Profiling Two Decades of Intelligent Systems Research in the Construction Industry

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Abstract

With the increasing complexity of problems in the construction industry, researchers are investigating computationally rigorous intelligent systems with the aim of seeking intelligent solutions. The purpose of this paper is therefore to analyse the research published on 'intelligent systems in the construction industry' over the past two decades. This is achieved to observe and understand the historical trends and current patterns in the use of different types of intelligent systems and to exhibit potential directions of further research. Thus, to trace the applications of intelligent systems to research in the construction industry, a profiling approach is employed to analyse 514 publications extracted from the Scopus database. The prime value and uniqueness of this paper lies in analysing and compiling the existing published material by examining variables (such as yearly publications, geographic location of each publication, etc.). This has been achieved by synthesising existing publications using fourteen keywords[2] '*Intelligent Systems*', '*Artificial Intelligence*', '*Expert Systems*', '*Fuzzy Systems*', '*Genetic Algorithms*', '*Knowledge-Based Systems*', '*Neural Networks*', '*Context Aware Applications*', '*Embedded Systems*', '*Human-Machine Interface*', '*Sensing and Multiple Sensor Fusion*', '*Ubiquitous and Physical Computing*', '*Case-based Reasoning*' and '*Construction Industry*'. The prime contributions of this research are identified by associating *(a)* yearly publication and geographic location, *(b)* yearly publication and the type of intelligent systems employed/discussed, *(c)* geographic location and the type of research methods employed, and *(d)* geographic location and the types of intelligent systems employed. These contributions provide a comparison between the two decades and offer insights into the trends in using different intelligent systems types in the construction industry. The analysis presented in this paper has identified intelligent systems studies that have contributed to the development and accumulation of intellectual wealth to the intelligent systems area in the construction industry. This research has implications for researchers, journal editors, practitioners, universities and research institutions. Moreover, it is likely to form the basis and motivation for profiling other database resources and specific types of intelligent systems journals in this area.

Keywords: Intelligent Systems, Artificial Intelligence, Construction Industry, Profiling, Scopus Database.

Article Type: Profiling Paper

1. Introduction

Global economic competition has prompted many organisations to explore potential opportunities for enhancing the delivery of their products or services (Park, Lee, Kwon, 2010). This trend has become apparent in the construction industry as well, with clients/partners demanding a better service and projects that meet their requirements more meticulously (Chen, Griffs, Chen, Chang, 2012; Chaphalkar & Patil, 2012). This inclination towards transformation of construction operations has challenged the industry to become more efficient, integrated and more attractive, both in the eyes of society and its prospective workforce (Bowden, Dorr, Thorpe, Anumba, 2006; Cheng, Tsai, Lai, 2009). In response to this challenge, several government, industry or research-led construction change initiatives have emerged in most developed countries (Courtney & Winch, 2002). In parallel with, and to serve these initiatives there has been a rigorous effort, within the research and academic sector, to investigate and implement existing and emerging intelligent solutions that facilitate the improvements required to develop the construction industry (Bowden et al., 2006). Globally, the construction industry is one of the main sectors that was estimated to reach an approximate US$5.5 trillion at the

[2] The search was conducted using a combination of two keywords e.g. 'Intelligent Systems AND Construction Industry'. This process was repeated with other keywords as well to extract relevant papers. This process is further explained in detail in the research methodology section.

end of 2007 (Harmon, 2003). The huge investment made in construction operations worldwide is representative of approximately 4.6% of gross domestic product expended at the national level (El-adaway, 2008). An industry of this size and magnitude, therefore, has across-the-board effects on the development and affluence of nations. The construction industry's contribution to the nation's economy is, however, inhibited by an increasing number of problems that unfold and often intensify as projects progress (Mahfouz & Kandil, 2012). In order to understand and address the complex problems in the construction industry many academics and practitioners have conceptually and empirically researched the intelligent systems area within different contexts. Some recent varied examples include:

- Liu & Tsai (2012) presenting a fuzzy assessment approach for occupational hazards in the construction industry;
- Jiang, Jang, Skibniewski (2012) exploring wireless technology for tracking construction materials;
- Coelho & de Brito (2011) proposing a knowledge-based system for materials distribution;
- Ooshaksaraie, Basri, Abu Bakar, Maulud (2012) developing an expert system in stormwater management planning for construction sites in Malaysia; and
- Chen et al., (2012) developing an evolutionary fuzzy hybrid neural network to enhance project cash flow management in the construction industry.

Research on applying intelligent systems (such as artificial intelligence techniques) to the management of construction industry projects started in the 1980s (Hua, 2008). These techniques were, in some instances, compared to traditional simulation and statistical regression approaches to evaluate enhancements in areas of labour productivity, litigation, forecasting demands, cost estimations, optimising construction site layout, cash flow prediction, and bidding in construction projects (Goh, 1996; Sonmez & Rowings, 1998; Seydel, 2003). More explicitly, in a review of the use of intelligent systems solutions (e.g. artificial neural networks) in the field of construction management, Boussabaine (1996) cited the benefits of artificial intelligence techniques over mathematical and statistical models in situations where the process to be modelled is complex and where traditional models lack the ability to learn by themselves, generate solutions and respond adequately to highly correlated, incomplete or previously unknown data. The scope and applicability of intelligent systems solutions clearly indicates that this area can and has addressed a multiplicity of organisational problems with the support of a large variety of techniques and methods – which can help solve complex decision-making queries and provide insights into them.

1.1 Research Aim

Since the review conducted by Boussabaine in 1996 on artificial neural networks in the field of construction management and more recently by Hua in 2008 on the applications of quantitative analysis techniques in construction economics and construction management (for both traditional and artificial intelligence techniques), this paper attempts to broaden the scope of their reviews by further assessing the applicability of different types of intelligent systems in the construction industry. Explicitly in respect of Boussabaine's and Hua's conclusion for construction economics and construction management (where it only focused on artificial neural networks and quantitative analysis techniques), this research specifically aims to:

> "*identify the historical trends and current patterns in the use of different types of intelligent system in the construction industry. These trends and patterns will support in anticipating the future propensities in the use of different intelligent systems in the construction industry*."

1.2 Research Objectives

This research intends to assess the extant research published on intelligent systems in the construction industry by employing a profiling approach and attempting to highlight the most frequently used intelligent systems in the construction industry. From the empirical findings (using 14 keywords), initially 550 papers were identified from the Scopus database during the period 1990 to 2012. After assessing the 550 publications, 514 papers were finally considered relevant and taken forward for further investigation. Since 1990, a number of academic outlets including among others: *Expert Systems with Applications, International Journal of Intelligent Systems, Construction Management and Economics, Computers and Operations Research, International Journal of Project Management, Journal of Construction Engineering and Management, Automation in Construction*, etc., have been dedicated to publishing research on intelligent systems. These sources offer a true reflection of the intelligent systems area and have emerged as quality outlets for publishing research in this field. Contributors from across the world have made contributions to the intelligent systems area. Given the limited research in the area of intelligent systems in the construction industry (as evidenced by the empirical findings), the rationale for undertaking this research is to provide a better understanding of the types of intelligent systems employed in existing studies (including other variables). In this respect, a review of the relevant intelligent systems outlets would help to shed light on intelligent systems types adopted to depict the evolution of the domain in future. This will inform researchers and academics engaged in the area of the most widely employed intelligent systems types and editorial preferences of the journals selected as part of this research. Thus, the aim of this research is realised by means of the following objectives – i.e. to identify the:

- number of publications in each year;
- geographic location of each publication;
- type of publication (i.e. research or technical paper, literature review, viewpoint);
- type of research methods employed (i.e. experiment, case study, mixed method, analytical);
- type of intelligent systems employed/discussed (i.e. artificial intelligence, expert systems, fuzzy systems, genetic algorithms, knowledge-based systems, neural networks, etc.);
- type of journal;
- context type (i.e. this variable specifically focuses on the type of construction sector e.g. road/highway construction, building construction, bridge construction, etc.); finally,
- citation analysis for each paper (i.e. by accessing the citations from the Scopus database);

The prime contribution of this research focuses on identifying the association between the following; these contributions, however, are derived as a result of the abovementioned objectives.

- yearly publications and geographic location;
- yearly publications and the type of intelligent systems employed/discussed;
- geographic location and the type of research methods employed; and
- geographic location and the type of intelligent systems employed/discussed.

The above four prime contributions are presented based on a comparison between the last two decades i.e. between 1990 to 1999 and 2000 to 2012. This comparison will provide insights into the historical trends and current patterns in using different types of intelligent systems in the construction industry. In order to achieve these objectives, the authors contribute by conducting a systematic review of 514 intelligent systems papers. This type of profiling research is essential in order to establish an understanding of intelligent systems (and their different types) and the state-of-the-art growth in the theory and application of intelligent systems within the construction industry. The remainder of this paper is structured as follows. Section 2 highlights the issues in the construction industry and the significance of intelligent systems in the construction industry. Thereafter, Section 3 presents the research methodology highlighting the overall research conducted in this paper. Then, in Section 4, we analyse and discuss the different variables (i.e. objectives) in intelligent systems studies with Section 5 summarising the contributions of this research. Finally, conclusions, implications for theory and practice and limitations are given in Section 6.

2. Construction Industry and Intelligent Systems: A Literature Perspective

The business world is replete with existing and emerging set of events that further complicate decisions and the decision-making process in organisations (Voordijk, Meijboom, de Haan, 2006; Al-

Zawahreh & Cox, 2009; Ning, Lam, Lam, 2011). For example, the construction industry is teeming with countless issues that make management exceptionally complex (Winch, 2010). The perils and uncertainties inherent in such a dynamic environment make the management of organisational resources even more crucial (Park et al., 2010). The latter argument is supported by Chen et al., (2012) who state that construction projects are becoming increasingly larger and more intricate in terms of physical size and cost; for this reason the risks and potential for losses require better management. According to Beavers et al., (2006), one of the foremost reasons for casualties in the construction industry is in deploying cranes or giant frames (i.e. derricks) while lifting operations are being carried out. This requires proper workforce training while using such machinery or perhaps developing intelligent solutions that can (if not completely) then partially replace the human resource (Munisamy, 2009; Al-Zawahreh & Cox, 2009). The construction industry is considered as one of the major high-risk industries globally, where accidents that include those that result from falling from a height being the most frequent (Guo, Li, Chan, Skitmore, 2011). For example, some recent events that received widespread exposure in the United States and Europe, respectively, include the 'Big Dig' ceiling collapse in Boston (2005) and the Cologne subway/historical archive collapse (2009), both of which involved casualties. In this regard, factors for success may also vary from project to project in the construction sector. Even though 'human' experts can often accomplish a reasonable project result, deficits almost always follow due to managers failing to take all relevant factors into consideration and/or lacking access to all relevant information (Cheng et al., 2009; Cheng, Tsai, Sudjono, 2012).

