Investigating an Author's Influence Using Citation Analyses: Christopher Alexander (1964-2014)

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ABSTRACT
Citation analyses are used to investigate the influence of architect Christopher Alexander over the period of 1964-2014. Alexander's work has been so influential that he has been cited by nearly 2000 source items in the Web of Science Core Collection, by Thomson Reuters. Alexander's work has had a profound interdisciplinary reach. Citation analyses reveal that scholars in computing disciplines have cited Alexander's work more than scholars in any other discipline including architecture. Alexander's most cited work, *A Pattern Language,* is one of two volumes that Alexander refers to as an *indivisible whole*. These analyses reveal very different citation patterns for the two volumes of this *indivisible whole*. Although the difference is measurable, in terms of number of citations, we cannot say why this is so. However, the results of these analyses raise several questions including why we, as a community, have for the most part cited only a piece of this *indivisible whole*. The citation patterns support that this series has been largely reduced to one of its parts, when possibly the whole is greater than the sum of its parts or one of its parts. In this paper I propose that we might begin to see the potential benefits of pattern languages in computing disciplines when we take holistic approach, considering and applying the theory as described in all of the volumes in the series.

Keywords
Human-computer interaction, scientometrics & scholarly communication.

INTRODUCTION
Christopher Alexander is a Professor Emeritus of Architecture at the University of California, Berkeley. He has published hundreds of books, articles and essays on topics in architecture, design and mathematics. Alexander has designed many houses, buildings, and communities, and created several works of art. Alexander's work has been focused mainly in the disciplines of mathematics and architecture, yet his work has influenced scholars and practitioners in many other disciplines including computer science, psychology, business, and economics.

The impact of an author's work or an architect's work may be measured in many ways including honors and awards, positions, h-index, altmetrics and citation analyses to name a few. The focus of a citation analysis may be among other things a discipline, a topic, a journal, or as in this case, an author. The influence of Alexander's body of work (1964-2014) and several individual works by Alexander are examined here using citation analyses. The data used in the analyses were retrieved from Web of Science Core Collection, by Thomson Reuters. From this point forward, for brevity, the Web of Science Core Collection by Thomson Reuters will be referred to as Web of Science. Web of Science was selected as the data source due to the breadth and quality of indexed materials. There are nearly 2000 source items that have cited Alexander's work over 2500 times in the Web of Science during the period of 1964-2014. More than 60 of Alexander's works appear as cited references in Web of Science.

Alexander's work has influenced the field of architecture, starting grass-roots movements and also raising questions about the theory and process of design. Surprisingly to some, and not surprisingly to others, most of the citations to Alexander's work come from disciplines other than architecture. Overall Alexander's work has received more citations from computer science than any other subject area or subject category, including architecture (as categorized by the Web of Science).

In the 1990s Alexander's work began to influence scholars and practitioners in computing disciplines. Alexander's work started the pattern movements in software engineering and human computer interaction. Most of the work in these disciplines has involved the capturing and sharing of patterns, pattern libraries, and pattern languages. Much of the literature in the computing disciplines has focused on the benefits of patterns, yet there is little empirical evidence to support the proposed benefits (Dearden & Finlay, 2006). There has also been a lack of focus on the process of design, the process of documenting patterns and pattern languages, and a lack of focus on the quality of the patterns

ASIST 2015, November 6-10, 2015, St. Louis, MO, USA.

(Wania & Atwood, 2009). We as a community must ask why this is so. Why have we focused so much on the patterns described in *A Pattern Language* and not as much on the design process and theory as described in *The Timeless Way of Building* and Alexander's other works? A brief and condensed review of Alexander's work is provided in the following section. This review is not meant to be comprehensive or exhaustive.

CHRISTOPHER ALEXANDER

Christopher Alexander is a Professor Emeritus of Architecture at the University of California, Berkeley. He has published hundreds of books, articles and essays on topics in architecture, design and mathematics. Alexander graduated from Harvard University with a Ph.D. in architecture and in 1964 published his first book titled *Notes on the Synthesis of Form* (Alexander, 1964). In this book Alexander (1964) introduces the concepts of pattern-like structures and goodness of fit. These concepts evolve in Alexander's later works into the concepts of a pattern language and the quality without a name.

In 1965 Alexander published *A City is Not a Tree*. In this work Alexander (1965) argued that natural cities, cities that remain alive are semilattice structures not (abstract) tree structures. *A City is Not a Tree* was subsequently published in several variations in different sources. Throughout the 1960s Alexander continued to design buildings and communities while also publishing several other works. In the 1970s Alexander published several works and designed several projects. Most notably, beginning in 1975 Alexander published a series of three volumes: *The Timeless Way of Building*, *A Pattern Language*, and *The Oregon Experiment* (Alexander et al., 1977; Alexander, 1979; Alexander, Silverstein, Angel, & Abrams, 1975).

