Understanding design research: A bibliometric analysis of Design Studies (1996–2010)

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The purpose of this paper is to investigate the core themes of design research by analysing citations of papers in the journal Design Studies. It also aims to find out the evolution and future trends of design research.
Employing a bibliometrics and network analysis, the paper analyses citations and co-citations from Design Studies. Instead of using the standard analysis method of aggregating author co-citations, this study conducts the analysis at the individual publication level.
Due to the limitation of the Scopus database, this study only managed to extract articles with full citations in Design Studies from 1996 to 2010. Further studies could also include articles from 1979 to 1995 by either using some character recognition software or manually extracting them.
The study identifies the core themes centered on design process and design cognition. In addition, it also reveals that the research method protocol analysis has become more popular in recent years among researchers.
The main contribution of this paper is the use of a network analysis technique to analyse 12 107 citations in the 459 articles published in Design Studies between 1996 and 2010. Unlike previous review papers which relied heavily on the qualitative observations and reflections of the authors, this paper is the first comprehensive quantitative analysis in this field.

Keywords: bibliometric study, design research, science of design

Over the years, there have been several notable studies on design research. From the very beginning of design studies, design was defined not to be a specialised subject but a fundamental discipline (Archer, 1979). Along the way, many research topics revolving around design have been developed. According to Friedman (2003), design research consists of six general areas, namely natural sciences, humanities and liberal arts, social and behavioral sciences, human professions and services, creative and applied arts and technology and engineering. With recent advancements in technology, computational methods have also been used in design and are believed to be one of the important factors presently driving design research (Cross, 1999a, 1999b). In addition, topics like robust design, design optimisation

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and tool support continue to gain popularity (Liu & Boyle, 2009). Looking into the future of design development, Liu and Boyle (2009) predict eco-design, ergonomic design, cognitive design, requirements management, decision support and integration support to be the main research focuses.

Most of the studies described earlier adopted a qualitative approach to analyse the field of design. To the best of our knowledge, no researcher has adopted a quantitative approach to systematically review the field of design research. Although Cross (2000) has used citation counts of the top twenty papers published by Design Studies to identify research themes, the references he used were only from Design Studies. Hence, a more comprehensive quantitative analysis is useful to gain more insights into design research. Indeed, such quantitative analysis has been found to be useful in fields such as operations management (Pilkington & Fitzgerald, 2006; Pilkington & Meredith, 2009), strategic management (Nerur, Rasheed, & Natarajan, 2008; Ramos-Rodriguez & Ruiz-Navarro, 2004) and technology management (Pilkington & Teichert, 2006).

Following Pilkington and Chai (2008), this study uses a combination of bibliometrics, citation, co-citation and social network analysis techniques to analyse the field of design research. Bibliometrics is a common technique used for the quantitative analysis of literature. It is one of the few quantitative approaches that can provide an objective view by studying citations, co-citations or an integration of both. Glänzel (2003) highlighted the strengths of using bibliometrics in literature analysis. He argued that this methodology is a state-of-the-art methodology which comprises of components from mathematics, social sciences, natural sciences, engineering and even life sciences.

Citation analysis is based on the assumption that authors cite papers deemed to be important to the development of their research. This means heavily cited articles are more likely to have a greater influence on the subject than those that are less frequently cited (Culnan, 1987; Sharplin & Mabry, 1985). Although there are concerns that some papers might be heavily cited because they are used as a counter example in the research, overall, such instances are rare. By and large, citation analysis can provide valuable insights, especially if the source articles are carefully selected and a large sample of articles is used (Pilkington & Chai, 2008).

In addition to citation analysis, co-citation analysis analyses the frequency that two citations appear together in the same paper. This, as a result, helps determine the relationship between the different cited references. If two publications are often cited together, it shows they are very likely to share similar ideas. On the other hand, if a pair are rarely cited together, they are unlikely to be closely linked (Pilkington & Chai, 2008). By establishing such a corresponding co-occurrence matrix, the relationship and interaction of different

papers can be further examined and this helps us to understand the way in which these papers are related to each other. Also, from the clustering of papers that are closely linked, core themes can be identified.

On top of co-citation analysis, social network analysis can be carried out to further analyse the social relations among the core themes identified. Social network analysis is the study of associations among a group of actors where a field of study, phenomenon or data is to be interpreted (Borgatti, 1998). In a social network analysis, actors are connected to each other by a set of ties which denote the co-citation frequency. These relations and the strength of association can be visually presented in a social network diagram for easy and straightforward interpretation.

1 *Methodology*

For this study, the journal Design Studies has been chosen because it is the only comprehensive and interdisciplinary journal on design research, albeit with a focus on the process of designing (Cross, 2010). As indicated by its publisher, Elsevier, Design Studies is the only journal to approach the understanding of design from comparisons across all domains of application, including engineering and product design, architectural design and planning, computer artefacts and systems design. In recent years, as other design journals are emerging, Design Studies focuses more than ever, on the aims of the Design Research Society, i.e. on 'promoting the study of and research into the process of designing in all its many fields'. (Cross, 2010, p.1). The second reason for choosing Design Studies is that it is one of the oldest journals in this field which allows us to study the development of design research starting from its early days. Hence, we believe that Design Studies provides a representative view of design research.