The construction industry in the past has been plagued with similar problems and is categorised by *(a)* specific intricacy variables due to individual industry ambiguities and inter-dependencies, and *(b)* insufficiency of operations (Tah & Carr, 2000; Dubois & Gadde, 2002; Beavers, Moore, Rinehart, Schriver, 2006). Despite the availability of several intelligent systems, construction managers are still perplexed when faced with a new problem in decision-making, when they ought to establish which existing intelligent systems are most apposite given the nature of the system, the objectives for development, time constraints and computing capacity (Bolduc, Renaud Boctor, Paporte, 2008; Cui & Lu 2009; Bisaillon, Cordeau, Paporte, Pasin, 2011). Decision-making in the construction industry is more about making robust decisions rather than optimal decisions (Winch, 2010). Construction industry projects whether dealing with steel bridge construction (Cui & Lu, 2009), highway construction (He & Sun, 2010) or developing partnerships between client and contractors (Bresnen & Marshall, 2000) have been marked as risky with uncertain decision-making resulting in poor performance. The latter argument is supported by AbouRizk (2010), who reports that when construction projects become large and/or complex[3], they become more difficult to manage by employing conventional techniques. According to Ruuska, Ahola, Artto, Locatelli, Mancini (2011), large and/or complex construction projects present exceptional challenges as a result of: *(a)* the dynamic network of organisations that combine resources, capabilities and knowledge of participating actors to achieve clients' needs and *(b)* differing and often conflicting objectives and expectations not evident if the projects were carried out by individual firms. As such challenges are not effortlessly dealt with using conventional techniques; they may result in lack of performance and, in some situations, project failure (Ruuska et al., 2011). Thus, the use of computer simulation techniques becomes vital, as these offer effective and efficient tools essential for designing and analysing construction related processes, irrespective of complexity or project size.

2.1 Significance of Intelligent Systems in the Construction Industry

The intelligent systems area has expanded remarkably over recent years; in terms of the range of techniques and number of applications where they often provide a competitive advantage when compared with other conventional approaches (Negnevitsky, 2005; Uraikul, Chan, Tontiwachwuthikul, 2007). Intelligent systems include a range of techniques (e.g. neural networks, fuzzy logic/systems, genetic algorithms and genetic programming, expert systems, case-based

[3] In this paper, we denote '*complexity*' of construction projects with an example i.e. the bundling of construction operations into fewer, but larger contracts signifies that more responsibility is transferred from major clients of the construction industry to contractors. The construction contractor in such a leading role is faced with the challenge of managing the interrelationships of the whole supply chain which make the projects complex (Hagan, Bower, Smith, 2012).

reasoning, etc.) that operate synergistically to improve strategic decision-making and provide flexible data/information processing abilities for dealing with real world situations (Li, 2007; Hines, Leeson, Martínez-Ramón, Pardo, Llobet, Iliescu, Yang, 2008). For example, the complexity of construction industry operations and the resulting problem-solving capacity required is recognised as a challenge. In this regard, intelligent systems have played a significant role in providing a standardised methodological approach to solving important and fairly complex problems, facilitate making consistent decisions by using appropriate artificial intelligence solutions, and obtaining consistent and reliable results over time (Byrd & Hauser, 1991; Arain & Pheng, 2006; Shi, 2012). Intelligent systems can thus exploit the tolerance for inaccuracy, indecision/uncertainties, estimated reasoning and fractional fact so as to realise compliance, vigour and cost-effective solutions (Hines et al., 2008). Intelligent systems have been defined in several ways, for instance according to:

- Curry and Moutinho (1991), "*intelligent systems are programs that stretch to represent the knowledge of an expert in a certain domain.*"
- Kumara, Joshi, Kashyap, Moodie, and Chang (1986), "*an intelligent system is a tool which is able to conceive the special knowledge of a problem and by using intelligently this knowledge of this special domain, it can suggest alternative actions.*"
- Feigenbaum (1982), "*intelligent system is an intelligent program that, in order to resolve a difficult problem necessitating a considerable experience for its solution uses a special knowledge and deduction procedures.*"

These definitions clearly indicate that intelligent systems are software programs that syndicate the knowledge of experts and attempt to resolve distinct problems by imitating the reasoning processes of experts (Matsatsinis & Siskos, 2003). In the context of the construction industry, Guo et al., (2011) recommended the use of artificial intelligent systems to enhance the safety levels i.e. using game technology-based safety training platforms in a virtual environment in order to reduce existing fatality rates. Behzadan, Aziz, Anumba, Kamat, (2008) report that the unplanned and vibrant nature of a construction site, with the dangers and hitches presented by on-site operations, demand the use of intelligent ways to support the on-site construction workforce. Context-aware information delivery offers the capacity to intelligently capture and infer the user context, and deliver data and services to the mobile-worker based on the user's context (Behzadan et al., 2008). Similarly, in the context of tainting construction industry operations and projects as risky, Tah & Carr (2000) report that organisations will have to reconsider their tactics to the approaches in which risks are handled within their projects. In doing so, proposing the development of robust knowledge-based systems that are capable of enhancing risk analysis and management processes and, as a result, directing the construction industry to develop benchmarks that are maintainable and frequently enhanced. On the other hand, repetitive construction projects are a common phenomenon in the construction industry that require resources to perform similar operations in different units (Vanhoucke, 2006). Due to the frequent resource movement from one unit to another, an effective schedule is imperative to guarantee the continuous usage of resources in repetitive operations between units. In this regard, Long & Ohsato (2009) developed a genetic algorithm-based method for scheduling repetitive construction industry projects. According to anecdotal references, the use of intelligent systems (e.g. expert systems) will most likely be the most important application of intelligent solutions for construction over the next decade. In the years to come, there is good potential for increased use of self-directed robots controlled by expert systems. Such advanced-application robots would finish concrete and spray paint buildings (already being done in Japan), apply sprayed insulation to structural steel members, and even install structural steel.

3. Research Methodology

Building a profile of the last two decades of intelligent systems publications necessitated that the authors systematically review a total of **514** papers to capture data on several variables (with the whole research design presented in Figure 1). In order to perform such research, the authors selected the Scopus database. The rationale for selecting the Scopus database was that it covers nearly 18,000 titles from over 5000 international publishers, including coverage of 16,500 peer-reviewed journals on different areas. Therefore, it is possible to search for and locate a significant proportion of the published material on intelligent systems using the general and advanced search facility. The authors utilised both facilities (i.e. general and advanced search) within this research exercise. The reason for employing a 'General Search' approach was simply that it is easy to use and its characteristics facilitate the repetition of searches without any confusion; hence it is relatively straightforward to obtain consistent results in repetitive searches provided the same search criteria are applied (Dwivedi et al., 2008; Williams et al., 2009). The 'Advanced Search' was used to further identify specific intelligent systems papers primarily focusing on the construction industry. However, the search was not restricted to occurrences of any of the selected keywords appearing in the article title only but also the abstract, keywords and the whole paper was considered. Thus, the authors initially searched the Scopus database using the 'intelligent systems' keyword only. This search resulted in **4,437** publications from 1990 to 2012, specifically focusing on journal articles only.

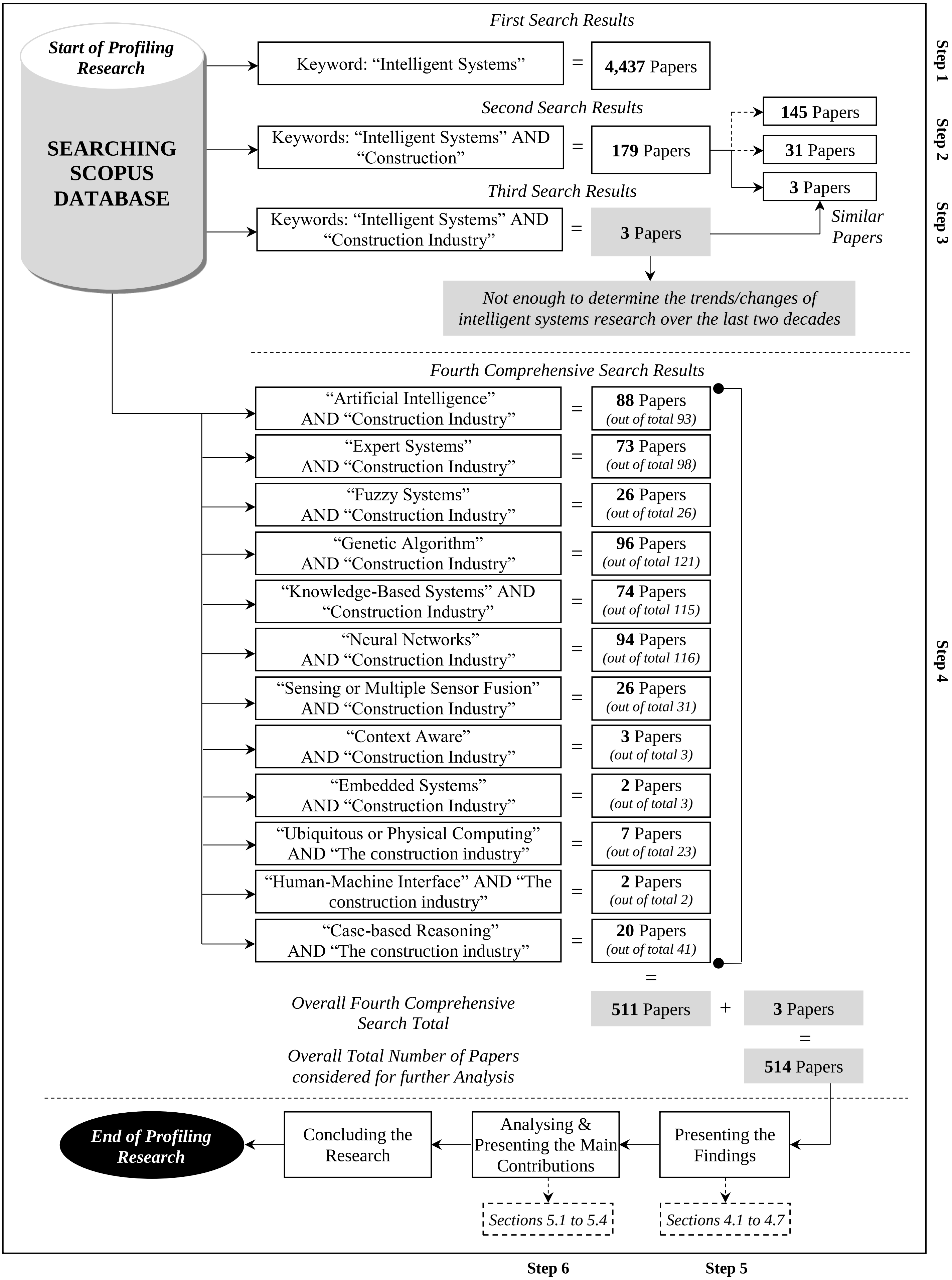

Figure 1: Research Design

However, as the focus of this research is on the construction industry, the authors repeated this process by restricting the search using the '*intelligent systems*' AND '*construction*' keywords together. This exercise resulted in **179** publications from 1990 to 2012. After analysing these **179** papers, the authors identified **seven** relevant papers. On further analysing these **seven** papers, only **three** specifically focused on the construction industry. The remaining articles were either not narrated in English (**31** papers) or not related to this research (**145** papers). Although these discarded papers highlighted the keywords (i.e. '*intelligent systems*' AND '*construction*') they were not specifically from the construction industry, but used the phrase 'construction' as a general terminology. To avoid further avoid any confusion and extract the correct number of publications on intelligent systems, the authors decided to use intelligent systems and construction industry keywords together i.e. stated in the following manner '*intelligent systems*' AND '*construction industry*'. This search resulted in **three** publications – similar to those that resulted after analysing **179** publications. This sample of **three** papers was certainly not realistic to determine changes in intelligent systems research over the last two decades. Therefore, the authors further explored the literature and identified different intelligent systems types i.e. Artificial Intelligence, Expert Systems, Fuzzy systems, Genetic Algorithms, Knowledge-Based Systems, Neural Networks, Context Aware Applications, Embedded Systems, Human-Machine Interface, Sensing & Multiple Sensor Fusion, and Ubiquitous & Physical Computing. The authors identified that these intelligent systems types are also central to the scope of the *Expert Systems with Applications* journal including its current special issue on 'Intelligent Systems in Construction'.

