INNOVATIVE CONSTRUCTION PROCUREMENT SELECTION THROUGH AN ARTIFICIAL INTELLIGENCE APPROACH

John Andrew Lewis[1], Henry Odeyinka and Robert Eadie

School of the Built Environment, University of Ulster, Jordanstown Campus BT37 0QB, UK.

The construction industry in the British Isles has long been accused of being low tech, averse to funding research and development, and reliant on other sectors allied to construction for innovative improvements. One area has been championed as reflecting change, especially post Latham and Egan, and that is construction procurement. The last few decades have witnessed a proliferation of procurement systems and sub-systems. The methodology herein proposes to customise and innovate bespoke construction project procurement strategies through the development of an intelligent system and to discover if the new procurement methods are indeed innovative. The approach has three main phases; firstly the planning and development phase, followed by the empirical phase and thirdly; the final quasi-experimental phase. After a detailed literature review in the planning stage, the empirical phase includes a pilot survey to ascertain the precise nature of innovation within building procurement in the British Isles and establish an appropriate knowledge acquisition model. This model will be utilised within the main survey to populate a database of relevant innovative procurement case histories. In the final quasi-experimental phase; a fuzzy hierarchical case-based reasoning (CBR) platform will be software engineered as an innovative procurement selection mechanism. This will be validated and verified through a Delphi process to ascertain its effectiveness and appropriateness. The outputted fuzzy hierarchical CBR mechanism will be beneficial to the construction professional seeking innovative procurement selection ideas in the strategy and consultation stages of a building project.

Keywords: artificial intelligence, building procurement, innovation.

INTRODUCTION

The construction sector is seen as a low tech sector, (Gann and Salter, 2000), with much of the new technology being adapted from new technologies or other disciplines to “fit” into old technologies of construction. Walker and Rowlinson (2008) maintain that innovation in the construction industry is occurring increasingly within a significant change in culture. One area of construction that has seen major innovative changes in the past twenty years is the proliferation of procurement systems and paths in line with government reports by Latham (1994) and Egan (1998). Within this realm, more and more clients are demanding better and more accurate procurement methods, methods that take into account prior learning and the “bespoke” customized procurement path has become increasingly popular (Chartered Institute of Building, 2008).

[1] Ja.lewis@ulster.ac.uk

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In view of these developments the aim of the research is to customise and innovate bespoke construction project procurement strategies through the application of an artificial intelligent (AI) system. The objectives are:

- To undertake a detailed and thorough critical review of relevant literature sources of procurement systems, innovation and construction, artificial intelligence and knowledge-based systems
- To examine procurement selection methods and derive an appropriate selection model
- To identify elements of innovation in procurement systems within the construction industry
- To propose an applicable methodology to capture innovation and knowledge within project procurement
- To formulate a process to adapt and reuse knowledge of procurement to innovate new procurement strategies
- To develop and validate an intelligent system to incorporate procurement selection, knowledge capture, adaptation and reuse to produce customised procurement innovations

As part of an ongoing research program, the aim of this paper is to propose an AI methodology to accommodate new client demands by capturing and adapting previous knowledge to customize new and novel bespoke procurement routes.

INNOVATION IN CONSTRUCTION

The Latham Report (1994), the Egan Report (1998) and more recently Wolstenholme Report (2009) criticised the innovative activity of construction and thus public policy became the driving force for change. Innovation is nominally measured as a direct measure of research and development (R&D) funding. According to Gann (2000), expenditure on R&D in construction is a total of 0.5% of total revenue compared to manufacturing average of 4-5%. Moreover, Mitropoulos and Tatum (2000) defined innovation in terms of industry as" innovation can be technological, such as a new product or process technology, or administrative, as in the case of a new structure or administrative system pertaining to organisational members." (p340)

With regards to models of innovation, the Market Pull Model and the Technology Push or Science-based Models are dominant. These models rely heavily on R&D and development of new branches of science through research. Nam and Tatum (1997) understand these innovations to be prevalent within construction, but it is advances through suppliers of machinery, materials and plant that are seen to advance the construction industry. Maybe without these forms of linear innovation models from supply chains, the construction industry would be in a worse situation regarding uptake of new technologies. However, Miller *et al* (1995), suggest that one-off, high value bespoke production is often too complex to apply these simple linear models. Therefore, two further models have become synonymous within the worldwide construction sector; namely Complex Production Systems (CoPS) and Slaughter's Five Systems Models.

