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Designing for Construction Procurement; an Integrated Decision Support Systems for Building Information Modelling

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Purpose: Many applications of Building Information modelling (BIM) are already integrated into project management processes. However, the construction industry is suffering from poor decision making, especially during procurement where fundamental decisions are made. In order to make the best decisions in earlier project stages such as design; large amount of information needs to be processed and classified. Therefore, this study seeks to create a Decision Support System (DSS) for construction procurement through the application of existing informatics infrastructure and BIM applications.

Methodology: Literature review expert interviews and case studies with complex procurement considerations were used to identify and validate attributes ad criterions for procurement decision-making. Accordingly, Multi Attribute Utility Theory (MAUT) methodology was used and mathematical models were driven as the foundation for a DSS.

Findings: Five major criterions of time, cost, relationship quality, sustainability and quality of work performed was identified for complex construction procurement decision-making. Accordingly, a DSS structure and mathematical model was proposed. Based on this a model architecture was proposed for the integration of the DSS into Autodesk Revit as a BIM platform, and assist in pre-contract decision making. In addition, suggestions for post-contract DSS and its integration with BIM is provided.

Practical implications: The results can be used to integrate the DSS outputs to nD models, cloud computing and potentially virtual reality facilities to facilitate better construction operations and smarter more automated processes. The outcomes may also be used directly in the pre-contract selection criteria for contractors and suppliers.

Originality/value: This study formulates and captures complex and unstructured information on construction procurement into a practical DSS model. The study provides a link to integrate solutions with already available platforms and technologies. The study also introduces the concept of designing for procurement as well as other specifications and construction requirements.

KEYWORDS: Decision Support Systems (DSS), Building information modelling (BIM); Multi Criteria Decision making (MCDM); Construction procurement; Multi Attribute Utility Theory (MAUT)

1. Introduction

The ability to make timely decisions is always vital in construction projects, the rule of thumb is to make informed decisions as early as possible. However, this is often a great challenge due to huge uncertainty, unavailability of structured processes and evaluation techniques. On the other hand, failing to make appropriate decisions at critical stages specially procurement can be detrimental to the outcome of construction projects. It can rapidly lend to huge costs and time overrun leading to project failure. This issue of decision making is extremely complex for construction projects because these projects are temporary and inherently complex, multifaceted with large number of tasks, multiple stakeholders, constraints and criteria (Jelodar *et al.*, 2016b). Especially in procurement related matters which range from contractor selection to decisions regarding building systems such as traditional cast in-situ, prefabrication, linear, modular, or panelised components in addition to transportation and handling requirements. For instance, concrete panels have special consideration for lifting hoisting, placing and erection and joints; which require the selection of specialised contractors and crews to carry out the work. Accordingly, there may be no absolute right or wrong decision, but the question is what could be the best decision with the optimal outcome which can contribute to project success. Supplier and crew selection normally involves a range of quantitative and qualitative factors (Sanayei *et al.*, 2008). Therefore, it is critical to make the best procurement decision at the right time and potentially the earliest possible time in project to increase chances of project success. Often due to large number of factors, data and information processing is required for such decisions information technology applications are used. However, integrating these applications with other modern tools and platforms used for design and project management is a big problem.

2. Background

In modern construction project management, the idea of collecting and managing data via the use of information technology is gaining popularity by the day. These new developed informatics infrastructures allow handling of big data which can have diverse applications and be interpreted for multiple purposes. The tools which have the capability to store, manage, classify and interface with potential users (clients, architects, engineers, contractors, suppliers, manufacturers, builder, etc.) are emerging with these advancements. BIM originally surfaced as an integration tool and was used for modelling applications, however recently it has been an interface of information for different users and applications through assortment of different input sources (Oh *et al.*, 2015; Oti *et al.*, 2016). Furthermore, compilation of raw data from design, detailed specification, schedule cost, sustainability and project lifecycle issues has become possible (Santos *et al.*, 2017). In addition, since the information technology revolution in the 60s and 70s an ongoing tendency existed towards the application of computerised decision support technology to process large number of complex models in a timely manner. The technology has made huge improvements to the quality of decision making processes by sharing, accumulating and updating information accurately; making processing much easier and faster with less human error (Lu *et al.*, 2007). With further advancement in computer programming and graphic capabilities the demand for decision making tools has increased and their application has amplified exponentially in all disciplines (Zopounidis and Doumpos, 2017).