After applying the same search process on each intelligent system type (using 'Construction Industry' as the second keyword), the authors found the following number of publications for each. As mentioned below the exact number of papers for each keyword is highlighted in bold, whereas the total number of papers with each keyword is mentioned inside the brackets (as the actual number of papers considered for further investigation and analysis). This is because while conducting the search with a certain set of keywords (e.g. artificial intelligence and construction industry) there were some papers that were already extracted with another keyword (e.g. in this category are expert systems, genetic algorithms, knowledge-based systems, and case-based reasoning). Due to the latter, the number of types of intelligent systems differs from the actual number of papers extracted. This can be attributed to the fact that expert systems, genetic algorithms, knowledge-based systems, and case-based reasoning are, in essence, the core techniques used in developing artificial intelligent systems. This is further explained in the following Table 1 with each point:

Keywords	Papers Extracted
‘Intelligent Systems’ AND ‘Construction Industry’	• **3** (out of a total of 7) papers. ○ *Out of the 7 papers, only 3 papers either employed or discussed intelligent systems in the construction industry*.
‘Artificial Intelligence’ AND ‘Construction Industry’	• **88** (out of a total of 93) papers. ○ *From the 88 papers:* ▪ 36 papers were on artificial intelligence, ▪ 10 papers on decision support systems, ▪ 9 papers on knowledge-based systems, ▪ 8 papers on neural networks, ▪ 8 papers on genetic algorithms, ▪ 6 papers on expert systems, ▪ 4 papers on case-based reasoning, ▪ 4 papers on different intelligent systems types (e.g. 2 papers on intelligent construction systems, and 1 each on intelligent scheduling systems and marketing intelligent systems), ▪ 2 papers on fuzzy systems, and ▪ 1 paper on sensor technology.
‘Expert Systems’ AND ‘Construction Industry’	• **73** (out of a total of 98) papers. ○ *All the 73 papers either employed or discussed expert systems in the construction industry.*
‘Fuzzy systems’ AND ‘Construction Industry’	• **26** (out of a total of 26) papers. ○ *From these 26 papers:* ▪ 21 were on fuzzy systems, ▪ 3 on artificial intelligence, and ▪ 2 on case-based reasoning.
‘Genetic Algorithms’ AND ‘Construction Industry’	• **96** (out of a total of 121) papers. ○ *From the 96 papers:* ▪ 91 were on genetic algorithms, ▪ 5 on artificial intelligence.
‘Knowledge-Based Systems’ AND ‘Construction Industry’	• **74** (out of a total of 115) papers. ○ *From the 74 papers:* ▪ 70 papers were on different types of knowledge-based systems, ▪ 1 paper on fuzzy systems, and ▪ 3 papers discussed case-based reasoning.
‘Neural Networks’ AND ‘Construction Industry’	• **94** (out of a total of 114) papers. ○ *From the 94 papers:* ▪ 89 discussed neural networks, ▪ 3 on artificial intelligence, ▪ 1 paper on case-based reasoning, and ▪ 1 on genetic algorithms.
‘Sensing’ OR ‘Multiple Sensor Fusion’ AND ‘Construction Industry’	• **26** (out of a total of 31) papers. ○ *All 26 papers discussed sensing or sensor technology in the construction industry.*
‘Context Aware’ AND ‘Construction Industry’	• **3** (out of a total of 3) papers. ○ *All three papers discussed context-aware systems in the construction industry.*
‘Embedded Systems’ AND ‘Construction Industry’	• **2** (out of a total of 3) papers. ○ *Both the papers discussed embedded systems such as cyber physical systems and environmental sensors for telepresence.*
‘Ubiquitous’ OR ‘Physical Computing’ AND ‘Construction Industry’	• **7** (out of a total of 23) papers. ○ *All 7 papers were on ubiquitous computing in the construction industry.*
‘Human-Machine Interface’ AND ‘Construction Industry’	• **2** (out of a total of 2) papers. ○ *Both papers discussed human-machine interface related systems in the construction industry e.g. augmented reality computer-aided drawing and robotic welding systems.*
‘Case-based Reasoning’ AND ‘Construction Industry’	• **20** (out of a total of 41) papers. ○ *All 20 papers were on case-based reasoning.*

Table 1: Keywords Used and Number of Papers Extracted through Overall Search

All the above paper numbers and the type of intelligent systems employed/discussed are summarised in Figure 1 and Table 5, respectively. Papers on other intelligent system types such as multi-agent systems, ambient intelligence, intelligent robotic systems, and autonomous computing, etc., were also searched using the same process as above, but there were no papers returned from the search by the Scopus database. Moreover, our search activities were restricted to the number of journals extracted from the Scopus database only, but there are many well-known journals focusing on intelligent systems and artificial intelligence e.g.:

- *Artificial Intelligence: An International Journal,*
- *International Journal of Neural Systems,*
- *International Journal of Intelligent Systems,*
- *Artificial Intelligence Review,*
- *Journal of Intelligent Material Systems and Structures,*
- *Journal of Intelligent Manufacturing,*
- *IEEE Intelligent Systems,*
- *Journal of Intelligent and Robotics Systems Theory and Applications,*
- *Knowledge-based Systems,*
- *Robotics and Autonomous Systems,*
- *Applied Artificial Intelligence,*
- *IEEE Intelligent Systems and their Applications,*
- *Journal of Intelligent Systems,*
- *Web Intelligence and Agent Systems,*
- *Journal of Intelligent and Fuzzy Systems, and*
- *Intelligent Automation and Soft Computing.*

Although these journals are also indexed in the Scopus database, they did not return any papers based on our 14 keywords.

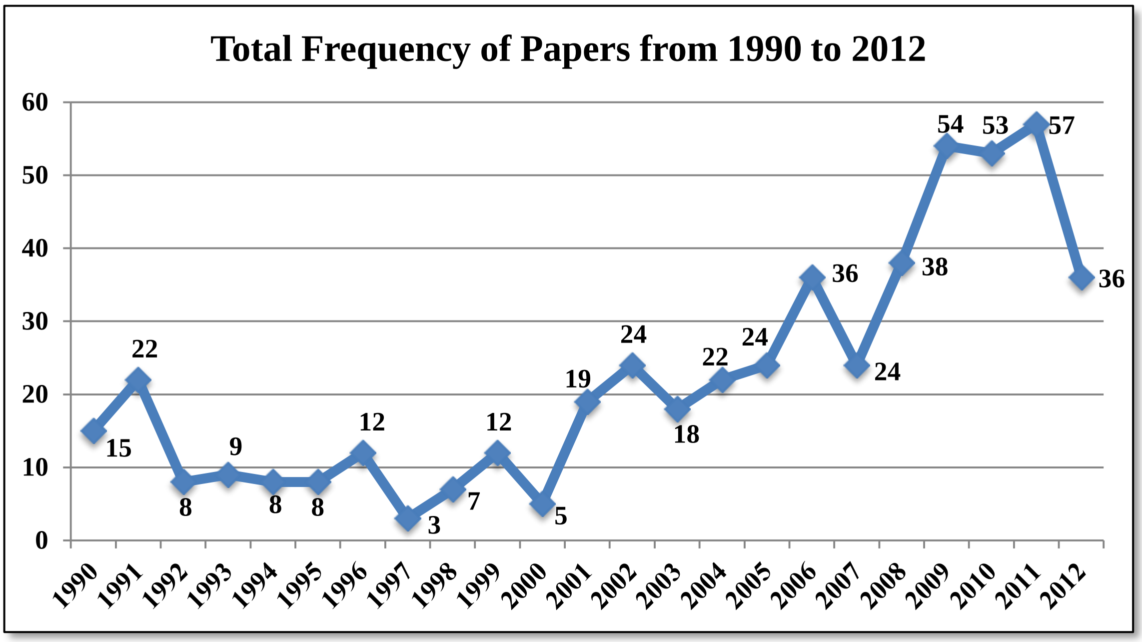

Figure 2: Total Number of Papers Published between 1990 and 2012

As presented in Figure 2, the largest number of publications were recorded for year 2011 (with C = 57, 11.19%), followed by year 2009 (with C = 53, 10.51%) and year 2010 (with C = 53, 10.31%). With fewer publications (i.e. below the 10 mark) are 1992 (with C = 8, 1.56%), 1993 (with C = 9, 1.75 %), 1994 (with C = 8, 1.56%), 1995 (with C = 8, 1.56%), 1998 (with C = 7, 1.36%), 2000 (with

C = 5, 0.97%) and 1997 with the least number of papers i.e. with C = 3, 0.58%. Figure 1 clearly highlights the trend of an increasing number of publications in the intelligent systems domain from 2000 onwards with 410 papers; whereas the 1990s decade generated rather small numbers of papers i.e. 104 out of the total 514. This trend evidently signifies that use of intelligent systems is gaining popularity in the research area of the construction industry, specifically from 1990 to 2011. However, there is a relatively sharp decrease in the number of papers in the year 2012 (with C = 36, 7.00%) compared to the previous year 2011, with 57 papers published. In 2011, the leading intelligent systems choice of researchers and practitioners was genetic algorithms with a total of 15 papers (published in different leading journals), followed by neural networks with a total of 11 papers (out of a total of 57). These two choices were followed by fuzzy systems (7 papers), knowledge-based systems and expert systems (with five papers each), artificial intelligence, case-based reasoning and sensor technology (3 papers each), decision support systems and intelligent systems (two papers each), and remaining one paper on context-aware computing. On the other hand, in 2012, the leading intelligent systems choice of researchers and practitioners was neural networks with a total of 8 papers, followed by genetic algorithms with a total of five papers (out of a total of 36). These two choices were followed by artificial intelligence and knowledge-based systems (four papers each), expert systems and fuzzy systems (three papers each), embedded systems, sensor technology and ubiquitous computing (with two papers each) with the remaining one paper on case-based reasoning. Although the number of papers decreased between 2011 to 2012, the types of intelligent systems employed/discussed in research studies during these two years were similar with a few exceptions (i.e. there are two papers on embedded systems and ubiquitous computing each in 2011, but none on these two types of intelligent system in 2012 and on the other hand, one paper on context-aware systems in 2012 and none on this type in 2011).

