to review a research field. The methodology presents an alternative approach to the conventional and time-consuming structure of scoping reviews. In an era of exponentially increasing academic production, keeping up with the pace of research is almost impossible, particularly for novice researchers and academics. The bibliometric data retrieved from the online sources are processed in the lights of bibliometric tools and through information visualization, a timeline is produced according to research interest. The integration of different layers into the timeline enables overlaying the existing networks in a research field. These layers are derived from bibliometric analysis, and literature reviews. However, the networks created through bibliometric analysis are far from readability in terms of visuality and content. So, it required the juxtaposition of these networks for the outcome to be expressive. The timeline illustrates the tendencies, trends, and pivotal points in a research field. The purpose of this study was to test and utilize this methodology with regards to a case study; sustainability in architecture and in architectural education. On the other hand, considering the scope of the timeline methodology, it contextually surpasses the general understanding of a modern timeline. So, the title of the end product is also up for debate for a more comprehensive denomination.

As reflected in the previous parts of this chapter, the outcomes of related research fields turned out quite different in terms of their ability to unroll the network. The primary reason behind this contrast is the amount of bibliometric data that this study was able to collect. The number of publications in each field affected the production of the timelines. For instance, the number of publications for sustainability in architectural education was around 600, and almost 350 of them turned out irrelevant based on the check of the publications' content. So, the study pursued approximately 250 papers that resulted pretty deficiently. For the field of education, the bibliometric analysis tools could not categorize the papers coherently to lay out a pattern of keywords illustrating the tendencies in the research field. Aside from the clusters presented for co-occurrence analysis, the bibliometric analysis tools ignored a wide range of research fields. As a result, the proposed methodology requires a large research field to be implemented. In this case, the scale in the research field indicates the bibliometric data that includes the number of publications, research outlets, and authors. It is evident that timeline methodology cannot present accurate conclusions if applied to a small research field in scale. Therefore, it will not be able to review the related research field. A scoping review, on the other hand, is recommended in research areas with few publications.

In summary, when a researcher analyses a field with the timeline methodology, the field must be advanced in a continuum. On the other hand, for newly arisen or unadvanced fields of studies, manually applied scoping reviews would provide conclusive results.

5.3 Further research on the timeline and its methodology

This study intends to further both the methodology and the timelines based on the conclusions derived from the case studies.

Digitalization has been gradually becoming inevitable as communication and information technologies develop. Today, almost all academic outputs are accessible online. A new visualization approach is utilized in this study to enable novice and experienced researchers to evaluate research fields by using digitally acquired bibliometric data. Thus, this study will present digital timelines as the next step. An interactive timeline can be created by using online tools, such as specific programs or websites. Thus, its users can interact with the information embedded in the timeline. For instance, if the user wants to reach one of the related publications on the timeline, it will be directed to its source database through online devices. Furthermore, it is also intended that this timeline will become a software that constantly regenerates itself via the implementation of live data.

The methodology for developing the timeline has numerous steps and branches. So, each step of the process utilizes different tools. In addition, the current bibliometric analysis tools can be considered a kind of prologue to this field which requires more development. Therefore, the study wonders if it is possible to integrate this multi-stepped methodology into a digital tool. By utilizing software to merge multiple steps that require different tools, the workload can be significantly reduced. Above all, it becomes available for end-users.

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