The Timeless Way of Building describes a theory and a process of building, in addition to the characteristics of the products of this building process (Alexander, 1979). Alexander (1979) describes the timeless way of building as "a process which brings order out of nothing but ourselves; it cannot be attained, but it will happen of its own accord, if we only let it" (p. ix). In this book Alexander (1979) describes what he refers to as the quality without a name, "*There is a central quality which is the root criterion of life and spirit in a man, a town, a building, or a wilderness. This quality is objective and precise, but it cannot be named"* [italics in original] (p. ix). Alexander (1979) suggests that this quality, that makes places and the people in them feel alive and whole, is a result of the process of building, the timeless way of building.

The second book in the series, *A Pattern Language*, contains 253 patterns that can be combined, using the process described in *The Timeless Way of Building*, to design buildings and towns that are alive, whole, and contain the quality without a name (Alexander et al., 1977). According to Alexander (1977) each pattern describes:

> "a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice" (p. x).

Each of Alexander's patterns contains the following elements: a name, a number, a picture, an introductory paragraph (sets the context and explains how the pattern helps complete larger patterns), three diamonds (beginning of the problem), headline (the essence of the problem), body of the problem, a solution, a diagram, three diamonds, and references to smaller patterns that are needed to complete a pattern. The intention of a pattern language, according to Alexander, (1977) was to capture the heart of solutions to recurring design problems in architecture and provide a process and a language that architects and non-architects could use to communicate. In the third volume in the series, *The Oregon Experiment*, Alexander provides an overview of the master plan he and his colleagues designed for the University of Oregon (1975). Alexander describes that this book is an experiment in the sense that they used the approach described in *The Timeless Way of Building* and the patterns in *A Pattern Language* to design a master plan for the University of Oregon.

In the preface of *A Pattern Language*, Alexander (1977) describes the close relationship between volumes 1 and 2 in detail. Alexander (1977) explains:

> "Volume 1, *The Timeless Way of Building*, and Volume 2, *A Pattern Language*, are two halves of a single work. This book provides a language, for building and planning; the other book provides the theory and instructions for the use of the language" [italics in original] (p. ix).

It is clear that Alexander (1977) viewed the series as a whole as he explains, "We have been forced by practical considerations, to publish these two books under separate covers; but in fact, they form an indivisible whole" (p. ix). He continues, "It is possible to read them separately. But to gain the insight which we have tried to communicate in them, it is essential that you read them both" (Alexander et al., 1977, p. ix). Together these three volumes (and several other volumes in the series, discussed further later) propose a new way of building, a new way of designing. For further discussion see the three volumes (Alexander et al., 1977; Alexander, 1979; Alexander et al., 1975).

In the 1980s Alexander continued to publish works that built on the ideas in the three volume series published in the late 1970s. *A New Theory of Urban Design* was published in 1985 (Alexander, Neis, Anninou, & King, 1985). In this book Alexander outlines an entirely new but at the time incomplete, theory of design based on their work and experience at the University of Oregon (1985). Here Alexander (1985) contrasts old cities that feel alive and whole, with the modern cities we see today that do not, and suggests, "it is the *process* above all which is responsible

for wholeness" [italics in original]. This book describes that process and a new theory. Alexander (1985) argues that the communities themselves created the old cities that are alive, whole and organic, by examining their needs and solving their problems together.

During the 1990s Alexander continued his writing and design work, designing several houses, communities, the well-known Mary Rose Museum, and more (Alexander; Alexander, Black, & Tsutsui, 1995). In 2002 Alexander published the first book in a new series of four volumes titled: *The Nature of Order: The Phenomenon of Life*, *The Nature of Order: The Process of Creating Life*, *The Nature of Order: A Vision of a Living World*, and *The Nature of Order: The Luminous Ground* (Alexander, 2002a; Alexander, 2002b; Alexander, 2004a; Alexander, 2004b). Much of this work built on many of his other previously published works. In *The Nature of Order* Alexander acknowledges that these volumes are volumes 9-12 in a series that continued from his first 3 volume series that began with *The Timeless Way of Building* (Alexander, 2002a; Alexander, 2002b; Alexander, 2004a; Alexander, 2004b). In volumes 9-12 Alexander explores the theory and nature of order and the processes that create order, as the title suggests. In these volumes Alexander explores ideas that are still related to architecture, but he also begins to explore ideas that in some ways push beyond the boundaries of architecture. Although some might argue Alexander had already pushed the boundaries of the discipline in his earlier works (Dovey, 1990).

Alexander's work has spanned several decades and influenced many disciplines. Patterns and pattern languages have been documented in a variety of disciplines outside of architecture, including software engineering (Gamma, Helm, Johnson, & Vlissides, 1995), e-business (IBM Patterns for e-business), pedagogy (Fincher, 1999), and human computer interaction (Dearden, Finlay, Allgar, & McManus, 2002; Dearden & Finlay, 2006). Over time there have been debates about Alexander's philosophy of architecture and some critics of his work (Dovey, 1990; Protzen, 1978). Nevertheless it is difficult to ignore the profound impact his work has had on several disciplines, especially the computing disciplines. The following sections are intended to highlight some of the work in computing related disciplines that has been influenced by Alexander's work, specifically in software engineering and human computer interaction.