Winch (1998) brought this CoPS model into the construction field with his seminal work identifying the need to analyse construction innovation within two realms: "top-down" and "bottom-up". He defined "top-down" being management or project team led innovation, whereas, "bottom-up" being at an operative level where most technical innovations have to be married with real life implementation. Also during the 1990's research carried out in the USA by Slaughter (1998) emerged as a influential series of works defining innovation within construction with her model, as illustrated graphically in Figure 1, dividing construction innovations into five sub models namely:

- Incremental: Small change using standard or non-specialist equipment
- Modular: small changes in core workings either by operatives or managers
- Architectural: low level but as their sources can be both internal and external
- System: interlocking innovations requiring complex analysis beforehand
- Radical: new entrants to the construction industry with brand new products or processes that are overarching to the construction process

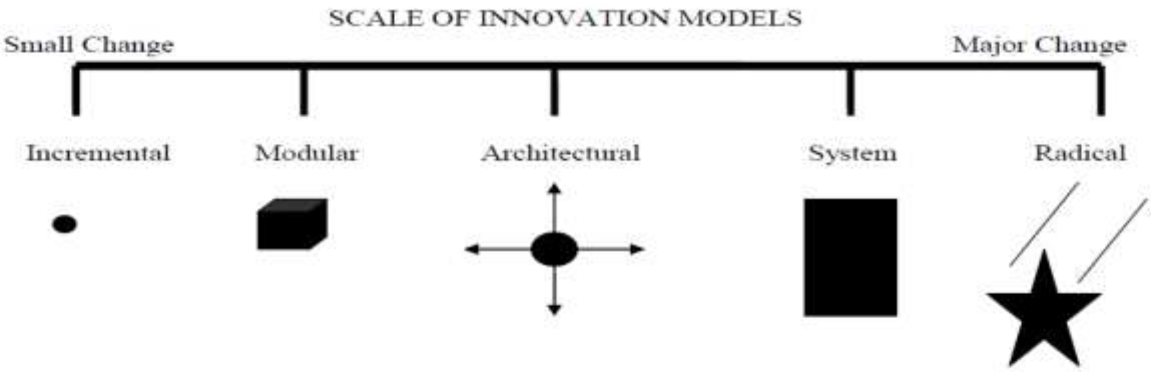

Figure 1: Innovation Models in Construction; Source: Slaughter (1998)

Before this the standard classifications of innovations in construction focused on the effects of new technologies on the construction process and not on innovations themselves.

CONSTRUCTION PROJECT PROCUREMENT

In the 1980's three reports by the National Economic Development Office (NEDO, 1983, 1985, 1988), indicated that clients were becoming disillusioned with the construction sector in the UK. The Latham Report (1994) was a joint industry and Government undertaking with the main impetus being a critique of production strategies. Therefore, as the major industry client, the UK Government would insist on a paradigm shift clearly focusing construction on delivering value for money and in a cooperative environment, (Mosey, 2009). The Egan Report (1998) through a cross industry collaborative agenda stated that project management, supply chain management, collaborative relationships through partnering and a new culture of trust was the true aim of strives for change. The Wolstenholme report (2009) updated the industry on the implementation of the Egan report (1998) and highlighted its shortcomings demanding further integration of construction professionals in projects and innovation being given a higher priority.

Procurement Selection

Procurement choices hinge on the characteristics of the client making them. Masterman (2002) suggested a client classification system which segregates clients into private or public with, primary or secondary attributes. Also he graded the level of experience through inexperienced, partially experienced to very experienced client organisations. With proliferation of procurement pathways becoming ever more complex, the procurement selection environment has become ever more intricate. To cope, it is now carried out using either a simple weighted score methods, a multi-criteria or an artificial intelligence selection method.

ARTIFICIAL INTELLIGENCE AND THE CONSTRUCTION INDUSTRY

The US Army was the first to suggest the use of an expert system in construction procurement by utilising the power of computing through AI, (Kruppenbacher, 1984). Gray and Little (1985) produced arguably the first AI engine to assist the selection of crane equipment. Ndekugri and McCaffer (1988) foretold that AI, although in its infancy would become a force within construction. The US Army produced the first AI expert knowledge-based System for contract claims in 1989 called the “Claims Guidance System”, (Kim and Adams, 1989). AI has been widely used within construction law in the construction industry with Waterman *et al* (1986) describing an expert system for legal decision making as a method to trawl through complicated case histories and funnel back information of import to the current claim. Since then many AI expert systems have been in the legal realm in construction, with artificial neural networks (ANN) forming the early machine learning platform for development.

With the advent of Case-based reasoning (CBR) from the early nineties, proliferations of expert systems were proposed. Systems were developed to manipulate data that depended on historical case information with Stottler (1992) being arguably the first in the construction industry to develop a system using CBR. Schmitt (1993) first conceived systems for construction design disciplines with excellent inputs from Perera *et al* (1995). As procurement selection depends on previous knowledge, it is has been widely suggested that CBR could assist in this field, and this will form the basis for the following methodology proposed.