The construction industry is also trying to apply more of the technological advancements; for instance, being able to estimate operation costs for a facility has always been desired and now is much more effectively achievable with the emergence of schematic design technologies and BIM in construction. The concept of life cycle costs and project whole life value has been rejuvenated through the application of BIM and is increasingly factored in decision making process. This is apparent in studies such as Jalaei *et al.* (2015) and Kainuma and Tawara (2006); where early design analysis for sustainability, energy performance and whole life cycle value has become more accessible and feasible as part of different decision making processes. Despite this the construction industry is still considered to be rudimentary and ineffective for the application of information technology especially in decision making processes of earlier project phases such as design. The design decisions generally have the most impact and are the less costly decisions for the project outcome. therefore, it is extremely important for designers to understand different project processes and potential implications of their design. Many researchers have tried to introduce Decision Support Systems (DSS) for multitude of purposes within construction projects (Jelodar *et al.*, 2014), but generally the industry is lacking integrated methodology; especially smarter tools which can automatically act on unstructured input data via available matrices to evaluate, demonstrate and visualise the outcomes in different formats and design scenarios (Kim *et al.*, 2015).

Generally decision making happens through gathering intelligence, process design, and making a choice followed by implementation (Lu et al., 2007). The prospective DSS has to have the ability to extract data from various sources and structure them. In many cases DSS deals with qualitative and unquantifiable information to make it practical for use; which will give the DSS a semi-structured formation (Jelodar et al., 2014; Lu et al., 2007). As the users gain experience and organisations complete their databases of different products, suppliers and collaborators; some sort of decision support tool is required to manage large proportions of data with many iterations and trials. Accordingly, the problem of compatibility with different platforms arises. For instance, in a conceptual design created in Autodesk Revit a plug-in may be needs to give the DSS an information inputting system which must be workable and easy to use. This is then coded and added as a user interface via an appropriate programming language.

Therefore, this study aims to conceptualise and create a mathematical tool which could be integrated through a user interface within conventional BIM platforms and applications such Autodesk Revit. In order to have a fully operationalised DSS databases must be completed and the model must be tested rigorously by means of making choices, validation and implementation (Lu et al., 2007). Due to the vast nature of the problem this study focuses on pre-contract decision making and further testing of the model is not included in the scope of this research; hence will be extended in future studies. The outcome of this study is a conceptual DSS which can be integrated and tested for databases on real projects. This is done through development of external databases which can be launched with a path to predefined library of BIM tools.

3. Methodology

To achieve the objective of this study three different stages are design and executed in sequence. These stages are discussed in this section.

Stage One Theoretical Conceptualisation: Initially the necessities of DSS for construction procurement is investigated through the review of relevant literature form well respected and recent sources. The literature search is the extension of the author's previous work on construction procurement literature (Jelodar *et al.*, 2016a, 2016b). Since the problem is multi criteria in nature, the literature findings focus on what kind of decisions should be considered and what their respected criteria and attributes are. The literature review results were validated through expert interviews. A total of thirteen experts responded to the multi criteria notion of procurement decision making. The experts were highly ranked managers and experienced construction project participants in New Zealand with minimum of ten and a maximum of 40 years of experience. The interviewees were involved in a mix of projects working as part of client, contractor and consultancy organisations with credible affiliations to construction industry bodies.

Stage two case studies: Three case studies were identified to look at their characteristics and criteria influencing procurement decisions. The case studies were selected based on access to information; use of software and IT tools and project complexity and multi-functionality. The results were classified and tabulated to provide triangulation of knowledge for the findings in the previous stage. The aim was to

Stage three Model formulation: After initial information was gathered on the criteria, parameters and type of decisions to be addressed the DSS model was defined and formulated using the Multi Attribute Utility Theory Method (MAUT). This techniques has been used in cases of semi structured decision making tools where both qualitative and quantitative data needs to be considered (Farajian and Cui, 2011). Based on a mathematical framework utility functions are defined and through scaling methods the function weights are identified which basically form the DSS. The solution function is parametric and results into a weighted matrices system ready for computer coding. In accordance a model architecture is proposed for the integration of the developed DSS into the BIM platform through Autodesk.