PATTERNS IN SOFTWARE ENGINEERING

In the early 1990s the software engineering community began using software patterns to support the re-use of quality software components. Patterns in software engineering follow a format that is somewhat similar to Alexander's patterns. One of the most well-known examples, if not the most well-known example, of the use of patterns in the software engineering community is *Design Patterns: Elements of Reusable Object-Oriented Software* by Gamma, Helm, Johnson, & Vlissides (1995). This book is commonly referred to as the Gang of Four book. In the 1990s Gabriel also published a set of articles in *The Journal of Object-Oriented Programming*. This collection of articles was later published as a book titled *Patterns of Software: Tales from the Software Community* (Gabriel, 1996). Today there are websites, books, and even entire conferences dedicated patterns in computing disciplines. In 2015 the well-attended Pattern Languages of Programs Conference will be held for the twenty-second time.

The focus in software engineering, for the most part, has been on documenting software patterns in order to promote reuse (Coplien, 1999; Gamma et al., 1995). Many would agree that this approach ignores the participatory aspects of Alexander's process of design and the language aspect of a pattern *language* (Dearden et al., 2002). This approach also overlooks the theories and experiences described in Alexander's later publications (Gabriel, 1996).

PATTERN LANGUAGES IN HUMAN-COMPUTER INTERACTION

Throughout the past few decades, there has also been a growing interest in patterns and pattern languages in Human Computer Interaction (HCI). This is reflected in the number of workshops, panels, books, websites, papers, and pattern libraries we see today (Saponas, Prabaker, Abowd, & Landay, 2006; Tidwell; Tidwell, 2006; van Duyne, Landay, & Hong, 2003; van Welie; Wania & Atwood, 2009; Yahoo!). Fincher et al. (2003) point out that there have been at least two motivations for exploring patterns and pattern languages in HCI:

> "It is relatively easy to make an analogy between the domains of architecture and UI design, based on concern for the effect of a constructed artifact on personal and social behaviours. Alexander's patterns (the 'first encounter' with patterns for most) 'make sense' to designers. They are also written compellingly and elegantly." (p. 1).

Erickson (2000) points to the two most often cited reasons for the use of pattern languages: reuse and quality. In architecture and HCI, and likely every other design discipline, we strive to design quality artifacts that people will use and enjoy, without having to reinvent the wheel each time. The participatory processes of design in HCI and in architecture, as described by Alexander, also share many similarities.

Although there is no agreed upon definition of a pattern or a pattern language in HCI, there are common characteristics found in various definitions (Wania & Atwood, 2009). Patterns in HCI, as defined by van Duyne et al. (2003),

> "communicate insights into design problems, capturing the essence of the problems and their solutions in a compact form. They describe the problem in depth, the rationale for the solution, how to apply the solution, and some of the trade-offs in applying the solution." (p. 19).

A pattern language in HCI, as described by Mahemoff and Johnson (2001), "is formed when a collection of patterns is arranged into a network of interdependent patterns, especially where higher-level patterns yield contexts which are resolved by more detailed patterns." The concept of a pattern *language* is clear in Alexander's work, but not reflected in all of the work in HCI (Wania & Atwood, 2009) or in other disciplines.

Within the HCI literature much of the focus has been on the possible benefits or promises of pattern languages (Pemberton, 2000). There has also been quite a bit of discussion about the problems with using patterns including: lack of tool support, lack of a standard format, lack of an organizing principle, and the misunderstanding about the difference between a pattern and a pattern language (Borchers, 2000; Casaday, 1997; Todd, Kemp, & Phillips, 2004; van Welie & van der Veer, 2003). In addition, there has been little empirical work to support the claimed benefits. Dearden and Finlay (2006) describe this in their critical review. The small number of empirical studies that have been done suggest that patterns may provide some benefits (Chung et al., 2004; Saponas et al., 2006; Wania & Atwood, 2009), but more empirical work must be done in this area.

If we reflect back on Alexander's work to where the notion of a pattern language began and examine how we, as a community, have cited and applied his work we may uncover some interesting things about the influence of his work. The goal of this paper is to explore Alexander's influence using citation analyses.

CITATION ANALYSIS

Citation analysis is one of the many types of bibliometric analyses used to explore the relationships between scholarly literatures. Bibliometrics, according to White and McCain (1989), is the quantitative study of literatures as they are reflected in bibliographies. In scholarly literature the cited references are assumed to have some type of relationship with the citing article. Citation analysis is one of the many ways to examine the relationships between articles. For a discussion of the types of possible relationships see Kostoff (1998). For an overview of bibliometrics and the visualization of literature see (Borgman & Furner, 2002; White & McCain, 1997).

Numerous bibliometric analyses have been conducted and they reveal interesting things about the structure of scientific disciplines (McCain, 1991; Wania, Atwood, & McCain, 2006; White & McCain, 1998), paradigm shifts (Small, 2006), the influence of an individual's work (McCain, 2008), and more. One of Alexander's works, *A Pattern Language*, was the subject of a citation analysis published by Abraham in 2011. This analysis was limited to examining the citations to *A Pattern Language* from the disciplines of computer science and architecture during the period of 1972-2007 (Abraham, 2011).