RESEARCH METHODOLOGY PROPOSAL

The research program is divided into three phases, the first phase is the planning and development phase, the second is the empirical phase and finally the quasi-experimental phase as shown.

Phase 1: Planning and Development Phase

The literature review forms the basis for the development and planning phase of the research. In this the theoretical basis for the study is cemented and from which this methodology is drawn.

Phase 2: Empirical Phase

The empirical phase consists of the collection and analysis of data in order to customise and innovate a bespoke procurement selection system envisaged in this study.

The Pilot Study

The initial investigation and gathering of primary data is undertaken in a pilot study. Two models were chosen for knowledge elicitation within this phase. The first of these is the construction project procurement system model (CPPS) as proposed by Kumaraswamy and Dissanayaka (1998) as shown adapted in Figure 2, the second being from Slaughter (1998), who identified the aforementioned five system innovation model. The five procurement sub-system areas of the CPPS; work packaging, functional groupings, payment modalities, contract formation and tendering/selection methods are seen to become the roots of decision trees for the selection of precise procurement methods in each sub-system and this adapted model is tested to ensure all areas of British and Irish procurement practice are covered. Within the Procurement Sub-systems adapted and updated, the pilot study is undertaken to understand and extract innovative activities with each procurement sub-system and relate these to Slaughter's innovation model through a web-based questionnaire and then elite actors interviews.