The raw data used in this study is the contents of 83 issues of Design Studies from 1996 (Volume 17, Issue 1) to 2010 (Volume 31, Issue 5), i.e. papers published in Design Studies over a period of 15 years. These contents include information such as authors, article titles, article years, author affiliations and references (citation list). All these data were exported from the Scopus database. As Scopus only has data on Design Studies from 1996 onwards, the analysis is thus confined to the period of 1996–2010. In order to observe any trends and developments in research, the data is categorised into 3 time periods, namely Period I (1996–2000), Period II (2001–2005) and Period III (2006–2010). They are summarised in Table 1.

As shown in Table 1, there are 83 issues in total. They consist of 459 articles which contribute about 12 035 citations to this study.

Before the analysis could be done, some work was needed to clean the raw data. First, it was necessary to ensure that they were all in the standard format.

Table 1 Summary of data source from design studies

Period (1996–2010)	*Number of Issues*	*Number of Articles*	*Number of Citations*
I (1996–2000)	24	135	3319
II (2001–2005)	30	166	3508
III (2006–2010)	29	158	5280
Total	83	459	12107

There were many cases where the same data were presented in different formats. For example, the journal 'Environment and Planning B' appeared in some papers, but it was named 'Environment and Planning B: Planning and Design' in other papers. Hence, when it came time to analyse the most-cited journal, the frequency of this journal being cited was actually incorrect. We rectified this problem by sorting the journal list in alphabetical order and combining the counts of the same journal appearing with different names.

Second, spelling errors also created many erroneous entries. For example, "Donald Schön" had different forms like 'Donald Schon', 'Donald Sch??n', 'Donald Shon', etc. Again, sorting the frequency table alphabetically in Microsoft Excel was used to standardise the incorrect terms. The same degree of care was taken for other terms like 'publication year' and 'affiliation'.

Third, because there are 12 035 citations in total, it was very difficult to make sure all the article titles were in the standard format. Particularly for articles with very long titles, one small spelling error can cause the same article to have different titles. Due to the large number of citations and long titles, such errors could not be easily spotted by implementing the frequency table sorting approach mentioned above. In this study, we use 'author name_year_journal' to indicate each specific article. For example, the article 'Kinds of seeing and their functions in designing' which was authored by Donald Schön and published in 1992 in Design Studies is denoted as 'Schon & Wiggins, 1992, Design Studies'. Because of this, the standardisation of the article titles became relatively easy and accurate. This manipulation of the article title is based on the assumption that the same author does not publish more than one paper in the same year in the same journal. The assumption is valid because it is not common for researchers to publish more than one article in the same journal within one year. We later confirmed the validity of this assumption by doing some checking on the top ten most-cited articles.

The next section presents the results of the data analysis.

2 *Results*

Since this is the first quantitative study that examines Design Studies in detail, it might be useful to present the locations of the authors and find out the journal's influence among the international design research community. After that,

network analysis and co-citation analysis techniques are applied to gain some deeper insights into the core themes in Design Studies, the current developments and future trends of design research.

2.1 Countries of the authors' affiliations

According to Cross (2010), a large proportion of articles in Design Studies come from the UK and the USA. However, in recent years, the journal has had many downloads from Turkey, Taiwan, Netherlands, China and Australia, indicating that Design Studies has become more international. To examine its international influence, we grouped the countries of the authors' affiliations into seven groups and displayed the result in bar charts (Figure 1) with stacked columns.

From Figure 1, it can be seen that more than 50% of the articles published in Design Studies are from North America and the UK. However, the dominance of Anglo-Saxon authors fell from nearly 60% in Period I to about 50% in Period III. This decrease is largely because the percentage of authors from the UK and Ireland region decreased from 36.8% (Period I) to 23% (Period III). Interestingly, the number of articles from North America increased in Period III, perhaps reflecting Cross (2010)'s observation that there has been a change within the USA's design research culture and a wider recognition of the quality of Design Studies in the USA (Cross, 2010). Moreover, we also observed that the number of published papers from Asia, Oceania and Scandinavia has increased in terms of percentage over the three periods. The increasingly geographic spread shows that the authors of Design Studies are now more international, suggesting that the journal is more internationally recognised and design research is a growing field.