Citation counts provide an overall view of an author's influence. Citations indicate an influence and impact at some level, but they are limited in that they do not reveal the nature or context of a citation. A citation context analysis (McCain & Salvucci, 2006; Meho & Yang, 2006) is another way to examine influence. Citation context analysis involves looking at the context surrounding a citation, by examining how a document is cited in the body of the citing documents. Examining the influence of Alexander's work using a citation context analysis is the subject of ongoing work by the author. It is important to recognize that citation analysis is *one* way to examine influence, not the only way. There are many other ways to examine influence, but these are not the focus of this paper. The methods used in these analyses are discussed in the following section.

METHODS

All articles citing anything by Alexander as first or co-author for the years 1964-2014 were retrieved from the Web of Science Core Collection, by Thomson Reuters in February 2015. Author disambiguation occurred at the time of retrieval by consulting Alexander's CV (Alexander, n.d.). For example source articles retrieved from Web of Science citing Carol Alexander as C. Alexander were removed by consulting Alexander's CV. Source documents were also retrieved and consulted when necessary. After reviewing source documents, two records were removed from the set because they referenced another C. Alexander, not Christopher Alexander. The remaining 1968 documents were used in the analyses described here. All cited references to Alexander's work were normalized with appropriate standard citation strings (in order to accurately attribute citations to a particular work).

In the Web of Science there are 5 broad areas that include 151 subject areas and 249 subject categories, as of February 2015. This categorization process warrants a brief explanation. Web of Science categorizes source titles (i.e. journal titles) into subject areas and subject categories. These will be referred to as subject areas and subject categories, respectively, from this point forward. A source title may be assigned to zero to six subject areas and zero to six subject categories. Items published in the respective source titles are assigned the subject areas and/or subject categories that were assigned to the source titles.

Citation analyses are used here to investigate the influence of Alexander's work. There are limitations inherent in citation analysis as described above. Additionally there are limitations in these analyses due to the fact that the data used were retrieved from Web of Science. This is only one source of citation data others could be examined. Please note: the citation counts reported here will vary from the citation counts in other citation databases such as Scopus and Google Scholar due to the indexing process and the scope/coverage of the collection of the source items indexed. For detailed discussions of the differences between

Web of Science, Scopus, and Google Scholar see (Bakkalbasi, Bauer, Glover, & Wang, 2006; Bar-Ilan, 2008; Kulkarni, Aziz, Shams, & Busse, 2009). Also, this analysis is merely taking into account citations, or citation counts over time, subject areas, and subject categories. There are several other analyses that could be conducted on a dataset such as this one, for example: algorithmic historiography or co-descriptor analysis, among other things. These analyses are outside of the scope of this paper, but are the subject of ongoing work by the author. Due to space limitations the figures, tables and discussions are also limited in this paper.

RESULTS AND DISCUSSION

Overall Alexander's body of work has been cited 2511 times in the Web of Science by 1968 source items during the time period of 1964-2014, as of February 2015. The 1968 source articles cite 62 of Alexander's works. The 1968 articles citing Alexander have collectively received over 30,000 citations in the Web of Science from approximately 24,000 articles over the period 1964-2014, providing over 30,000 second generation citations to Alexander's work. Please note: the number of citing articles is not the same as the number of citations due to the fact that one citing article may cite multiple works by an author. Only 27 of Alexander's works are included as source items in Web of Science as of February 2015. These 27 items are not included in the set of 1968 documents used in these analyses. These documents have been removed in order to remove Alexander's self-citations from these analyses.

The 1968 articles from Web of Science that cite Alexander's work are from 64 of the 151 Web of Science subject areas and 114 of the 249 Web of Science subject categories. These numbers indicate the broad, interdisciplinary impact of Alexander's work. The top ten subject areas and top ten subject categories, ranked by number of citing documents, are shown in tables 1 and 2 respectively. As shown in table 1, the documents categorized in the following subject areas contain the most citing documents (in descending order): Computer Science, Environmental Sciences & Ecology, and Architecture. As shown in table 2 the subject category containing the most citing documents is Environmental Studies, followed by Architecture. However, if we consider all the computing related subject categories including: Computer Science, Software Engineering, Computer Science, Information Systems, and Computer Science, Artificial Intelligence, they have together contributed more citations than the other subject categories. It is surprising to many, and was surprising to Alexander himself, when he was asked to appear at computing conferences, that his work has had such a profound influence on the computing disciplines (Alexander, 1999). This influence is clearly shown in tables 1 and 2.

Another way to examine this data is to look at the number of citing documents from different subject areas and subject categories over time. Looking at the citation trends over time may indicate when Alexander's work began to influence a particular area, as reflected in reference lists, and how his work has been cited over time in a particular subject area. Due to space constraints only the top 5 subject areas are shown here. As seen in figure 1 Alexander has received many citations from these five subject areas throughout the past 50 years. Citations from the top 5 subject areas are seen as far back as the 1960s.