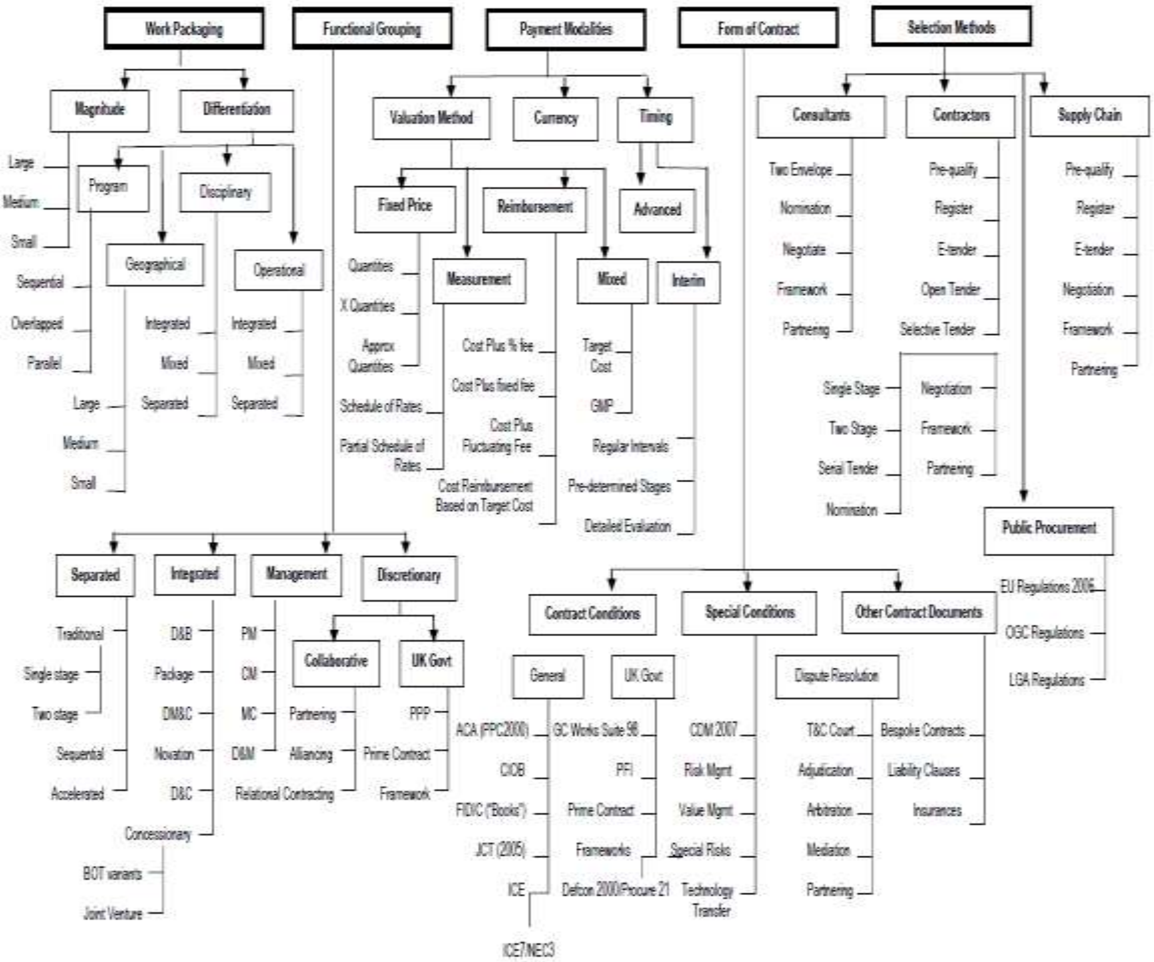

Figure 2: Construction Project Procurement Systems; adapted from: Kumaraswamy and Dissanayaka (1998)

Main Knowledge Acquisition Process for Populating the Case-base

This portion of the research forms the basis for the intelligent system to populate a case-base of innovative procurement case histories, using the pilot study information to design an appropriate case study acquisition model. The outputs from the pilot study applicable to the knowledge acquisition process are the detailed elements of innovative practice within each sub-system of the CPPS Model based upon the IMC Model. It is these aspects of innovative procurement practice that will give the intelligent system its context and deliver the aim and objectives. Video conferencing or face to face interviews with building procurement experts drawing participants from across the British Isles will be undertaken to ensure that the subsequent intelligent system will output more appropriate and innovative solutions. These knowledge acquisition interviews will be required from participant building organisations that can populate the case base drawing on individual cases with a minimum of 60 cases to be sampled in this way.

Phase 3: The Quasi-experimental Phase

In this section the precise method for the design and development of the intelligent systems is prescribed. Also the validation and verification process through the Delphi Method is proposed. The CBR cycle identified by Aamodt and Plaza (1994) has four stages, initially to retrieve similar cases to the problem description, secondly reuse a solution suggested by a similar case, then revise or adapt that solution to better fit new problem and finally retain the new solution once it has been validated.

After completion of the pilot survey, the analogue procurement selection methods as employed by construction professionals have been mapped in a decision tree format. It is this method that forms the interface that will open the AI system to the user. As the parameters of the current case are inputted the user is then prompted to retrieve cases that match from the case-base. Two methods are proposed for the retrieval of cases then ranked and averaged so that the best matched case is retrieved. Subsequently, the user is given another input interface and asked to adapt the input parameters with respect to the output solution and their thoughts on how to adapt to their specific needs. Then the users re-input the adaptation they have undergone into the retrieval mechanism for the second time. This can be done as many times as needed. This AI system is shown in Figure 3.

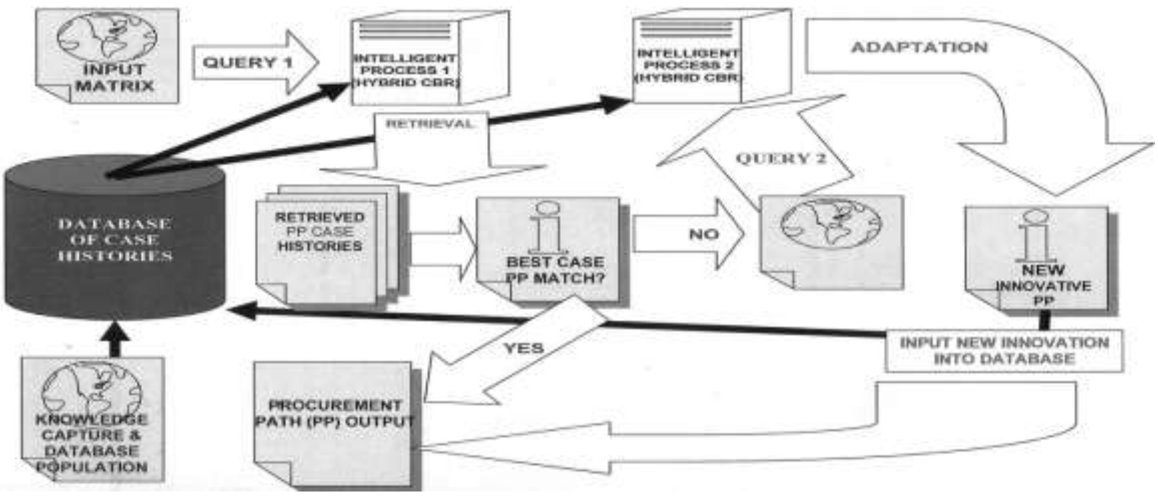

Figure 3: Schematic for Intelligent System Design

Validation and Verification of Intelligent System

The Delphi Method was formulated from scenario playing techniques and is used to form consensus from a panel of experts in the respective field of research, Turoff (1975). The Delphi process will be undertaken using online surveys to test the application of the prototype hybrid CBR system.