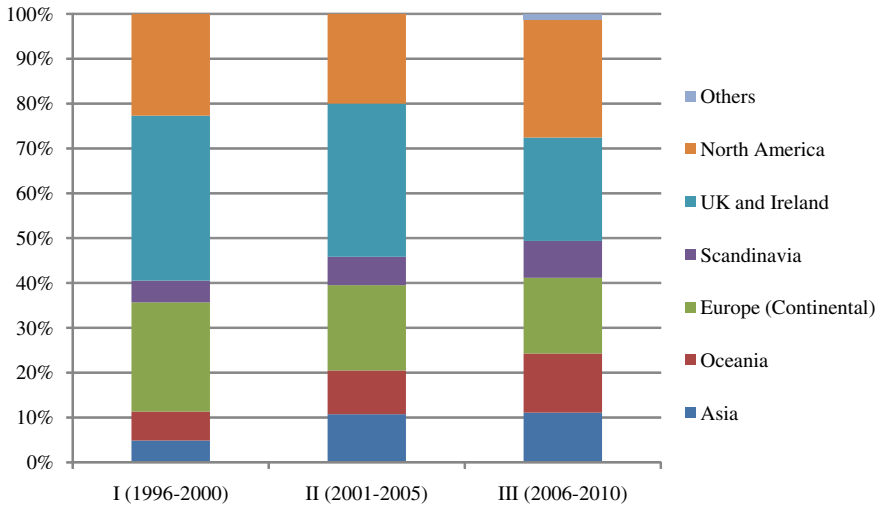

Figure 1 Country of the Authors' Affiliations

2.2 Co-authorship patterns

Next, we analysed co-authorship among the papers published in Design Studies as a way to understand the collaboration patterns among its authors.

The three tables (Table 2, Table 3 and Table 4) show the authorship pattern and the degree of international collaboration in the journal. The percentage of articles with only one single author decreased from 40.9% in Period I to 31.6% in Period III. That means more articles have been written by more than one author and more collaborations have taken place in the field of design research in recent years.

Taking the countries of the authors' affiliations into consideration, we can see that the number of articles with authors from more than two countries is 9 (or 7.3% of the articles published in that period), 12 (or 9.1%) and 20 (or 15%) in Period I, II and III respectively. This indicates that there is an increasing trend of international collaboration among the authors.

2.3 Most-cited journals

Table 5 shows the most-cited journals in Design Studies for each of the three periods as well as over the whole period from 1996 to 2010. The purpose of this analysis is to identify the main sources of ideas in Design Studies and determine which journal has the most influence in shaping the contents of Design Studies and the design research field. Moreover, we also present the percentage of the journals being cited in different periods. This allows us to observe the change of the cited journals' influence on Design Studies.

As observed from Table 5, Design Studies is the most-cited journal in all periods. Its percentage of citation frequency increased from 7.53% in Period I to 8.72% in Period II and to 9.30% in Period III. The percentage of other journals is about 1% or less of the total citations. This implies that design research has become a mature discipline that does not depend too much on journals from other fields. This observation contrasts sharply to the field of service research where Pilkington and Chai (2008) found the most-cited journals for the

Table 2 No. of international collaborations for the period I (1996–2000)

Period I				
No of authors in articles (X)	*No. of articles with X authors (%)*	*No. of different countries(Y)*		
		one	*two*	*three*
1	54 (40.9%)	53	1	0
2	45 (34.1%)	39	6	0
3	22 (16.7%)	21	1	0
4	7 (5.3%)	7	0	0
5	4 (3.0%)	3	1	0
Total	132 (100%)	123	9	0

Table 3 No. of international collaborations for the period II (2001–2005)

Period II				
No of authors in articles(X)	*No. of articles with X authors (%)*	*No. of different countries(Y)*		
		one	*two*	*three*
1	45 (31.3%)	45	0	0
2	50 (34.7%)	45	5	0
3	33 (22.9%)	28	4	1
4	11 (7.6%)	9	1	1
5	5 (3.5%)	5	0	0
Total	144 (100%)	132	10	2

International Journal of Service Industry Management were those from the marketing area. Nevertheless, we cannot ignore the fact that citations from Design Studies are less than 10%. If we sum up all the percentages of the journals from the top list in each period, this percentage is about 15%. This suggests that the influence of Design Studies on itself is not very strong; it still takes ideas from journals in different fields. Considering that the primary focus of Design Studies is to promote study and research in the process of design in all its many fields, this is not too surprising (Cross, 2010). The diversity of citation sources testifies to the comprehensiveness of Design Studies.

2.4 Core literature

Table 6 shows the references cited most frequently by papers in Design Studies. Based on Table 6, it can be seen that the core literature revolves around central themes such as design process and design cognition. The concept of design process is represented by the most frequently cited papers: Schön (1983) and Goldschmidt (1991). Schön (1983) described the importance of reflection during the process of design and Goldschmidt (1991) investigated the process of sketching in design. In addition, design cognition is an important theme that underlies Design Studies. For example, Goel (1995) introduced design problem solving as a domain of cognition. The research method of protocol analysis (Suwa & Tversky, 1997) is also highly cited in all three periods.