Web of Science Subject Area	Number of Citing Documents
Computer Science	621
Environmental Sciences & Ecology	252
Architecture	184
Business & Economics	152
Engineering	106
Public Administration	96
Education & Educational Research	64
Psychology	56
Art	40
Geography	36

Table 1. Top ten subject areas

As seen here Alexander received more citations from subject areas such as environmental science & ecology and architecture prior to about 1989. Around 1989 we see that the citing documents from computing disciplines begin to outnumber the citing documents from other disciplines. In more recent years we see the number of citing documents from computing related disciplines is much greater than the other areas. Examining the trends over time broadly across areas and categories is interesting in that it illustrates the breadth of the influence and the changes in influence over time.

Web of Science Subject Category	Number of Citing Documents
Environmental Studies	193
Architecture	184
Computer Science, Software Engineering	158
Computer Science, Information Systems	147
Computer Science, Artificial Intelligence	110
Planning & Development	88
Management	82
Computer Science, Cybernetics	70
Computer Science, Interdisciplinary Applications	55
Education & Educational Research	52

Table 2. Top ten subject categories

Another way to assess influence is to examine citation patterns to individual works. The five works of Alexander's receiving the most citations are seen along with the associated citation counts in table 3. *A Pattern Language*,

Alexander's most cited work, has received more than twice the number of citations than *The Timeless Way of Building* received during the same time period of 1964-2014. The third volume in the series, *The Oregon Experiment*, does not appear in the top 5 list. *The Oregon Experiment* has only been cited 66 times during the period 1964-2014. *Notes on the Synthesis of Form* published in 1964 received the second highest number of citations. *A City is Not a Tree* is fourth on the list. It was first published in Architectural Forum in 1965 and was subsequently published in several variations. All versions were normalized into one citation. Alexander's most recent series contains four volumes. Each begins with the title *Nature of Order* (Alexander, 2002a; Alexander, 2002b; Alexander, 2004a; Alexander, 2004b). Due to the title (and therefore citation and indexing issues) and because these volumes were published recently, all four volumes have been normalized into one citation. If *The Nature of Order* series is excluded the next most cited work, receiving 67 citations, is *A New Theory of Urban Design*, published in 1985.

Another way to examine this data is to analyze how particular works are cited over time. While publication dates, and therefore the years accumulating citations may vary it is still interesting to see how different works have been cited over time. Figure 2 shows how the top 5 most cited works have been cited over the time period 1964-2014. Some of Alexander's works have had a greater influence than others, as measured by number of citations. Again, this is only one way, not the only way, to measure influence. *A Pattern Language*, which is Alexander's most cited work and continues to be on the best sellers list for architecture on Amazon.com, has received over 800 citations (in Web of Science). As seen in figure 2, *A Pattern Language* accounts for most of the citations to Alexander's works from approximately 1995 onward. Prior to 1995 most of the citations Alexander received are to *Notes on the Synthesis of Form*. In table 4 we see the broad influence of some of Alexander's individual works by examining the number of subject areas and subject categories from which Alexander's top 5 most cited works have received citations. Again we see the broad influence of Alexander's work across many subject areas and subject categories.

One way to analyze this data further is to look at how individual works have been cited by particular subject areas and subject categories over time. Due to space limitations only the top 3 most cited works and the top 5 subject areas are shown here. Figures 3-5 show how Alexander's 3 most cited works are cited by the top 5 respective subject areas over time. Those in computing related disciplines may understand the increase in the number of citations to *A Pattern Language* that begins at about 1995. As mentioned above The Gang of Four book titled *Design Patterns: Elements of Reusable Object- Oriented Software* was published in 1995 (Gamma et al., 1995). Gabriel's articles were published around this time also (1996). It is around 1995 when we begin to see citations to *A Pattern Language* outnumber citations to *Notes on the Synthesis of Form*. This trend continued from 1995 to 2014.

Work, Publication Date	Number of Citations
A Pattern Language, 1977	878
Notes on the Synthesis of Form, 1964	625
The Timeless Way of Building, 1979	326
A City is Not a Tree, 1965	163
The Nature of Order, 2002-2004 (four volumes)	89

Table 3. Most cited works in Web of Science

In figure 3 we see that *A Pattern Language* is cited most by documents in following subject areas (in descending order): Computer Science, Environmental Sciences & Ecology, Architecture, Education & Educational Research, and Engineering. Followed by (not shown) Public Administration, Business & Economics, Psychology, Art, and Construction & Building Technology. As mentioned above *A Pattern Language* has received over 800 citations. As shown in table 4, *A Pattern Language* was cited by papers in about a third of the 151 subject areas and about a third of the 249 subject categories, with most of the citations coming from several computing related disciplines. In figure 4 we see that *Notes on the Synthesis of Form* is cited most by documents in the subject areas of: Computer Science, Business & Economics, Engineering, Environmental Sciences & Ecology, and Architecture. Followed by (not shown) Education & Educational Research, Psychology, Public Administration, Art, and Government & Law. Figure 5 shows *The Timeless Way of Building* is cited most by same top 5 subject areas as *A Pattern Language*, but in different order: Computer Science, Architecture, Environmental Sciences & Ecology, Education & Educational Research, and Engineering. Followed by (not shown) Business & Economics, Public Administration, Art, Psychology, and Geography. While there are similar themes across each of these works, we see that the influence of each work, as measured by number of citations, has not been the same in subject areas over time. However, in the figures above Computer Science appears in the top 5 subject areas for all of Alexander's 3 most cited works. It is intriguing that an architect's work has influenced computing disciplines in such a significant way.