The reasons for fewer papers published in 2012 may be attributable to the changes in the global economic situation. Most of the developed economies are still struggling to overcome the economic problems caused by the global financial crisis in 2007-2008 (Altman, 2008). While this recession resulted in the total collapse of many large financial organisations and a decline in stock markets around the world, the construction industry (specifically those companies involved in home construction) was also directly affected (Altman, 2008). According to the World Economic Situation and Prospects (WESP) 2012, although there were some dispersed signs of developments in 2011 following the aftermath of the global financial crisis, growth of manufacturing production and the construction industry operations specifically remained on the decline (owing to weaker external demand). After a noticeable slowdown in 2011, global economic development was anticipated to remain lukewarm in 2012, with most EU regions growing at a pace below potential (WESP, 2012; Langdon, 2012). Thus, it may be suggested that the weakening situation of the construction industry due to the global financial crisis, has resulted in researchers and academics paying less attention to research in this area during 2010-2011, which resulted in fewer publications in 2012 (owing to limited case study projects and a lack of primary data in 2010-2011). Moreover, it can also be argued that a number of papers may have been submitted sometime in late 2011 or early 2012 but not all papers appear or get published, resulting in lower number of papers in 2012 than previous years. In this context, the top ranking peer-reviewed journals such as '*Journal of Construction Engineering and Management*', '*Journal of Computing in Civil Engineering*', '*Automation in Construction*', '*Construction Management and Economics*', and '*Expert Systems with Applications*' and other journals may have contributed to fewer papers in 2012 (i.e. taking a longer time to publish papers).

Nevertheless, some anecdotal evidence suggests that regardless of adverse economic conditions, the global construction industry is predicted to reach US $8,929 billion in 2017 with a Compound Annual Growth Rate (CAGR) of 7.3% over the next five years. This increase in construction industry operations will be supported by the major global event organisers including among others: the 2014 FIFA World Cup, the 2016 Olympic Games in Brazil, the 2014 Winter Olympic Games, and 2018 FIFA World Cup in Russia (Lucintel, 2012). These global corporations are anticipated to provide stimulus to the construction industry over the forecasted period. Having seen the gradual increase in the number of papers over the years (i.e. from 1990 to 2011) and the increasing support to the construction industry by the global corporations, it can be argued that after the decrease in the number of papers in 2012, a relatively significant increase in the number of publications may be anticipated to follow from 2013 onwards, with researchers presenting more intelligent solutions to the ever-growing problems in the construction industry (Cheng et al., 2012; Chen et al., 2012). Moreover, the authors also assert that those papers submitted sometime in 2012, but which were not published in 2012, may appear in 2013 and onwards. Analysis shown in subsequent sections also highlights the type of intelligent systems employed/discussed in different contexts of the construction industry e.g. use of different types of intelligent systems in road construction, bridge construction, building construction, construction site layout planning, case flow prediction, construction litigation, dispute resolution, etc.

4. Findings and Discussion

The findings of this study are now presented under different subsections. Each of the seven subsections discusses the findings in relation to a particular variable. The variables are as follows: number of regions – geo-spatial coverage (Section 4.1), types of publication (Section 4.2), types of research methods employed (Section 4.3), types of intelligent systems employed/discussed (Section 4.4), types of journal (Section 4.5), publication context type (Section 4.6), and citation analysis (Section 4.7).

4.1 Number of Regions (Geo-Spatial Coverage)

Table 2 highlights the number of publications from 48 different geographical regions across the globe between 1990 and 2012 on intelligent systems in the construction industry. From the total number of publications (i.e. 514) analysed, the largest number of contributions came from researchers from the USA (C = 120, 23.35%), followed by Taiwan (C = 56, 10.89%), the UK (C = 52, 10.12%) and Canada (C = 51, 9.92%). The results in Table 1 clearly indicate that the first seven regions (i.e. USA, Taiwan, UK, Canada, China, Korea and Hong Kong) lead on intelligent systems research in the construction industry. Although it is not the intention of this research to present the contributing co-authors' geographic locations, most of the co-authors (i.e. 2nd, 3rd, 4th and even 5th) are also from the top seven regions with the exception of a few from Egypt, India and Iran.

Geo-Spatial Coverage	Frequency of Publications	Per cent	Geo-Spatial Coverage	Frequency of Publications	Per cent
USA	120	23.35%	Poland	3	0.58%
Taiwan	56	10.89%	Switzerland	3	0.58%
UK	52	10.12%	Greece	2	0.39%
Canada	51	9.92%	Ireland	2	0.39%
China	31	6.03%	Qatar	2	0.39%
Korea	29	5.64%	Serbia	2	0.39%
Hong Kong	25	4.86%	Sri Lanka	2	0.39%
Turkey	15	2.92%	Chile	1	0.19%
Iran	13	2.53%	Croatia	1	0.19%
Egypt	13	2.53%	Cyprus	1	0.19%
Australia	11	2.14%	France	1	0.19%
India	10	1.95%	Indonesia	1	0.19%
Singapore	8	1.56%	Israel	1	0.19%
Spain	7	1.36%	Mexico	1	0.19%
Saudi Arabia	7	1.36%	Nigeria	1	0.19%
Portugal	5	0.97%	Norway	1	0.19%
Italy	4	0.78%	Oman	1	0.19%
Malaysia	4	0.78%	Philippines	1	0.19%
Sweden	4	0.78%	Romania	1	0.19%
Netherlands	4	0.78%	South Africa	1	0.19%
Finland	3	0.58%	Thailand	1	0.19%
Japan	3	0.58%	Tunisia	1	0.19%
Jordan	3	0.58%	Vietnam	1	0.19%
Lithuania	3	0.58%	Yugoslavia	1	0.19%
			Total	**514**	**100.00%**

Table 2: Frequency of Publications in each Geographical Location between 1990 and 2012

4.2 Type of Publication

In this section, the authors categorise their list of 514 papers in our data-set based on the type of publication. The authors used a fairly similar list of publication types to that employed by Dwivedi & Mustafee (2010). This list is also similar to those identified by the publisher – Emerald. The data presented in Table 3 illustrate that the vast majority of the publications are research papers (C = 458, 89.11%), followed by general review and literature review papers (with C = 16, 3.11%, respectively). The remaining types of publication with their frequencies are presented in Table 2. The large number of research papers clearly indicates the significance of the intelligent systems area in the construction industry and that most researchers are focused on developing and proposing intelligent solutions to the many problems within the construction industry e.g. construction site layout planning, case flow prediction, construction litigation, dispute resolution, etc.

Type of Publication	Total Frequency	Per cent
Research Paper	458	89.11%
General Review	16	3.11%
Literature Review	16	3.11%
Conceptual Paper	14	2.72%
Technical Note	8	1.55%
Research Report	1	0.19%
Short Paper	1	0.19%
Total	**514**	**100.00%**

Table 3: Classification of Publication Types between 1990 and 2012

4.3 Type of Research Methods Employed

The findings suggest that although a total of 15 different research methods were recorded from our data analysis, the majority of studies employed analytical methods (C = 204, 39.70%), followed by case study (C = 89, 17.31%) and conceptual/descriptive/theoretical (C = 49, 9.53%) methods. With regard to the analytical method – it was denoted as a combination of five different methods i.e. statistics, computer programming, simulation, algorithm and mathematical modelling. The other categories with their associated counts and percentages are presented in Table 4.

Type of Research Methods Employed	Total Frequency	Per cent
Analytical	204	39.70%
Case Study	89	17.31%
Conceptual / Descriptive / Theoretical	49	9.53%
Secondary Data Analysis	40	7.78%
Experiment	38	7.39%
Survey	29	5.64%
Design Research	25	4.86%
Interview	15	2.92%
Mixed Method	11	2.14%
Questionnaire	6	1.17%
Primary & Secondary Data Analysis	3	0.58%
Meta-Analysis	2	0.38%
Focus Group Interviews	1	0.19%
Field Trial	1	0.19%
Observation	1	0.19%
Total	**514**	**100.00%**

Table 4: Research Methods Employed between 1990 and 2012

4.4 Type of Intelligent Systems Employed/Discussed

The authors conducted a thorough analysis of the papers in order to identify the different types of intelligent systems employed (as highlighted in Table 5). This was to determine the most frequently employed intelligent systems types among the 514 papers used in this research. From the findings, it is clear that genetic algorithms (with C = 100, 19.45%), neural networks (with C = 97, 18.87%), knowledge-based systems (with C = 79, 15.37%) and expert systems (with C = 79, 15.37%) are the most frequently used among 514 papers assessed, followed by artificial intelligence (with C = 47, 9.14%), case-based reasoning (with C = 30, 5.84%), and sensor technology (with C = 27, 5.25%). Genetic algorithms have been widely studied, experimented and applied in many fields of engineering. Not only does the genetic algorithm provide an alternative method to problem-solving, it consistently outperforms other traditional methods in most problems. Many real-world construction problems (e.g. occupational hazards, materials distribution, increasing disputes that unfold and often escalate as construction projects progress, construction site layout planning, predicting the risks of contractor defaults, resource allocation and management in construction projects, and contractual claims) involve finding optimal parameters, which might prove difficult using traditional methods (e.g. developing knowledge management functionalities based on conventions of practice – such an approach is established using reactive problem-solving methods) but are ideal for genetic algorithms. However, due to its outstanding performance in optimisation, the genetic algorithm has been wrongly regarded as a function optimiser.

Type of Intelligent System Employed/Discussed	Total Frequency	Per cent
Genetic Algorithm	100	19.45%
Neural Network	97	18.87%
Knowledge-Based Systems	79	15.37%
Expert Systems	79	15.37%
Artificial Intelligence	47	9.14%
Case-Based Reasoning	30	5.84%
Sensor Technology	27	5.25%
Fuzzy Systems	24	4.67%
Decision Support Systems	10	1.94%
Ubiquitous Computing	7	1.36%
Intelligent Systems	7	1.36%
Context-Aware Systems	3	0.58%
Human-Machine Interface	2	0.39%
Embedded Systems	2	0.39%
Total	**514**	**100.00**

Table 5: Type of Intelligent System Employed/Discussed between 1990 and 2012

4.5 Type of Journal

From the total of 514 papers selected, a list of 122 different types of journal was used by researchers, academics and practitioners to publish their research. To avoid lengthy tables in the paper, the authors excluded those journals that had a frequency of one and denoted with '…' i.e. out of the 122 journals used, 91 journals had a frequency of one. According to the findings illustrated in Table 6, the *Journal of Construction Engineering and Management* was the most used by researchers (with C = 109, 21.21%), followed by the *Journal of Computing in Civil Engineering* (C = 58, 11.28%), *Automation in Construction* (with C = 57, 11.090%), *Construction Management and Economics* (C = 38, 7.39%) and *Expert Systems with Applications* (C = 27, 5.25%). The scope of these leading journals is broad, covering all stages of the construction lifecycle from initial planning and design, through construction of the facility, its operation and maintenance, to the eventual dismantling and recycling of buildings and engineering structures. Moreover, these journals are key resources for researchers, practitioners, and students on advances and innovation in construction engineering and management, scheduling, estimating, cost control, quality control, labour productivity, inspection, contract administration, construction management, computer applications, and environmental concerns. The remaining journals and their frequencies and percentages are presented in Table 6.