Table 4 No. of international collaborations for the period III (2006–2010)

Period III					
No. of authors in articles (X)	*No. of articles with X authors (%)*	*No. of different countries(Y)*			
		one	*two*	*three*	*four*
1	48 (31.6%)	47	1	0	0
2	46 (30.3%)	34	12	0	0
3	34 (22.4%)	31	3	0	0
4	18 (11.8%)	15	3	0	0
5	5 (3.3%)	5	0	0	0
6	1 (0.7%)	0	0	0	1
Total	152 (100%)	132	19	0	1

Table 5 Top 22 most-cited journals in design studies

Overall	*Freq*	*%*	*Period I*	*Freq*	*%*	*Period II*	*Freq*	*%*	*Period III*	*Freq*	*%*
All References	*12107*	*100*	*All References*	*3319*	*100*	*All References*	*3508*	*100*	*All References*	*5280*	*100*
Design Studies	1047	8.65	Design Studies	250	7.53	Design Studies	306	8.72	Design Studies	491	9.30
Environment and Planning B: Planning and Design	91	0.75	Environment and Planning B: Planning and Design	41	1.24	Research in Engineering Design	34	0.97	Design Issues	55	1.04
Research in Engineering Design	72	0.59	Journal of Engineering Design	19	0.57	Environment and Planning B: Planning and Design	25	0.71	Journal of Product Innovation Management	40	0.76
Design Issues	67	0.55	Cognitive Science	18	0.54	AI Magazine	15	0.43	Automation in Construction	27	0.51
Cognitive Science	52	0.43	Psychological Review	17	0.51	Automation in Construction	15	0.43	Research in Engineering Design	23	0.44
Journal of Engineering Design	49	0.40	Management Science	16	0.48	Human−Computer Interaction	14	0.40	Creativity Research Journal	21	0.40
Automation in Construction	47	0.39	Cognitive Psychology	16	0.48	Artificial Intelligence	14	0.40	Cognitive Science	21	0.40
Journal of Product Innovation Management	42	0.35	Artificial Intelligence	15	0.45	Journal of Engineering Design	14	0.40	Environment and Planning B: Planning and Design	20	0.38
Psychological Review	40	0.33	Research in Engineering Design	15	0.45	Cognitive Science	13	0.37	International Journal of Human−Computer Studies	19	0.36
Creativity Research Journal	39	0.32	Memory and Cognition	14	0.42	Journal of Product Innovation Management	13	0.37	Psychological Review	17	0.32
Management Science	39	0.32	Computer-Aided Design	14	0.42	Ergonomics	13	0.37	Construction Management and Economics	16	0.30
Artificial Intelligence	37	0.31	Communications of the ACM	12	0.36	Computer-Aided Design	11	0.31	Management Science	16	0.30
Human−Computer Interaction	36	0.30	Creativity Research Journal	11	0.33	Engineering Design	11	0.31	Journal of Engineering Design	16	0.30
Journal of Mechanical Design	35	0.29	Journal of Mechanical Design	11	0.33	Design Management Journal	11	0.31	Human−Computer Interaction	14	0.27

(*continued on next page*)

Table 5 (*continued*)

Overall	*Freq*	*%*	*Period I*	*Freq*	*%*	*Period II*	*Freq*	*%*	*Period III*	*Freq*	*%*
All References	*12107*	*100*	*All References*	*3319*	*100*	*All References*	*3508*	*100*	*All References*	*5280*	*100*
AI Magazine	34	0.28	Engineering Design	9	0.27	Journal of Mechanical Design	10	0.29	Journal of Mechanical Design	14	0.27
Computer-Aided Design	34	0.28	Journal of Experimental Psychology: General	9	0.27	International Journal of Human–Computer Studies	9	0.26	Research Policy	12	0.23
Cognitive Psychology	31	0.26	International Journal of Man-Machine Studies	9	0.27	Design Issues	8	0.23	AI Magazine	12	0.23
International Journal of Human–Computer Studies	30	0.25	Interacting with Computers	9	0.27	International Journal of Industrial Ergonomics	8	0.23	Journal of Cleaner Production	12	0.23
Communications of the ACM	28	0.23	Journal of Architectural and Planning Research	8	0.24	Harvard Business Review	8	0.23	Journal of Marketing	11	0.21
Memory and Cognition	25	0.21	Knowledge-Based Systems	8	0.24	IEEE Expert	7	0.20	Int.l Journal of Technology & Design Education	11	0.21
Ergonomics	24	0.20	Human–Computer Interaction	8	0.24	Creativity Research Journal	7	0.20	CoDesign	10	0.19
Engineering Design	24	0.20	Organizational Behavior and Human Decision Processes	8	0.24	Cognitive Psychology	7	0.20	Journal of Engineering Education	10	0.19

