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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 14 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.

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 (Chaphalkar & Patil, 2012; Chen, Griffs, Chen, & Chang, 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 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

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[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.

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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 and Tsai (2012) presenting a fuzzy assessment approach for occupational hazards in the construction industry;
- Jiang, Jang, and Skibniewski (2012) exploring wireless technology for tracking construction materials;
- Coelho and de Brito (2011) proposing a knowledge-based system for materials distribution;
- Ooshaksaraie, Basri, Abu Bakar, and 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; Seydel, 2003; Sonmez & Rowings, 1998). 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 1990–2012. 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