Type of Journal Extracted from Scopus	Total Frequency	Per cent
Journal of Construction Engineering and Management	109	21.21%
Journal of Computing in Civil Engineering	58	11.28%
Automation in Construction	57	11.09%
Construction Management and Economics	38	7.39%
Expert Systems with Applications	27	5.25%
Canadian Journal of Civil Engineering	15	2.92%
Journal of Information Technology in Construction	13	2.53%
International Journal of Project Management	12	2.33%
Engineering, Construction and Architectural Management	9	1.75%
Journal of Civil Engineering and Management	8	1.55%
Journal of Management in Engineering	8	1.55%
Computers & Structures	8	1.55%
Building and Environment	7	1.36%
Computer-Aided Civil and Infrastructure Engineering	7	1.36%
KSCE Journal of Civil Engineering	7	1.36%
Advanced Engineering Informatics	6	1.17%
Advances in Engineering Software	4	0.78%
Engineering Applications of Artificial Intelligence	3	0.58%
Journal of Professional Issues in Engineering Education and Practice	3	0.58%
Journal of Quality in Maintenance Engineering	3	0.58%
Tsinghua Science and Technology	3	0.58%
Computing in Civil Engineering	2	0.39%
Energy and Buildings	2	0.39%
Engineering Structures	2	0.39%
Indian Journal of Engineering & Materials Sciences	2	0.39%
Industrial Management & Data Systems	2	0.39%
International Journal of Industrial and Systems Engineering	2	0.39%
Journal of Engineering and Applied Sciences	2	0.39%
Journal of Infrastructure Systems	2	0.39%
Sensors and Actuators B: Chemical	2	0.39%
WSEAS Transactions on Computers	1	0.19%
...	...	...
Yugoslav Journal of Operations Research	1	0.19%
Total	**514**	**100.00**

Table 6: Type of Journals and their Frequency between 1990 and 2012

4.6 Publication Context Type

From the total of 514 papers selected, a list of 43 context types was used by researchers, academics and practitioners to publish their research. To avoid lengthy tables in the paper, the authors considered developing appropriate categories to sum the relevant context types under a suitable category. For example, the ‘Large Construction Project’ category includes papers on context types related to electric power construction projects, hydropower construction projects, rural construction, and tunnel construction. Similarly, the ‘Knowledge Management in Construction Project’ category includes papers on knowledge acquisition, evaluation, planning, and knowledge networks. The same process was repeated for all context types (out of a total of 43) that had more than three papers. Nevertheless, there are 15 papers that focus on ‘Highway Construction’ with the exception of one on road construction. The process did not occur by coincidence, it was initially planned and the authors evaluated the papers accordingly (especially when there were 514 publications to review). A similar categorisation of paper context type is conducted by Williams et al., (2009) and Dwivedi et al., (2008). According to the findings illustrated in Table 6, ‘Construction Project Operations’ was the most researched (with C = 92, 17.90%), followed by ‘Building Construction Projects’ (C = 55, 10.70%) and 'Information Technology in Construction Projects' (with C = 47, 9.15%). The remaining context types and their frequencies and percentages are presented in Table 7.

Context Type	Total Frequency	Per cent
Construction Project Operations	92	17.90%
Building Construction Projects	55	10.70%
IT in Construction Projects	47	9.14%
Decision-Making in Construction Projects	29	5.64%
Planning and Scheduling in Construction Projects	22	4.28%
Computing in Construction Projects	18	3.50%
Construction Project Management	18	3.50%
Construction Site Investigation	18	3.50%
Knowledge Management in Construction Projects	18	3.50%
Highway Construction Projects	15	2.92%
Construction Project Costs	14	2.72%
Resource Allocation in Construction Projecta	14	2.72%
Concrete Products in Construction	11	2.14%
Construction Engineering Projects	11	2.14%
Risk Assessment & Management in Construction Projects	11	2.14%
Construction Litigation	9	1.75%
Performance in Construction Projects	9	1.75%
Safety Hazard Identification in Construction	8	1.55%
Estimation in Construction Projects	8	1.55%
Contractor-related Issues in Construction Projects	7	1.36%
Dispute Resolution in Construction Project	7	1.36%
Large Construction Projects	7	1.36%
Forecasting in Construction Projects	5	0.92%
Labour Deployment & Productivity in Construction	5	0.92%
School & Housing Construction Projects	5	0.92%
Cash Flow Predictions in Construction Projects	4	0.78%
Claims in Construction Projects	4	0.78%
Financial Crisis & Management in Construction	4	0.78%
Recruitment in Construction Projects	4	0.78%
Sustainable Construction	4	0.78%
Construction Plant Maintenance	3	0.58%
Environmental Impact Assessment in Construction	3	0.58%
Heavy Construction Equipment	3	0.58%
Information Management in Construction Projects	3	0.58%
Stone Crushing and Cutting in Construction	3	0.58%
Value Engineering in Construction	3	0.58%
Bridge Construction Projects	2	0.39%
Construction Management Research	2	0.39%
Construction Supply Chain Management	2	0.39%
Fibre Optic Technology in Construction	2	0.39%
Procurement Selection System in Construction	2	0.39%
Recycling Construction Waste	2	0.39%
Welding in Construction Projects	1	0.19%
Total	**514**	**100.00**%

Table 7: Context Type and Frequency of Publications between 1990 and 2012

4.7 Citation Analysis

Citation analysis was conducted to determine the research impact of the most influential research studies. With regard to recording the citation data pertaining to all 514 articles, the authors started extracting this information from Scopus as of 02 December, 2012 onwards. These data were successively updated until submission. Data gathered from the Scopus database on total citation count per article indicates that 76 articles received 20 or more citations (with one paper receiving 127 citations), 77 papers received between 10 and 19 citations, while 278 papers received between nine to one citation. The second largest portion of the data collected (i.e. 78 papers) received no citation.

Most of the articles with no citation were published between 2008 and 2011, with a few articles between 2000 and 2007. Citation frequencies for all the papers are presented in Table 7. In total, 43 studies with larger values of citation counts (with a maximum count of 127 and a minimum count of 30) from each year are listed in Table 8 which includes the study with the largest count by Chua (1999) with a citation count of 127 (as per Scopus database). As noted by Dwivedi et al., (2008, 2009), older papers are more likely to have larger numbers of citations, while newer papers are likely to have lower citation counts. This can be shown by the fact that papers possessing the largest number of citations were published in early volumes of the selected journals and very few of the papers from a relatively recent volume had a large citation count. This is not an exceptional case as a similar tread has been identified in previous studies, including the profiling of the *Journal of Electronic Commerce Research* (Dwivedi et al., 2008) and *Information Systems Frontiers* (Dwivedi et al., 2009). The high citation count (e.g. specifically for those papers with a citation count between 127 and 40) may reflect the interest generated in their respective topic by intelligent systems practitioners and academics. It may also be due to the high level of project problems in the construction industry reported in a number of studies (evaluated as part of this research) and which might have attracted academics to re-examine intelligent systems related topics and related methodological practices.

Citation Analysis			
Scopus Database Citation Counts	**Number of Studies**	**Scopus Database Citation Counts**	**Number of Studies**
127	1	27	3
92	1	26	2
82	1	25	6
70	2	24	5
68	1	23	7
66	1	22	5
54	1	21	1
51	1	20	3
49	1	19	4
48	2	18	8
47	1	17	6
46	3	16	4
45	4	15	8
43	2	14	8
42	1	13	7
41	1	12	9
40	2	11	15
39	1	10	8
38	1	9	11
37	2	8	13
36	3	7	16
35	1	6	21
34	2	5	35
33	1	4	31
32	2	3	41
31	2	2	61
30	2	1	49
28	1	0	78
Total Citation Count			**514**

Table 8: Frequency of Citation Counts between 1990 and 2012

5. A Comparison between 1990-1999 and 2000-2012: Highlighting the Main Contributions in this Research

The findings presented in the previous section are general and based on straight counting of, for example, the number of papers published in each year, the geographical region of each publication, etc. This section provides insights into the relationship between some of the variables analysed in the previous section. The variables that are associated in this section are: geo-spatial coverage and yearly publication (Section 5.1), geo-spatial coverage and type of research methods employed (Section 5.2), geo-spatial coverage and type of intelligent systems employed/discussed (Section 5.3), and the association between the yearly publications and type of intelligent systems employed/discussed (Section 5.4).

5.1 Association between Yearly Publications and Geographic Location

According to Figures 3 and 4, the USA is in the lead in conducting research into intelligent systems with C = 54 (45% of a total of 120) papers in the 1990s and C = 66 (55% of a total of 120) papers from 2000 onwards until 2012, followed by Taiwan (with three [5.35% of a total of 56] papers in the 1990s and 53 [94.64% of a total of 56] papers from 2000 onwards), the UK (with C = 13 [25% of a total of 52] papers in the 1990s and 39 [75% of a total of 52] papers from 2000 onwards) and Canada (with 10 [21.27% of a total of 47] papers in the 1990s and 37 [78.72% of a total of 47] papers from 2000 onwards). However, comparing the findings of both decades, it is clearly evident that more research was conducted from 2000 (i.e. with a total of 410 papers) onwards on intelligent systems than during the 1990s (i.e. with a total of 104 papers). Moreover, from the number of publications extracted from the 1990s era, it can be argued that there was less attention given to intelligent systems research or a limited need to product innovative and intelligent solutions as compared to 2000 (and onwards). The latter argument may be considered as factual, particularly as global economic competition has compelled many organisations to explore and develop intelligent solutions to improve the delivery of their products or services.

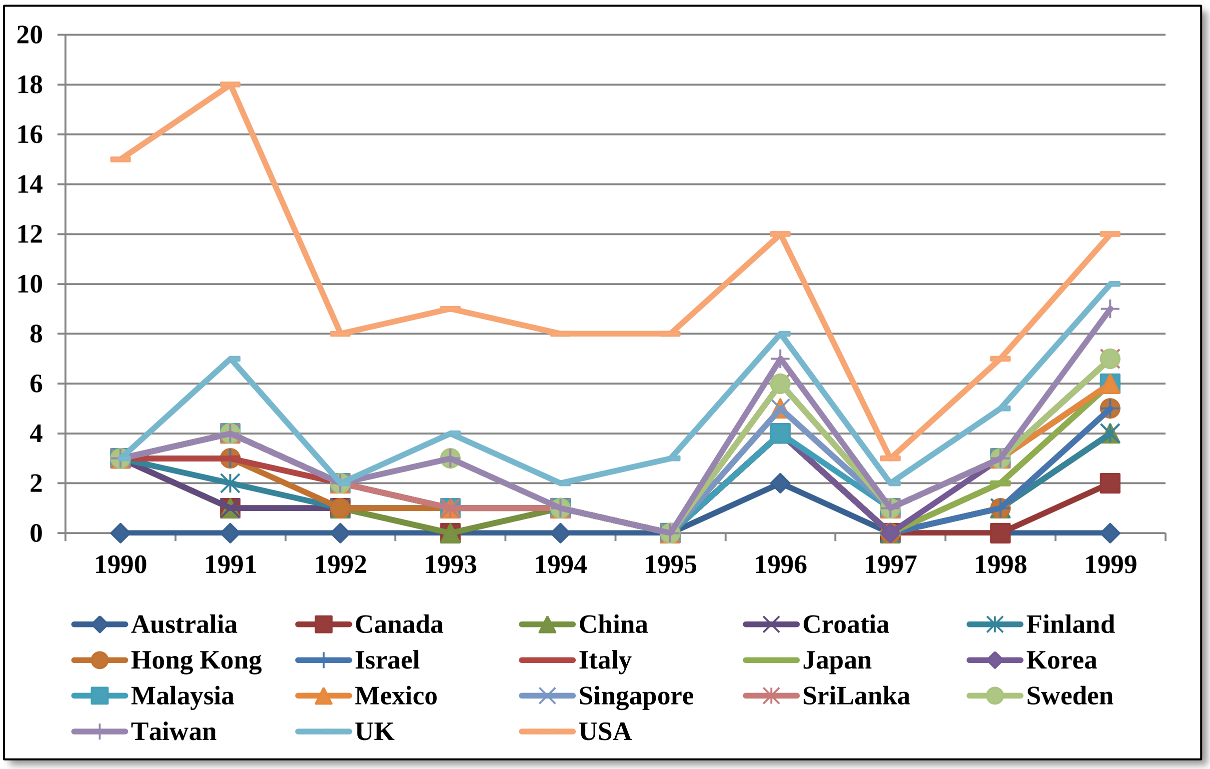

Figure 3: Yearly Publications for each Geographic Location from **1990** to **1999**