Table 6 List of core literature

Literatures	*Frequency*			
	Overall	*I*	*II*	*III*
Schon, 1983, The Reflective Practitioner	51	11	16	24
Goel, 1995, Sketches of Thought	40	13	12	15
Schon & Wiggins, 1992, Design Studies	37	15	11	11
Cross et al., 1996, Analysing design activity	33	4	15	14
Goldschmidt, 1991, Creativity Research Journal	29	11	7	11
Suwa & Tversky, 1997, Design Studies	25	6	11	8
Akin, 1986, Psychology of architectural design	23	6	7	10
Bucciarelli, 1994, Designing Engineers	22	6	8	8
Lawson, 1994, Design in Mind	18	6	7	5
Purcell & Gero, 1998, Design Studies	17	5	6	6
Rowe, 1987, Design Thinking	16	5	7	4
Suwa, Purcell & Gero, 1998, Design Studies	16	3	6	7
Dorst & Cross, 2001, Design Studies	16	0	2	14
Dorst & Dijkhuis, 1995, Design Studies	15	6	4	5
Simon, 1973, Artificial Intelligence	15	4	6	5
Goldschmidt, 1994, Design Studies	15	7	4	4
Ericsson & Simon, 1993, Protocol analysis: verbal reports as data	14	0	6	8
Gero & Mc Neil, 1998, Design Studies	13	3	6	4
Newell & Simon, 1972, Human Problem Solving	13	4	5	4
Lévi-Strauss, 1962, La Pensée sauvage	12	12	0	0
Alexander, 1964, Notes on the Synthesis of Form	12	6	4	2
Pahl et al., 1984, Engineering Design	12	4	4	4
Cross, 1994, Engineering Design Methods	12	7	5	0
Stiny, 1980, Environment and Planning B	12	7	3	2
Cross, 1999, Design Studies	12	2	6	4
Cross & Clayburn Cross, 1995, Design Studies	12	5	2	5
Gero, 1990, AI Magazine	12	2	5	5
Ulrich & Eppinger, 1995, Product Design and Development	12	2	6	4
Roozenburg & Eekels, 1995, Product Design: Fundamentals and Methods	12	1	5	6
Fish & Scrivener, 1990, Leonardo	11	6	2	3
Rittel & Webber, 1973, Policy Sciences	11	5	2	4
Goel & Pirolli, 1992, Cognitive Science	11	1	4	6
Pahl & Beitz, 1988, Engineering Design: A Systematic Approach	11	7	3	1
Cross, 1982, Design Studies	11	3	2	6
McGown, Green & Rodgers, 1998, Design Studies	10	1	5	4
Darke, 1979, Design Studies	10	5	3	2
Finke, Ward & Smith, 1992, Creative cognition: theory	10	2	2	6
Casakin & Goldschmidt, 1999, Design Studies	10	0	4	6
Bucciarelli, 1988, Design Studies	10	6	1	3
Cross, 1984, Developments in design methodology	10	8	0	2
Tovey, 1997, Design Studies	10	5	3	2
Jansson & Smith, 1991, Design Studies	9	3	2	4
Coyne & Snodgrass, 1991, Design Studies	9	7	2	0

Figure 2 describes the change in the top cited 57 references from Period I to Period II and from Period II to Period III. Unlike Table 6, in Figure 2 the literature is sorted in order of increasing popularity from Period I to Period II. Hence, it can be seen that Cross, Christiaans & Dorst (1996) gained the most popularity from Period I to Period II, whereas Lévi-Strauss (1962) lost the most popularity. However, when it came to Period III, quite a few publications, including Cross, Christiaans & Dorst (1996), started to lose their popularity. There are also articles like Ericsson & Simon (1993), Schön (1983) and Dorst & Cross (2001) which continuously increase in popularity over the whole timeframe from 1996 to 2010.

This citation analysis provides some insights into the field of design research. The articles that are less cited over time (e.g. Stiny (1980), Pahl & Beitz (1988)), tend to be more technical papers and involve more mathematical methodologies. The articles gaining popularity are more related to the design process, cognition design and design methods.

2.5 Co-citation network analysis

With some understanding of Design Studies from its citations' sources, we now go further to analyse the frequency of these citations and find out if there