4. Results of Theoretical Conceptualisation

The construction procurement is a vast a multifaceted phase which extends through different periods of time. Some of the decisions a solely made by the client some are made by the contractor and some even by the sub-contractor or tradesmen involved. In addition some decisions are made as a joint informed effort (Jelodar et al., 2016a). As a consequence, any DSS should factor in these issues. For instance, at the tender or in cases of negotiated contracts the main decision effecting the procurement would be for the client to actually choose a contractor. Material is normally selected based on known properties or previous use; however challenges are inherent in this approach, such as expectations, how does it fit in standards, budgets, resources required, skills, capabilities to handle and implement (Jalaei et al., 2015). For supplier selection capacity, price, lead time, customer service, and quality are the attributes to consider (Jelodar et al., 2016a; Kainuma and Tawara, 2006; Scott *et al.*, 2015)

Looking into the project timeline and depending on the procurement strategy different parties are involved with different liabilities and responsibilities for construction procurement and the whole project itself (New Zealand Council of Infrastructure Development, 2013). Furthermore, the development of logic and flowchart requires the identification of what kind of decisions are to be made during the procurement process. Then it can be decided that the DSS should function on a top-down or a bottom-up approach. Some of the decisions prior to contract are taken by the client team which could be inclusive of designers and architects. The main issue would be to find a prospective contractor weather through tender or negotiations to adhere their concerns and be able to build the facility with the standard required in an efficient manner (Walker and Hampson, 2003).

Please insert Table I

The above-mentioned timeline and project life cycle represent only a fraction of the facilities overall lifecycle and captures the conception only. The broader picture is the whole life cycle of the built facility post construction and handover into operation, maintenance and finally to demolition (Jalaei et al., 2015). Therefore, decisions made at design and conception will affect all future phases of the facility and its whole life value. Considerations such as operation costs, energy consumption, regular and major maintenance, waste management, sustainability and green rating of the products used become an inevitable part of the decision-making process. However, at post-contract stage the contractor is also involved in decision making; hence for better constructability and maximising project outcomes it is recommended that the contractor should be involved as earliest possible, even in the design phase. This would significantly reduce errors, rework and waste (Jelodar *et al.*, 2013). With the aid of BIM applications design alternatives can be assessed and potentially compared even in early conceptual stages. This is performed through recognition of prospective Life Cycle Costs (LCC) for components and the built facility (Jalaei et al., 2015).

Acknowledging these facts, means that the DSS should have a double mechanism one for very early decisions such as contractor selection with the ability to run in the conceptual planning phase. The second mechanism should consider the involvement of the project team and clients for making design and procurement decisions early in project lifecycle, which could entail material selection, supplier and logistics decisions. Table I demonstrated the main attributes and criteria for different procurement decisions identified through literature and validated via expert interviews. The results are classified into three broad groups of contractor selection, material selection and supplier and logistics. Patterns and trends of time, cost and cost related issues in procurement decision are dominant within the results. However, strategic and long-term relationship with issues of sustainability and energy efficiency were also identified in decision trends.

5. Case study results

The case studies provided insight as to how procurement and logistics decisions are made. Three cases were chosen to reflect the complexity of the construction project and decision-making criterions. The cases were classified and documented in Table II. All cases had some type of data visualisation and modelling capability; however, the more recent of all case 1: airport department terminal had the most sophisticated application of BIM platforms to aid in design and construction management (Table II). This suggests that most modern construction cases have access to visualisation or modelling capabilities which could be influential in different DSS applications; this is in line with the current trends of BIM and construction modelling application in construction decision-making and management (Ahn *et al.*, 2019; Pan and Zhang, 2020).