Work, Publication Date	Subject Areas (Total 151)	Subject Categories (Total 249)
A Pattern Language, 1977	49	84
Notes on the Synthesis of Form, 1964	31	69
The Timeless Way of Building, 1979	28	50
A City is Not a Tree, 1965	24	44
The Nature of Order, 2002-2004 (four volumes)	28	42

Table 4. Number of citing documents in subject areas and subject categories

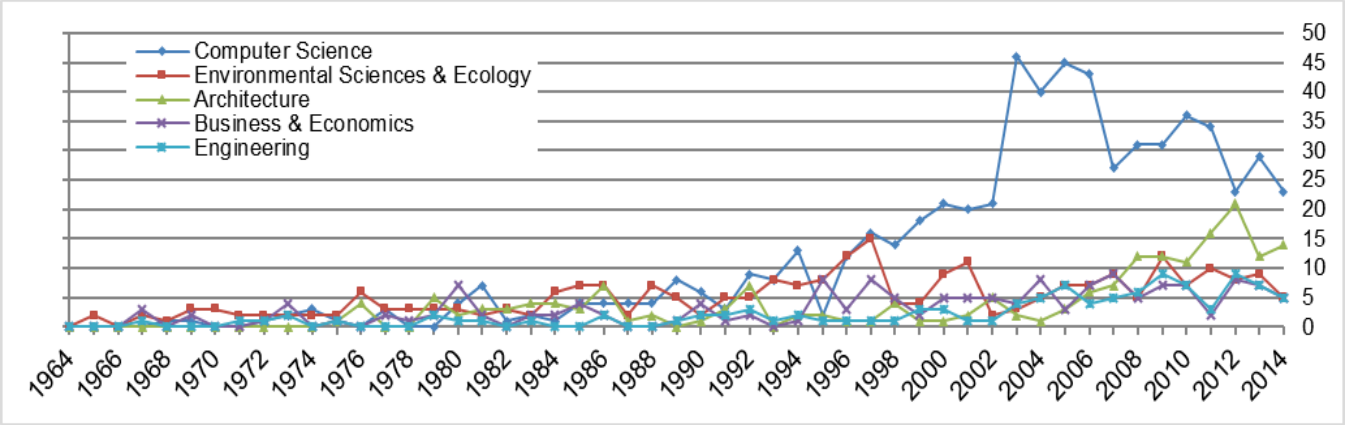

Figure 1. Top five subject areas (1964-2014)

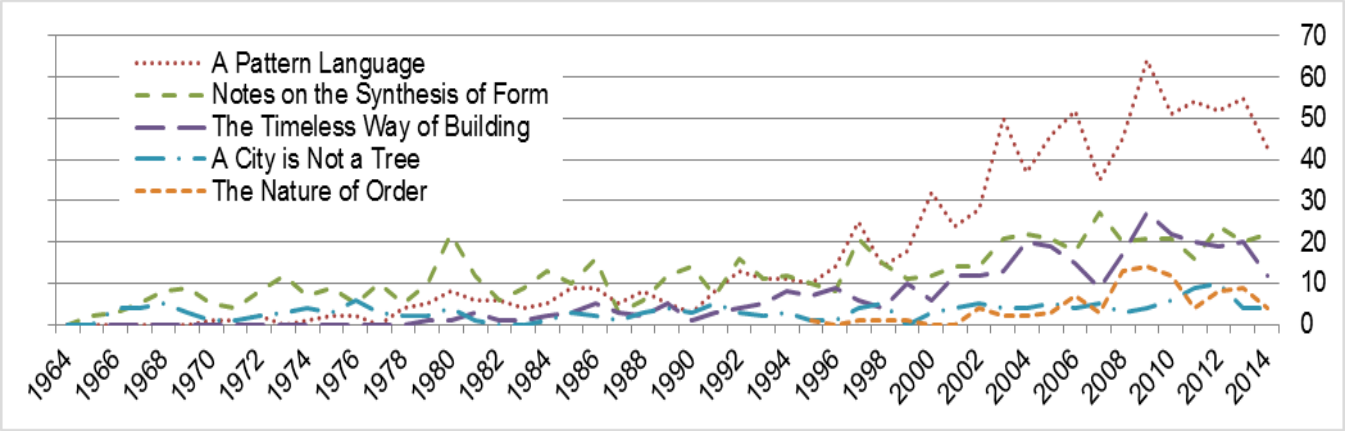

Figure 2. Citations to Alexander's top five most cited works (1964-2014)