DISCUSSION OF ADOPTED METHODOLOGICAL APPROACH

Procurement Landscape Mapping

Some of the first decisions to be made regarding this methodological approach concerned how to describe the building procurement landscape for the construction professional in a manner applicable for AI manipulation. Kumaraswamy and Dissanayaka (1998) developed research through examining project objectives and what impacts on choices in procurement and in subsequent studies this model was further developed and used. An adapted version of this is shown in Figure 2, this is to be tested within the pilot study and refined for UK/Ireland use within the proposed expert system.

Choices in Procurement Selection

Three basic factors to be of most importance when deciding the relevant option for procuring the built asset and have been widely used as the basis for procurement selection and are described by Nahapiet and Nahapiet (1985) as: client characteristics, project requirements or project characteristics.

A simple weighted scoring method by NEDO (1985) became the cornerstone of most of the later analysis of procurement selection with Griffith and Headley (1995), Franks (1990), Bennett and Grice (1990) also developing a simple method based around a small number of criteria. A multi-criteria procurement selection method as developed by Skitmore and Marsden (1988) and their multi-attribute utility technique, later improved by Skitmore and Love (1995) further adapted client decision making by ascertaining better weightings. Molenaar and Songer (1998) developed a four criteria multi-attribute analysis model for best choice in design build procurement options and Love *et al* (1998) advanced the multi-attribute analysis by researching additional procurement scenarios.

Innovative Procurement Choices

Slaughter (1998) describes the five innovation models for construction as being ranged from rather small easily introduced adaptations of current practice, incremental, to massive innovative changes often coming from outside the industry, radical. Therefore three early choices for the methodology would have to be figured out within the pilot study, namely:

- How construction professionals choose their procurement options based on fuzzy use and expanding NEDO (1985) factor areas
- The range of procurement options available in the UK/Ireland basing this on the CPPS model
- The range and type of innovations in procurement options taken from Slaughter's IMC work

Application of CBR and Construction Procurement

What type of expert system is to be designed? By examining previous research in CBR applications within construction procurement, the type of CBR platform and the differing choices in retrieval, matching, adaptation and representation can be ascertained.

Ng (2001) proposed a CBR system using five case bases and retrieval mechanism is the simple "nearest neighbour" algorithm, and for adaptation the system simply asks the user to adapt the case or accept. Ng and Luu (2008) studied sub-contractor selection using a hybrid CBR method adopting a fuzzy retrieval mechanism with an adaptation process involving parameterisation. Luu *et al* (2003) researched procurement selection; this is thus very relevant to the current study but this research was criticised for only having a case base of 30 cases. They proposed a hybrid CBR method, the hybrid engine being the fuzzy retrieval mechanism. The parameterisation method of adaptation was further developed by Luu *et al* (2005) and Cheung *et al* (2004), who researched a hybrid agent CBR method. Most important are the conclusion that most of these are hybrid knowledge-based systems have some sort of inference, retrieval or adaptation of previous cases hence, the choices made and ruminated on for this methodology resulted in the following design for the hybrid CBR expert system architecture:

- Intelligent System 1 Retrieval: Fuzzy inference/ID3 decision tree
- Intelligent System 2 Retrieval Fuzzy inference/ID3 decision tree
- Matching System: Nearest neighbour matching
- Adaptation method: User parameterisation
- Knowledge representation method: Hierarchical case representation

Knowledge representation is based upon Watson and Perera (1998) and this mode of parameterised adaptation of cases has been widely used and gives the proposed user some control over the eventual outcome.

CONCLUSION

Previous attempts at using AI in procurement selection have been limited due to the number of procurement options involved in the research or the ineffectiveness of using too few cases for testing. Where the methodology advances current understanding, is in attempting to ascertain the entire procurement selection landscape within the British Isles. Then having mapped this successfully, proposing an intelligent system using two hybrid fuzzy CBR systems interlinked and capable of eliciting effective procurement choices for the client or construction professional. Using Slaughter's (1998) IMC Model through five levels of innovation in terms of products, processes or administrative and organisational advances in the maze of procurement pathways sets this methodology apart from others. Basing the hierarchical decision tree matrix on an adapted CPPS Model first suggested by Kumaraswamy and Dissanayaka (1998) is also extending previous expertise. After successfully initiating this prototype method for capturing innovative and adaptive construction procurement knowledge in the British Isles, other interested researchers could add to this to unlock a national or even international database of the best and most up to date procurement methods available.

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