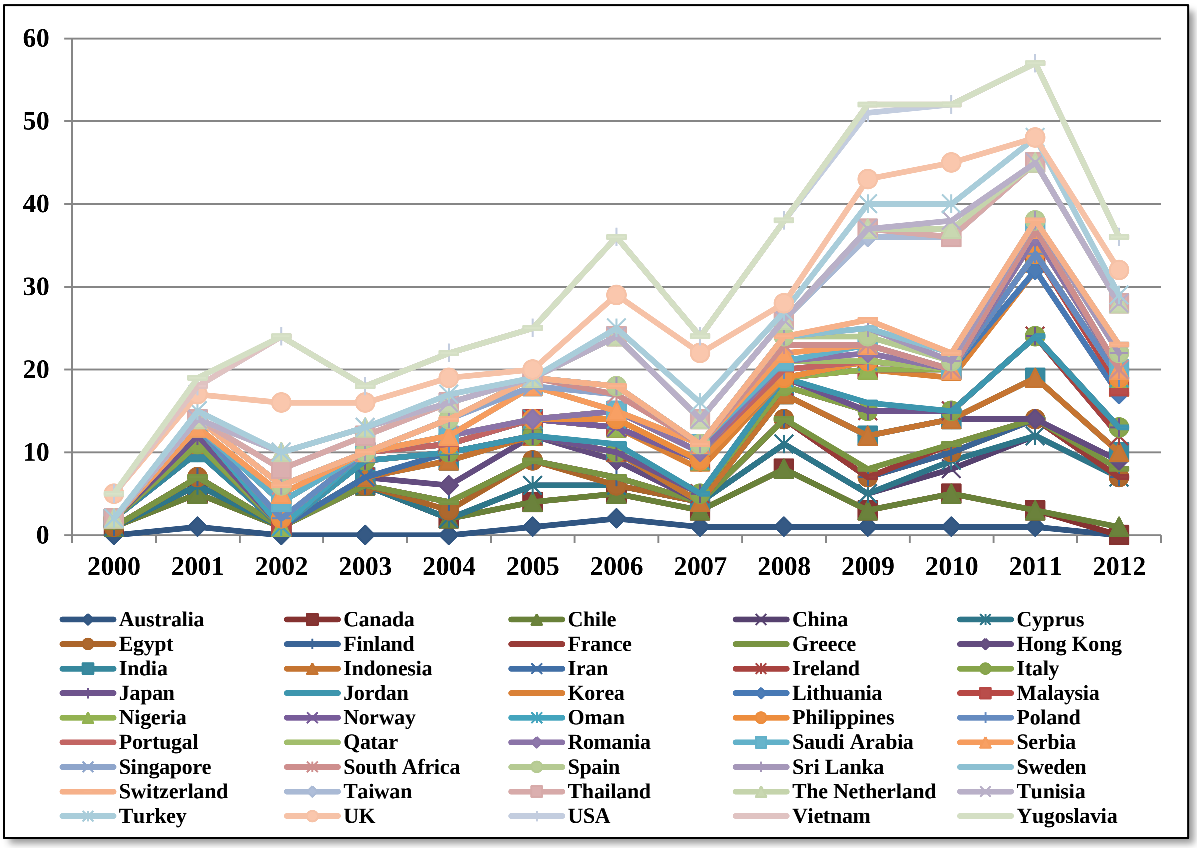

Figure 4: Yearly Publications for each Geographic Location from **2000** to **2012**

5.2 Association between Yearly Publications and the Type of Intelligent Systems Employed

According to Figures 5 and 6, there has been a sharp increase in the number of publications on intelligent systems in the construction industry in the past decade. For example, from 1990 to 1999, there was a total of 104 papers published on types of intelligent systems, whereas, from 2000 onwards there were 410 papers published from the total of 514 papers. In the 1990s, expert systems seemed to gain the attention of researchers, with 50 papers generated on expert systems (48.175) out of total of 104 papers, followed by knowledge-based systems (with C = 18, 17.31%) and neural networks (with C = 11, 10.58%). On the other hand, from 2000 onwards, there are 96 publications that have either employed or discussed the significance of genetic algorithms (23.41% of 410 papers), followed by neural networks (C = 86, 20.97% of 410 papers) and knowledge-based systems (C = 61, 18.88% of 410 papers). The increasing trend towards the use of intelligent systems in the construction industry over the last decade clearly indicates that the construction industry is without doubt attempting to deal with its myriad problems. For example, forecasting of project completion dates, litigation, planning construction site layout, cost estimations, issues on building construction projects, evaluating construction projects, predicting the risks of contractor defaults, resource allocation and management in construction projects, sustainability, contractual claims, etc., all make management extremely complex. Thus, the need for appropriate intelligent solutions to solve these construction problems.

Construction industry projects are highly information intensive and many factors (such as financial, social, human factors) need thorough attention. In this case, factors for success may vary from project to project. Even though 'human' experts can often accomplish a reasonable project result, deficits almost always follow due to managers failing to take all relevant factors into consideration and/or lacking access to all relevant information (Cheng et al., 2009; Cheng et al., 2012). Moreover, the increase in the use of intelligent systems can be attributed to the fact that today's business environment is progressively transforming to a state of hyper-competitiveness. In this context, construction organisations need to continually explore innovative ways to re-orchestrate their products and services for their customers (Park et al., 2011; Sonmez, 2011; Chen et al., 2011; Mahfouz & Kandil, 2012).

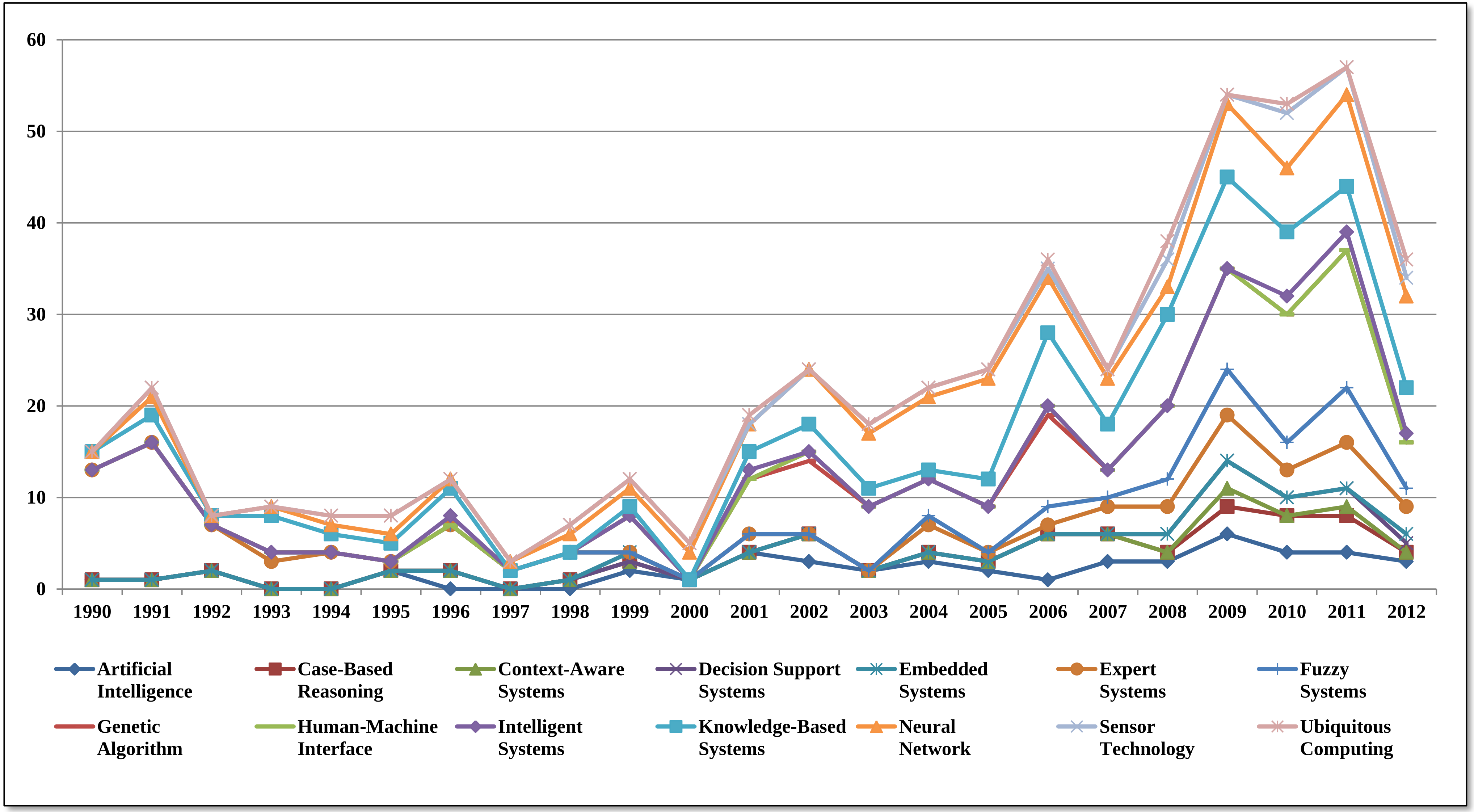

Figure 5: Type of Intelligent System Employed/Discussed between **1990** to **1999** and **2000** to **2012**

5.3 Association between Geographic Location and the Type of Research Methods Employed

According to Figures 5 and 6, analytical research methods have been employed by most of the research studies conducted over the last two decades. In the 1990s there were 25 research studies overall (24.04% of a total of 104 papers) that employed analytical research methods (over 11 regions); with the USA leading with nine papers (i.e. 36% of 25), followed by Canada with six papers (i.e. 24% of 25 papers in total in 1990) and the remaining nine regions with one or two papers each. Following analytical research methods, 28 (26.92% of a total of 104 papers) research studies focused on conceptual/descriptive/theoretical research methods and 21 (20.19% of a total of 104 papers) focused on design research. On the other hand, from 2000 onwards there were 179 research studies (43.66% of a total of 410 papers) that employed analytical research methods (over 34 regions). However, from 2000 onwards, Taiwan had taken the lead in research studies employing analytical research methods (with C = 33 papers i.e. 18.43% of 179), followed by the USA (C = 24 papers i.e. 13.41 of 179), China (C = 19 papers i.e. 10.61 of 179) and Canada (C = 16 papers i.e. 8.94% of 179). Following analytical research methods, the case study method was in second place (with C = 85, 20.73% of 410 papers). These 85 papers using case study research methods are spread across 23 regions with the UK and USA in the lead with 14 papers each. In third place are experiments (with C = 33, 8.05% of 410), followed by papers on secondary data analysis (with C = 32, 7.80% of 410) and papers using survey research methods (with C = 25, 6.09% of 410).