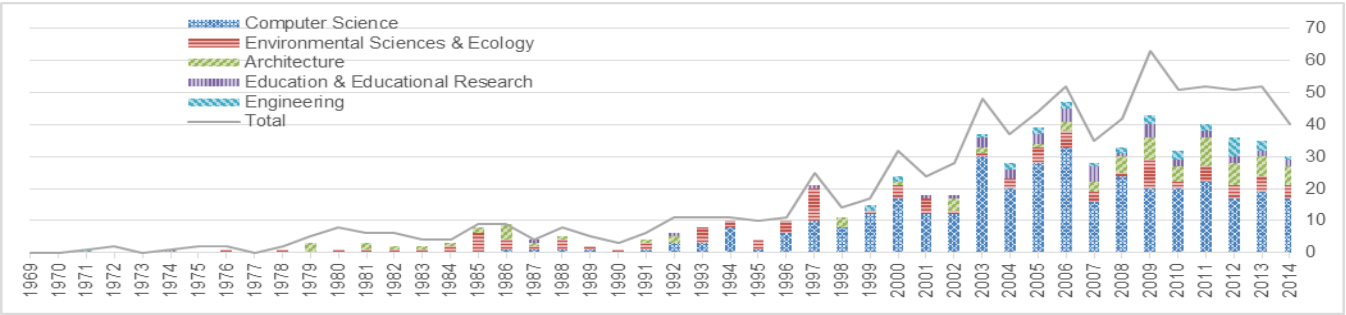

Figure 3. Citations to A Pattern Language

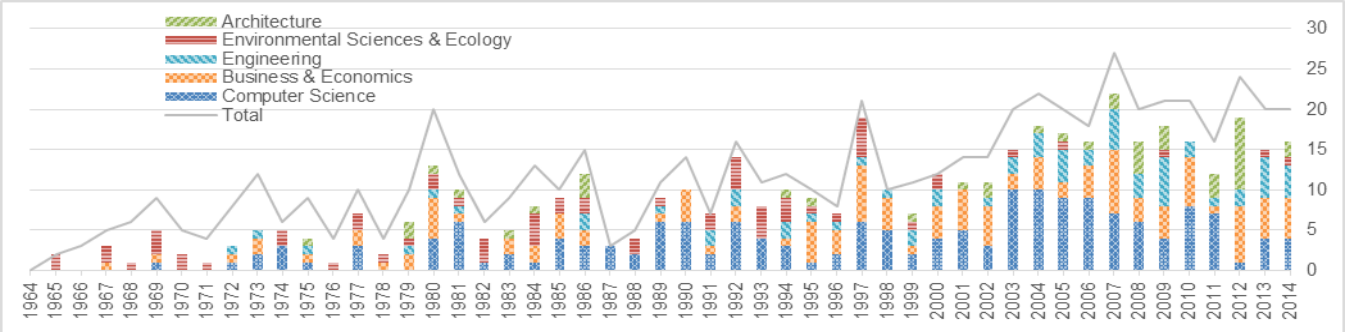

Figure 4. Citations to Notes on the Synthesis of Form

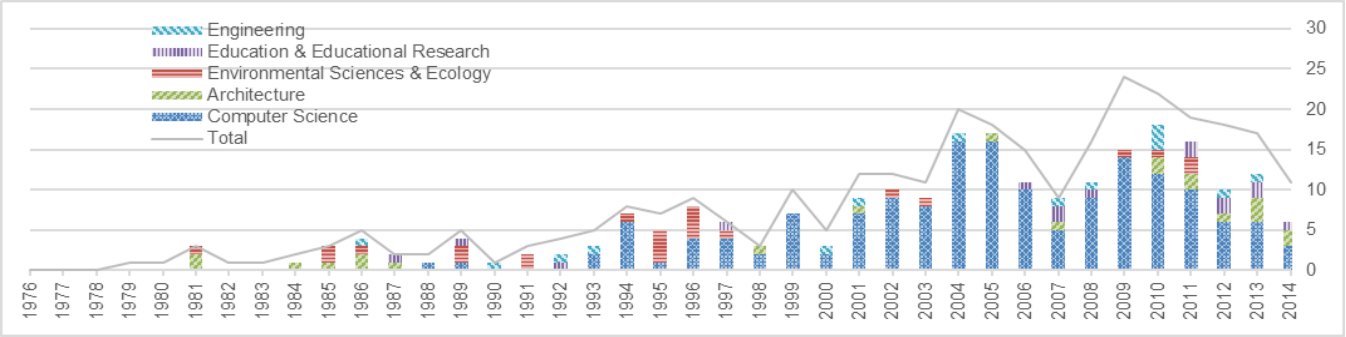

Figure 5. Citations to The Timeless Way of Building

As mentioned above, in the preface of *A Pattern Language*, Alexander describes the close relationship between volumes 1 and 2 in detail. Given that there is such a close connection between these volumes, or an intended connection as described by the authors, one might expect to see similar citation patterns for the three volumes over time. We see in figure 6 that this is not the case. Figure 6 shows the citations to each of the 3 books in this series over time. As discussed above, *A Pattern Language* has been cited much more than *The Timeless Way of Building* and *The Oregon Experiment*. In fact, volumes 1 and 3 have received less than half the number of citations *A Pattern Language* has received.