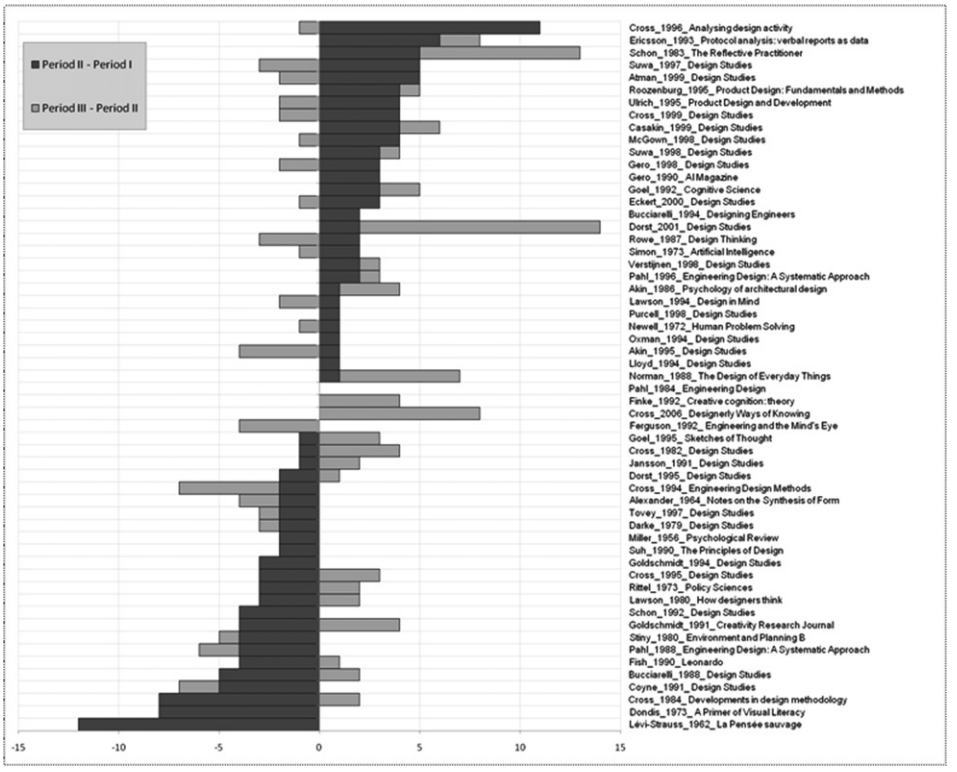

Figure 2 Change in citation frequency over the years

are any patterns among them. To do this, we analyse how often a set of articles are cited together. If a set of articles are co-cited very often, this indicates that these articles most likely share common ideas. These clusters of articles constitute what is termed a "structural knowledge group" (Pilkington & Meredith, 2009). These groups usually represent the central themes and intellectual structures of a field (Leydesdorff & Vaughan, 2006).

Articles that are cited less frequently might have less impact on the research of this field. Hence, for our analysis to be meaningful, this study only focused on articles that were cited at least 6 times overall and at least 3 times in one of the three periods. With this condition hold, there are about 107 such articles in Period I, 91 articles in Period II and 124 articles in Period III. In total, we used 322 articles for this co-citation analysis.

Bibexcel, a toolbox developed by Olle Persson, was used to conduct such a co-citation analysis. We used Bibexcel to tabulate the frequency of paired co-citations (Table 7). The frequency of each individual citation had already been tabulated and arranged in descending order (Table 6) in the previous section. Based on the data from these two tables (Table 6 and Table 7), network diagrams (Figure 3) were drawn using the software UCINET 6. In the diagrams, the size of the nodes indicates the frequency of articles being cited: the larger the size, the greater the frequency. The strength of the relationship between the cited articles (or nodes) is represented by the width of the line that connects the two articles. For example, in Figure 3, the line between Goel

Table 7 List of top co-citations in terms of frequency

Citation 1	*Citation 2*	*Freq of Co-citation*
Goel, 1995, Sketches of Thought	Schon & Wiggins, 1992, Design Studies	17
Goel, 1995, Sketches of Thought	Suwa, 1997, Design Studies	16
Goel, 1995, Sketches of Thought	Goldschmidt, 1991, Creativity Research Journal	15
Schon, 1983, The Reflective Practitioner	Schön & Wiggins, 1992, Design Studies	14
Goldschmidt, 1991, Creativity Research Journal	Schön & Wiggins, 1992, Design Studies	13
Goel, 1995, Sketches of Thought	Purcell & Gero, 1998, Design Studies	13
Goel, 1995, Sketches of Thought	Suwa et al., 1998, Design Studies	11
Goldschmidt, 1991, Creativity Research Journal	Suwa, 1997, Design Studies	11
Akin, 1986, Psychology of architectural design	Goel, 1995, Sketches of Thought	11
Cross et al., 1996, Analysing Design Activity	Schon, 1983, The Reflective Practitioner	11
Goel, 1995, Sketches of Thought	Goldschmidt, 1994, Design Studies	10
Cross et al., 1996, Analysing Design Activity	Goel, 1995, Sketches of Thought	10
Goel, 1995, Sketches of Thought	Schon, 1983, The Reflective Practitioner	10
Lawson, 1994, Design in mind	Schon, 1983, The Reflective Practitioner	10
Purcell & Gero, 1998, Design Studies	Schon & Wiggins, 1992, Design Studies	10
Schon & Wiggins, 1992, Design Studies	Suwa et al., 1998, Design Studies	10

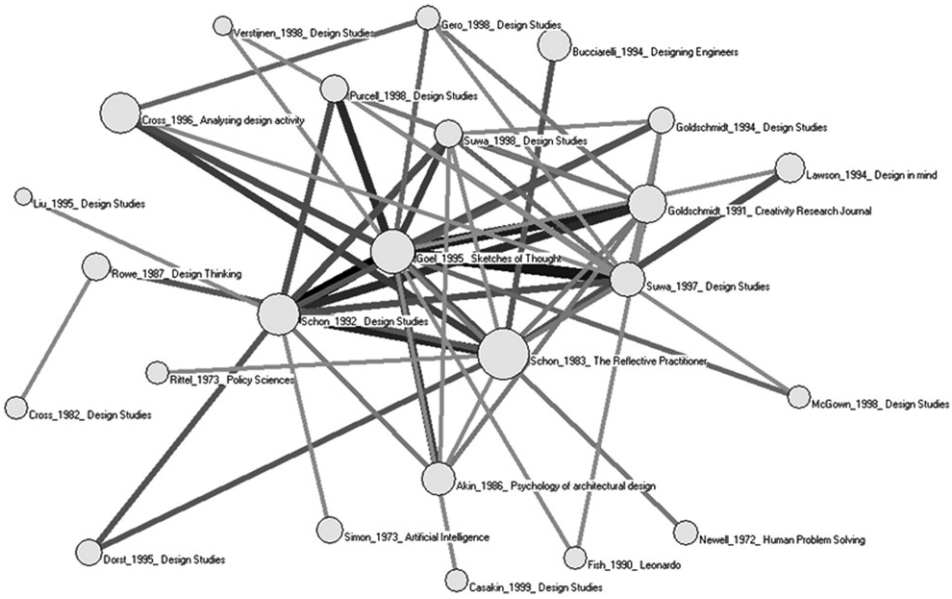

Figure 3 Network diagram of the core literature (1996–2010) in Design Studies

(1995) and Suwa & Tversky (1997) is very thick, indicating a strong co-citation relationship between the 2 articles (i.e. they are often cited together).