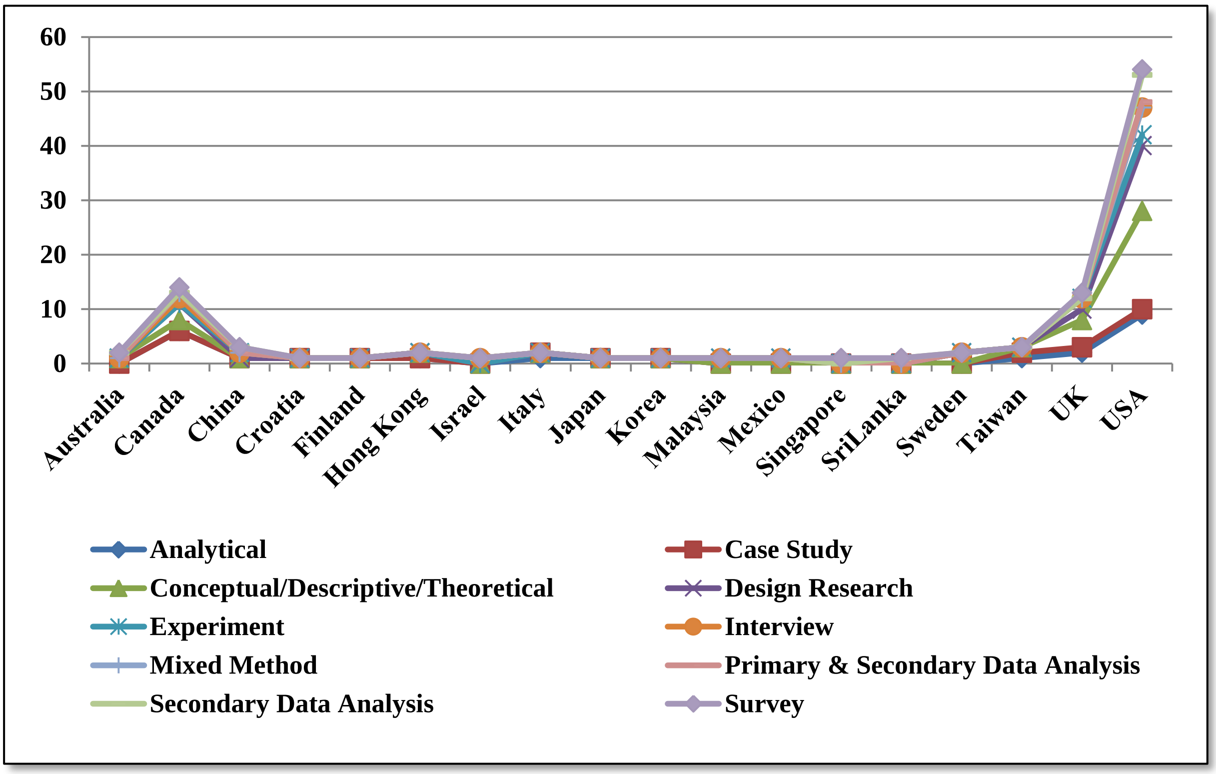

Figure 6: Research Methods Employed in each Geographic Location from **1990** to **1999**

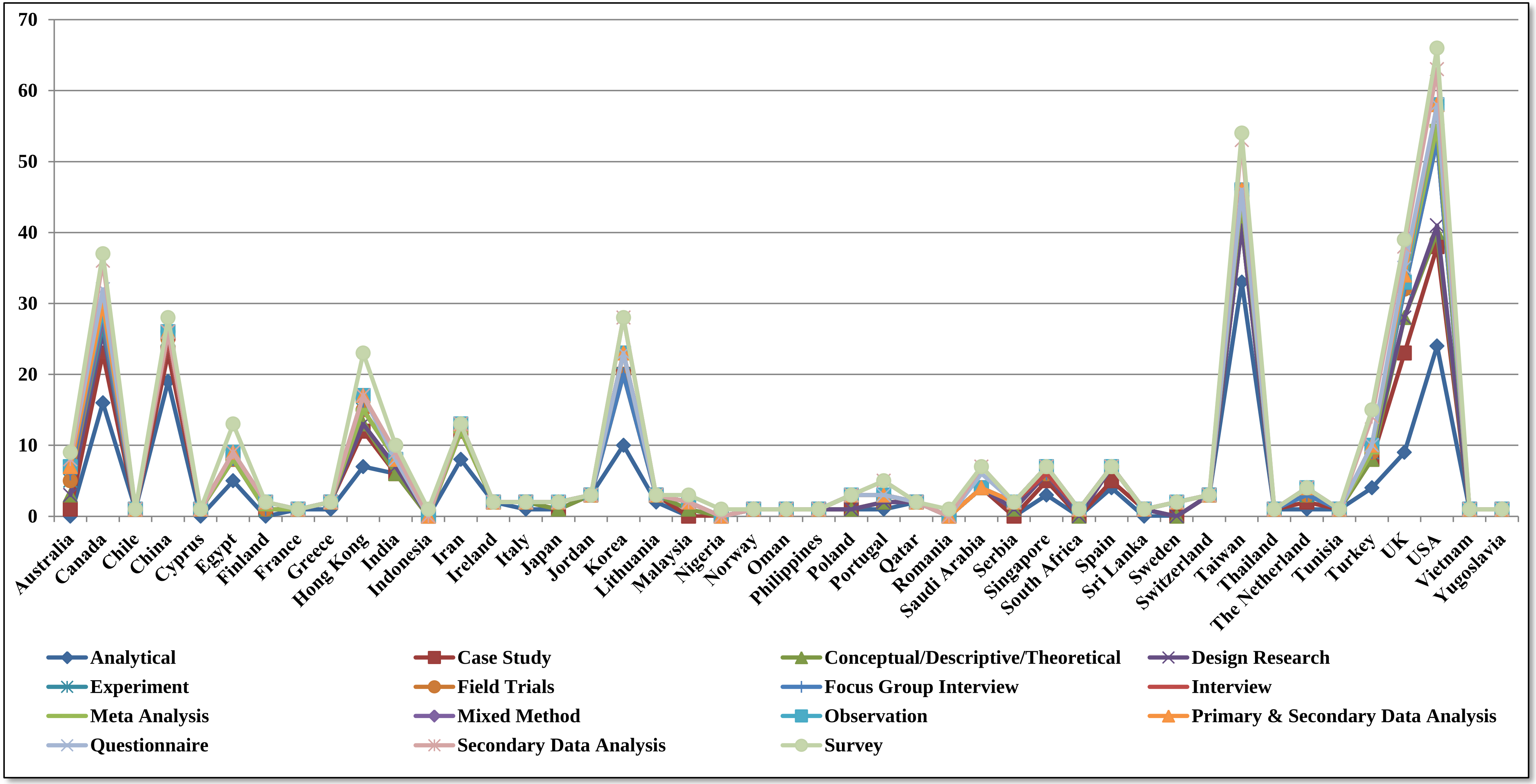

Figure 7: Research Methods Employed in each Geographic Location from **2000** to **2012**

5.4 Association between Geographic Location and the Type of Intelligent Systems Employed

The findings presented in Table 9 are related to the type of intelligent systems employed/discussed in each research paper from 1990 to 2012. These findings illustrate that the USA is the leading research region in intelligent systems throughout this period. The total numbers of papers generated from this region was 120 with a primary focus on expert systems (with C = 25, 20.83% of 120), knowledge-based systems (with C = 23, 19.16% of 120), neural networks (with C = 20, 16.67% of 120) and genetic algorithms with (C = 17, 14.16% of 120). In second place is Taiwan which generated 56 papers, of which genetic algorithms were employed in 16 papers, followed by neural networks and fuzzy systems (with C = 11, 19.64% of 56 each, respectively). In third place is the UK with 52 papers. Papers generated from the UK mainly focused on knowledge-based systems (with C = 14, 26.92% of 52), followed by artificial intelligence (with C = 8, 15.38% of 52). One of the main findings from this analysis is that out of the top 12 regions (as illustrated in Table 9), 10 regions focused on genetic algorithms to generate intelligent solutions to the problems of the construction industry. Following genetic algorithms, in second place are neural networks which have been employed by all the top 10 regions (as illustrated in Table 9). Following the significance of genetic algorithms in the literature (e.g. Leu & Hung, 2002; Long & Ohsato, 2009; Huang & Sun, 2009; Li et al., 2010), neural networks have been the choice of many researchers due to their remarkable ability to derive meaning from complicated or imprecise data that can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques (Baalousha & Çelik, 2011; Cheng et al., 2012). A trained neural network can be thought of as an 'expert' in the category of information it has been given to analyse. This expert can then be used to provide projections given new situations of interest and answer 'what if' questions (Liao, 2004).