If we examine the data by taking the three volumes as a whole, in other words looking at the number of times all three volumes were cited by a source item, we see that only 23 of the almost 2000 source items cite all three volumes, as seen in figure 7. Fifteen of the 23 are documents in subject areas and subject categories in computing disciplines, 4 in architecture disciplines. If we limit this to the first two volumes, we see that only 160 source items cite volumes 1 and 2, out of almost 2000 documents. Although Alexander is very explicit about the relationship between volumes 1 and 2, and between volumes 1-3, we do not necessarily see this relationship reflected in the citations to these volumes. In fact we see very few items cite all three volumes. Less than 3% of the citations to these three volumes are to all three volumes. This may or may not be intentional, but it does raise questions about the interpretation of a piece or pieces of an *indivisible whole*.

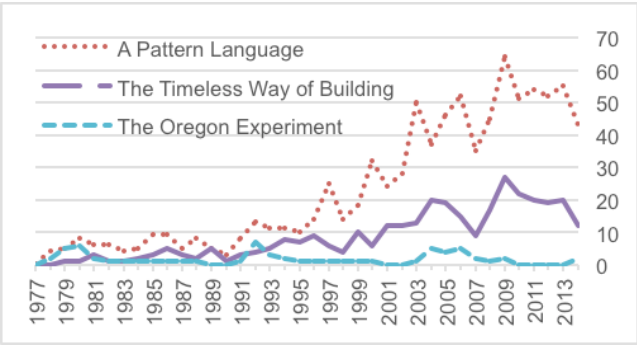

Figure 6. Citations to volumes 1-3 (1977-2014)

When Alexander addressed the audience at *The 1999 ACM Conference on Object-Oriented Programs, Systems, Languages and Applications (OOPSLA)* (Alexander, 1999) he too raised some questions about the interpretation and application of his theories in computing disciplines.

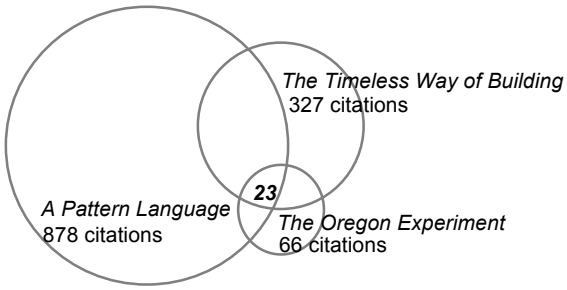

Figure 7. Source items citing volumes 1-3

Based on the results of these analyses it appears as though we in the computing disciplines have taken a reductionist approach instead of a holistic approach when interpreting and applying Alexander's work. In other words perhaps we have only adopted a piece of his theory, not his entire theory, as outlined in several volumes. The citation patterns shown here reflect this. The results of these analyses raise several questions about the influence of Alexander's work on the computing disciplines including:

- What did we take away from Alexander's theories and experiences and what did we leave behind?
- Why have we not followed the process that Alexander stressed is so important?
- Why did we as a community not take a holistic approach and use all of Alexander's theories?

The answers to these questions are not in this paper. These are questions that we must address as a community. Although some might argue that the answers to these questions may or may not matter, these are questions that we must ask, especially because of the profound influence Alexander's work has had on the computing disciplines. We must ask ourselves if we knew about the other works and if we did we must ask ourselves why we have not used the ideas and theories outlined in these works. It could possibly be that many believe the process, as described in *The Timeless Way of Building*, and an example, as

described in *The Oregon Experiment*, are not as important as the patterns. I am echoing Alexander's sentiment and suggesting that the process is more important or at least just as important as the patterns. I propose that one of the reasons we have not been able to realize the promises of pattern languages in HCI is because we have been too focused on patterns and not focused enough on the process. It appears as though the discipline that makes it possible to use the patterns, as described in *The Timeless Way of Building* has been in many ways overlooked. It appears as though many practitioners and scholars in fact divided the *indivisible whole*. As reflected in the citation patterns described in this paper it appears as though Alexander's later works in which he explains more about the theory, the process, the use of a pattern language, and lessons learned from his experiences have also possibly been overlooked.

CONCLUSION

Although Christopher Alexander is an architect, his work, as reflected in the citation analyses discussed herein, has had a broad interdisciplinary reach, influencing many disciplines outside of architecture and profoundly influencing the disciplines of software engineering and HCI. The documents that cite Alexander's work include documents from 64 of the 151 Web of Science subject areas and 114 of the 249 Web of Science subject categories. Overall, scholars in computing disciplines have cited Alexander's work more than scholars in architecture and its related disciplines. Citation analysis provides an important yet limited view into the influence of an author's work. The analyses described here provide an important view into the profound influence of Alexander's work, especially in the computing disciplines. These analyses suggest that we as a community need to ask some important questions about how we have interpreted and applied Alexander's work in the computing disciplines. It may be that we will only we begin to realize the benefits and promises of pattern languages when we view Alexander's work in a holistic way, acknowledging and applying his theories fully.

FUTURE WORK

As an extension of this work the author is conducting a longitudinal contextual citation analysis, also referred to as content-based citation analysis, or semantic content citation analysis, to examine how, in other words in what context, Alexander has been cited in computing and architecture related disciplines. This type of analysis might help us better understand how Alexander's work has been interpreted and how it is being applied.

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