2.6 Evolution of the core literature

By using network analysis, not only can we determine the central themes in the field of design, we can also understand the interaction between these core topics and their evolution over the years. With the techniques described in the previous section, we use NCINET 6 to draw three different network diagrams (Figure 4, Figure 5 and Figure 6) for the three periods. In order to present the diagrams in a rather uncluttered manner (without too many nodes), only the co-citations with a frequency of more than two were included in the analysis. This was applied to all three respective diagrams to make sure that they are comparable.

As can be observed from the three diagrams, the central themes that we just identified, namely design process and design cognition, remain the most important research topics over the years. They are indicated by the large nodes (Schön (1983), Goel (1995), Goldschmidt (1991), etc.) in the three periods and, clearly, they are the top references in Tables 4-5 In relation to other nodes, these nodes appear to be very well connected with other nodes. The thickness of their connection also indicates that these articles have strong co-citation associations with other articles.

Furthermore, by comparing the three network diagrams side by side, some other interesting observations can be made. Although the top references

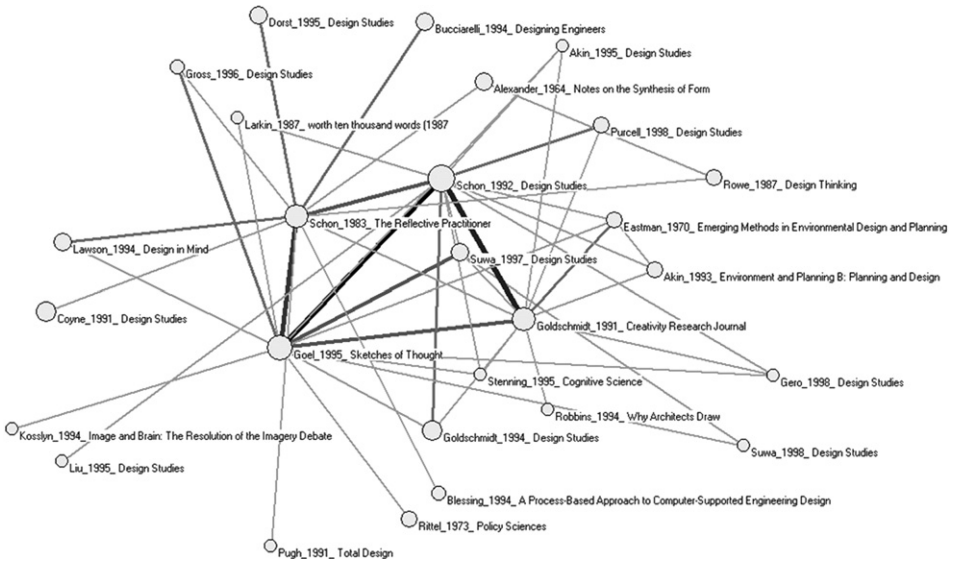

Figure 4 Network diagram for the period I (1996–2000) core literature

(Schön (1983), Goel (1995), Goldschmidt (1991), etc.) are strongly associated with other articles, their strength decreased from Period II to Period III (i.e. a decrease in the width of the lines). Other nodes like Suwa & Tversky (1997) and Dorst & Cross (2001) are becoming more strongly connected to other references. This indicates that protocol analysis has been co-cited more frequently in recent years and is starting to emerge as a popular research method.