Geographic Region	Type of Intelligent System Employed	Total Individual Count of Intelligent System Type for Each Region
USA	Expert System (25)	**120**
	Knowledge-Based Systems (23)	
	Neural Network (20)	
	Genetic Algorithm (17)	
	Sensor Technology (13)	
	Artificial Intelligence (11)	
	Intelligent System (2)	
	Context-Aware System (2)	
	Ubiquitous Computing (2)	
	Case-based Reasoning (2)	
	Fuzzy Systems (2)	
	Decision Support System (1)	
Taiwan	Genetic Algorithm (16)	**56**
	Neural Networks (11)	
	Fuzzy Systems (11)	
	Artificial Intelligence (8)	
	Case-based Reasoning (5)	
	Knowledge-Based Systems (3)	
	Intelligent System (1)	
	Sensor Technology (1)	
UK	Knowledge-Based Systems (14)	**52**
	Artificial Intelligence (8)	
	Neural Network (7)	
	Expert System (7)	
	Genetic Algorithm (6)	
	Sensor Technology (3)	
	Fuzzy Systems (1)	
	Context-Aware System (1)	
	Decision Support System (1)	
	Fuzzy Reasoning Approach (1)	

	Artificial Intelligence (1)	
	Case-based Reasoning (1)	
	Intelligent Systems (1)	
Canada	Expert Systems (18)	**51**
	Genetic Algorithm (11)	
	Neural Network (11)	
	Knowledge-Based System (3)	
	Artificial Intelligence (3)	
	Case-based Reasoning (2)	
	Intelligent Systems (1)	
	Automated Data Collection Technology (1)	
	Sensor Technology (1)	
China	Genetic Algorithm (8)	**31**
	Neural Network (7)	
	Case-based Reasoning (4)	
	Artificial Intelligence (3)	
	Ubiquitous Computing (2)	
	Sensor Technology (1)	
	Fuzzy Systems (1)	
	Intelligent System (1)	
	Decision Support System (1)	
	Expert System (1)	
	Knowledge-Based Systems (1)	
	Ubiquitous Computing (1)	
Korea	Artificial Intelligence (8)	**29**
	Case-Based Reasoning (6)	
	Genetic Algorithm (5)	
	Ubiquitous Computing (3)	
	Expert System (3)	
	Knowledge-Based Systems (3)	
	Neural Network (1)	
Hong Kong	Genetic Algorithm (8)	**25**
	Knowledge-Based System (6)	
	Neural Network (5)	
	Decision Support System (2)	
	Case-based Reasoning (1)	
	Fuzzy Systems (1)	
	Artificial Intelligence (1)	
	Expert System (1)	
Turkey	Neural Network (5)	**15**
	Knowledge-Based Systems (3)	
	Fuzzy Systems (2)	
	Case-based Reasoning (2)	
	Sensor Technology (1)	
	Decision Support System (1)	
	Expert System (1)	
Iran	Genetic Algorithm (6)	**13**
	Fuzzy Systems (3)	
	Neural Network (1)	
	Intelligent Systems (1)	
	Decision Support System (1)	
	Expert System (1)	
Egypt	Genetic Algorithm (4)	**13**
	Neural Network (3)	
	Expert System (2)	

	Fuzzy Systems (1) Knowledge-Based System (1) Sensor Technology (1) Artificial Intelligence (1)	
Australia	Knowledge-Based Systems (4) Case-Based Reasoning (3) Expert System (2) Artificial Intelligence (1) Human-Machine Interface (1)	**11**
India	Genetic Algorithm (4) Neural Network (3) Expert Systems (1) Artificial Intelligence (1) Fuzzy Systems (1)	**10**
Singapore	Artificial Intelligence (2) Knowledge-Based Systems (2) Neural Network (2) Case-based Reasoning (1) Genetic Algorithm (1)	**8**
Spain	Neural Network (2) Embedded Systems (1) Decision Support System (1) Artificial Intelligence (1) Fuzzy Systems (1) Sensor Technology (1)	**7**
Saudi Arabia	Neural Network (5) Genetic Algorithm (2)	**7**
Portugal	Knowledge-Based Systems (2) Genetic Algorithm (2) Human-Machine Interface (1)	**5**
Italy	Knowledge-Based Systems (1) Expert System (1) Sensor Technology (1) Neural Network (1)	**4**
Malaysia	Expert System (3) Decision Support Systems (1)	**4**
Sweden	Sensor Technology (2) Knowledge-Based Systems (2)	**4**
The Netherlands	Sensor Technology (2) Case-based Reasoning (1) Knowledge-Based System (1)	**4**
Finland	Knowledge-Based Systems (1) Expert System (2)	**3**
Japan	Knowledge-Based Systems (2) Expert System (1)	**3**
Jordan	Genetic Algorithm (3)	**3**
Lithuania	Knowledge-Based System (1) Expert System (1) Intelligent System (1)	**3**
Poland	Neural Network (2) Expert System (1)	**3**
Greece	Decision Support System (1) Knowledge-Based System (1)	**2**
Ireland	Genetic Algorithm (1) Neural Network (1)	**2**

Qatar	Genetic Algorithm (2)	**2**
Serbia	Artificial Intelligence (1)	**2**
	Case-based Reasoning (1)	
Sri Lanka	Knowledge-Based Systems (1)	**2**
	Neural Network (1)	
Switzerland	Expert System (3)	**3**
Chile	Fuzzy Inference System (1)	**1**
Croatia	Expert System (1)	**1**
Cyprus	Artificial Intelligence (1)	**1**
France	Genetic Algorithm (1)	**1**
Indonesia	Intelligent Systems (1)	**1**
Israel	Expert System (1)	**1**
Mexico	Expert System (1)	**1**
Nigeria	Expert Systems (1)	**1**
Norway	Knowledge-Based Systems (1)	**1**
Oman	Knowledge-Based Systems (1)	**1**
Philippines	Genetic Algorithm (1)	**1**
Romania	Knowledge-Based Systems (1)	**1**
South Africa	Sensor Technology (1)	**1**
Thailand	Neural Network (1)	**1**
Tunisia	Case-based Reasoning (1)	**1**
Vietnam	Genetic Algorithm (1)	**1**
Yugoslavia	Artificial Intelligence (1)	**1**
48 Regions	**514**	**514 Publications**

Table 9: Association between Geographic Location and Intelligent Systems Employed/Discussed (1990 – 2012)

6. Conclusions

This paper aimed to reveal the current state of intelligent systems research published in a number of key journals (extracted from the Scopus database), thereby focusing on the historical trends and current patterns in the use of different types of intelligent system in the construction industry. Using a systematic review of 514 papers, this paper has primarily analysed the type of intelligent systems employed in construction industry related research studies between 1990 and 2012 – thus fulfilling the aim of this research (as indicated in Section 1.1). Figure 2 and Table 5 clearly indicate the historical trends and current patterns in the number of papers published on intelligent systems and the type of intelligent systems employed/discussed in each paper. As per Table 5, the genetic algorithm takes the lead with 100 papers (19.45% out of total 100%), followed by neural networks with 97 (18.87% out of total 100%), and knowledge-based systems and expert systems both with 79 papers each (i.e. 15.37% each, out of total 100%). The extensive use of these four intelligent system types also indicates that in future research studies; academics, researchers and practitioners may focus on these intelligent system types to propose robust intelligent solutions to the ever increasing problems of the construction industry. The papers selected for this profiling study focused on 14 search phrases, '*Intelligent Systems*', '*Artificial Intelligence*', '*Expert Systems*', '*Fuzzy systems*', '*Genetic Algorithms*', '*Knowledge-Based Systems*', '*Neural Networks*', '*Context-Aware Systems*', '*Embedded Systems*', '*Human-Machine Interface*', '*Sensing and Multiple Sensor Fusion*', '*Ubiquitous & Physical Computing*', '*Case-based Reasoning*' and '*Construction Industry*'.

Within this context, employing an established methodology, the paper examined a number of dimensions in the 514 papers analysed: publications in each year; geographic location of the paper; type of publication; research methods employed; type and number of intelligent systems employed; citation analysis; type of journal; and the context in which each article was published. This study has analysed the largest number of papers compared to existing review articles on the theme of '*Intelligent Systems in Construction*'. The intention in conducting this investigation was to provide a useful and usable resource of information for future researchers. The findings of this study clearly indicate a significant increase in the number of papers published on the different types of intelligent system from 1990 to 2011, although there is a sharp decrease in the number of papers in 2012 (owing to the global financial crisis in 2007-2008) with limited research conducted in earlier/later in 2011 and early 2012, resulting in fewer publications in 2012. However, increasing support to the construction industry given by the global corporations in the future is anticipated to encourage researchers and academics to publish more papers on different types of intelligent systems in the construction industry from 2013 onwards.

Based on the research conducted and understanding acquired, the authors anticipate that this research may contribute in conducting future research studies. Two areas that may require further attention from academics and researchers in the future and further work may be carried out, e.g.:

- According to Table 2, the USA region has taken the lead with the highest number of publications followed by Taiwan (with C = 56), UK (with C = 52) and Canada (with C = 51). From the total of 48 regions reported in this research, 36 regions produced less than 10 publications with 17 regions generating one publication each. Looking at the trends from 1990 to 2012, it is anticipated that more research will be conducted in the years to follow in the top four regions, leaving many regions behind with no substantial or quality research and few publications. Therefore, academics and researchers from these regions may need to explore more avenues for quality research both conceptually and empirically to generate more publications in the area of intelligent systems in the construction industry.
- According to Table 5, four types of intelligent systems i.e. *ubiquitous computing*, *context-aware systems*, *human-machine interface*, and *embedded systems* are among the least employed/discussed intelligent systems in the construction industry amounting to 14 papers (out of a total of 514) only from 1990 to 2012. Nevertheless, a significant body of research exists for each of these specialised intelligent systems areas and a number of contributions have been made towards theory and practice (e.g. Marwedel, 2003; de Vos et al., 2008; Irani et al., 2010; Rezazadeh et al., 2011; Themistocleous et al., 2012). Table 4 results indicate that these four intelligent systems types are still underexplored areas in both the academic and practical fields of the construction industry. Further research in such directions would enrich the body of knowledge in the research areas of *ubiquitous computing*, *context-aware systems*, *human-machine interface*, and *embedded systems* with a specific focus on the construction industry.

6.1 Implications for Theory and Practice

From the *theoretical implications* perspective, the authors assert that these findings may help new researchers in the intelligent systems field to identify more relevant journals to refer to and in which to publish their work. The review presented in this paper can also help new researchers to strengthen research into construction in intelligent systems by facilitating consideration of less used but useful alternative methodological perspectives. Whereas from the *practical implications* perspective, the findings in this study clearly indicate that genetic algorithms, neural networks, expert systems and knowledge-based systems appear to be preferred over other intelligent systems available such as sensor technology and case-based reasoning. The main rationale that can attributed to this is that there were more papers on genetic algorithms, neural networks, expert systems and knowledge-based systems compared to sensor technology and case-based reasoning or even context-aware systems and ubiquitous computing. We anticipate that intelligent systems and artificial intelligence researchers and practitioners will find this paper a useful source of information, especially if they wish to learn more about the various facets pertaining to the existing body of published intelligent systems research in different construction related journals.

6.2 Limitation

We fully acknowledge that our study has a *limitation*, and readers and future academics and researchers should be aware of it and indeed interpret the material presented in this paper within the context of the limitation. Using the set of 14 keywords, our search activities were restricted to the number of journals extracted from the Scopus database only, but there are many well-known journals focusing on intelligent systems and artificial intelligence (such as *Artificial Intelligence: An International Journal*, *International Journal of Neural Systems*, *International Journal of Intelligent*

Systems, *Artificial Intelligence Review*, *Journal of Intelligent Material Systems and Structures*, *Journal of Intelligent Manufacturing*, *IEEE Intelligent Systems*, *Journal of Intelligent and Robotics Systems Theory and Applications*, *Knowledge-based Systems*, *Robotics and Autonomous Systems*, *Applied Artificial Intelligence*, *IEEE Intelligent Systems and their Applications, Journal of Intelligent Systems*, *Web Intelligence and Agent Systems*, *Journal of Intelligent and Fuzzy Systems*, and *Intelligent Automation and Soft Computing*) which, although indexed in the Scopus database, did not return any papers based on the keywords. This will clearly have limited our ability to identify all relevant papers, although *further research* is required to determine the extent of the influence of such factors. Even though we consider that this paper has analysed the largest number of papers compared to other existing review papers, we believe that more comprehensive research is required in order to reduce the impact of the existing limitation we have identified in order to provide a greater understanding of the field of intelligent systems research.

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