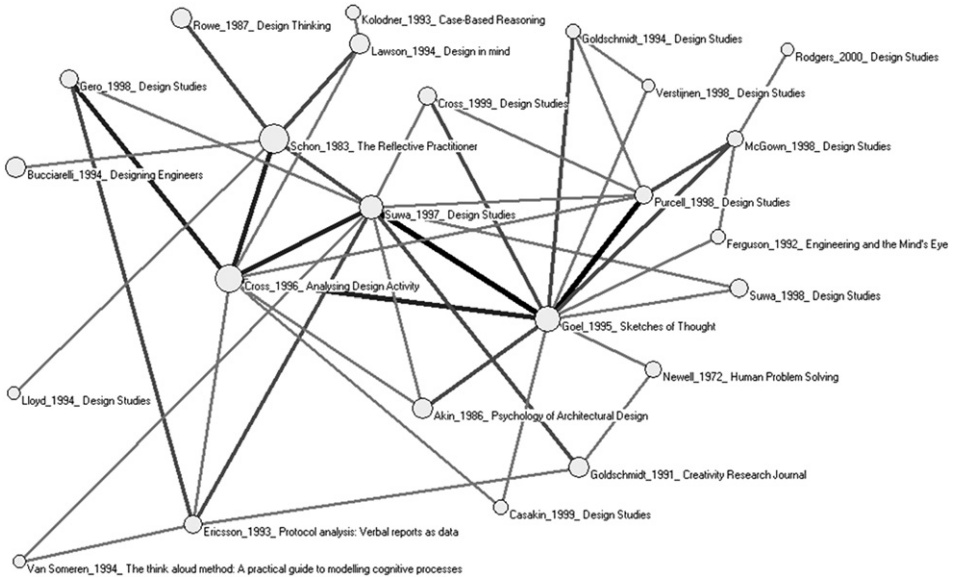

Figure 5 Network diagram for the period II (2001–2005) core literature

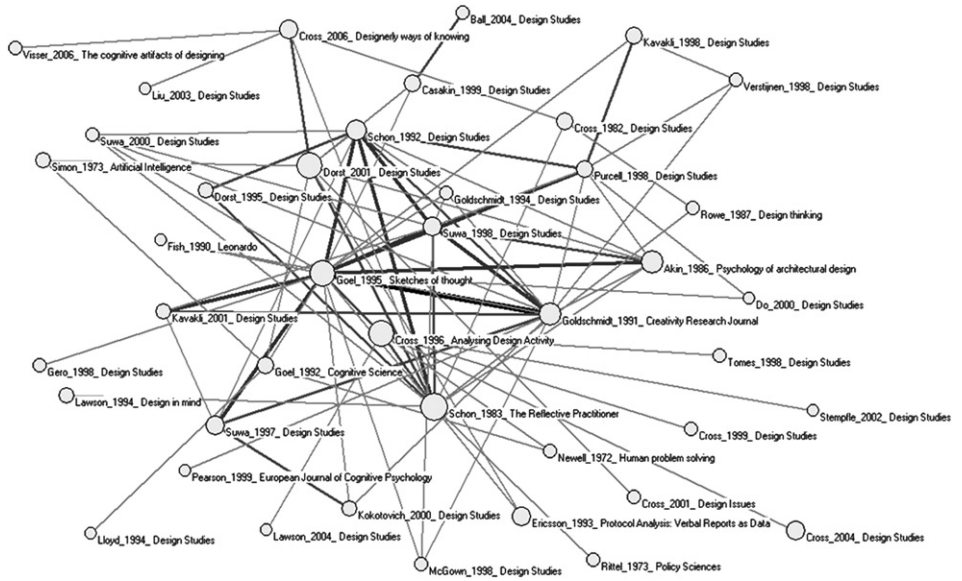

Figure 6 Network diagram for the period III (2006–2010) core literature

Another interesting observation is that the quantity of nodes in Period I and Period II are relatively few compared to Period III. Due to this, Figure 6 appears more cluttered than Figures 4 and 5. This suggests that other important studies are now being cited in Design Studies' papers. While Design Studies' primary focus has always been related to the aim of the Design Research Society: 'promoting the study of and research into the process of designing in all its many fields' (Cross, 2010), the field has possibly become richer over the years with references, books etc from new areas.

3 *Conclusion*

In total, this paper analysed 12 035 citations in the 459 articles published in Design Studies from 1996 to 2010 by using a novel network analysis. Unlike previous papers which used qualitative approaches to review design research in one certain aspect, this study has revealed some important findings that provide a comprehensive understanding of the design research area in a quantitative way.

Firstly, we ascertained that Design Studies has indeed become more international. Non-European countries have increased their article contribution to Design Studies from Period I to Period III. In addition, articles are increasingly co-authored by more than 2 authors of different nationalities compared to the past. The level of international collaboration in this journal has increased to about 15%.

Secondly, Design Studies was found to be the most-cited journal over the three periods. This shows that Design Studies is the main source of knowledge for design research. However, it is interesting to note that the percentage of Design Studies citations is actually less than 10 percent, suggesting that journals from other areas are also regularly referenced.

Thirdly, the paper combined bibliometrics analysis with network analysis to determine the core themes in Design Studies. The journal's core themes over the past 15 years have been identified as design process and design cognition. Other topics revolving around the two main research themes, such as the research method protocol analysis, is also show increasing importance. These were later confirmed as emerging topics in Design Studies by examining the evolution of the core literature in this journal.

Lastly, due to some constraints in this study, future improvements are recommended to address these limitations. The first limitation is that the accuracy of our findings depends on how and why authors cite references. Because of the background, writing skills, and other reasons, it is possible that references are cited for different reasons. As a result some of the references may not be truly 'popular'. That said, while our findings may be less valid on a micro or specific reference level, they are still valid at a macro level, i.e. identifying trends and major research areas in design research using empirical data. A second limitation is that this paper only analyses articles in Design Studies between 1996 and 2010. The understanding of the design revolution from the very old days to the present is not complete. Future study could include data from 1979 to 1995 when the data has become available Thirdly, our analysis of the locations of the authors could be extended to examine the geographical distance between co-authors. This information would be useful to describe the flow of knowledge and ideas through international collaboration in the area of design.

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