The obvious step in all cases was cost profiling of all activities and having a realistic cost-benefit analysis for the purpose of each project as a common success and critical consideration of construction projects (Bortolini *et al.*, 2019; L. Chen *et al.*, 2018; Q. Chen *et al.*, 2016). The requirements and the success criteria of each project was different, for instance in the airport case (Case 2) the challenge was to keep the airport safely operational while construction was ongoing. In the case of the hospital (Case 2) the control of noise and hazardous material and minimum disturbance was key; the hospital development was funded on a tight District Health Board (DHB) budget and required further sources of funding to fully evaluate the sustainability strategy requirements and implementation. The project had ambitious sustainability goals; which incurred extra costs to initiate, however the final cost was lower than estimate.

Please insert Table II

For case 3, primarily an educational building was designed with special facilities to house research and lab equipment. The university campus is located in the dense urban environment making access challenging. In addition, during semester periods the campus is filled with students and people on foot which work closely to the construction site; crating hazards which required extra provisions. The university has special suppliers and contractors with long-term strategic relationships who are involved in project procurement too. This trend of involving other stakeholders and contractors early on was also observed in the hospital case (Case 2) as well; where strategic long-term relationships of DHB with multiple stakeholders was considered in creating the collaborative design brief.

What is apparent is that project success criteria have changed with the modern development of the industry. It is no longer just time, cost quality only focused anymore; other factors such as sustainability, carbon footprint, strategic relationships and quality of these relationships have become major factors to consider (Aga *et al.*, 2016; Pal *et al.*, 2017; Zou *et al.*, 2014). Accordingly, these are also reflected in the procurement strategies and decisions too (L. Chen et al., 2018; Shen *et al.*, 2017), as illustrated by the three case studies. Finally, five major criterions of time, cost, relationship quality, sustainability and quality of work performed was identified for construction procurement decision-making. This is in line with the findings of the literature and interviews in the previous phase. Detailed description of Procurement decision-making factors for the three cases are included in Table II.

6. Model formulation

The client makes initial decisions regarding procurement of construction projects. These decisions are made on different issues. Traditionally, where the lowest cost bidder was the dominant selection criteria, other attributes were neglected and led to all sorts of problems in the project. The attributes which are of concern have been identified through a range of studies and industry reports. The attributes were refined and confirmed through expert interviews and further case studies (Table 1 and 2). However, the greater problem is how to compare and evaluate these naturally different attributes and how to weigh them against each other. In decision-making this is done to find the best possible combination of attributes and identification of the best alternative (Greco *et al.*, 2016). In this case because of the studies focus on pre-contract decisions and contractor selection it would be a contractor profile best fitting for the job. Hence with the range of qualitative and quantitate attributes to consider it is very much like "comparing apples and oranges".

These type of comparisons are often termed as Multi Criteria Decision Making (MCDM); and one of the popular methods is the use of utility functions for evaluating choices (Zopounidis and Doumpos, 2017). Through handling actual trade-offs among multiple attributes, the utility function converts numerical attribute scales into a unified numerical utility scale for those attributes. This numerically representation can be used in reconstructing choices and their corresponding values allowing for direct comparisons of choice, attributes and profiles (Hillier and Lieberman, 2010). Hence the utility function serves as a method to unify the scales and unites in order for comparison to happen, and this particular method of MCDM is called the

Multi Attribute Utility theory (MAUT)(El Sawalhi and El Agha, 2017; Farajian and Cui, 2011; Jelodar et al., 2014). Consequently, this method would be appropriate for the current study and is intended to mathematically capture the utility functions for all the potential contractor profiles as part of the decision-making process. For the resolution of MAUT method and developing the DSS the utility of five major attributes for contractor selection indicated in Table I and II are defined in this section.

6.1 The utility function definitions

Utility of cost profile U(CP): this attribute considers all the costs incurred on the project. The estimated cost used is based on the preliminary conceptual design with limited information. Normally the preliminary design is generated through Autodesk Revit software package which is considered as part of the BIM platform, and the cost data will be generated accordingly using the various built in and external databases. Independent estimation using other software's can also be performed and integrated into the BIM platform. The gaol is to maximise the utility function of this attribute by minimising project costs.

Utility of time profile U(TP): this attribute considers the project duration. The estimate will be also based on preliminary information, drawings, and conceptualisation of the project with limited details and technical specifications. Can be generated through Autodesk Revit and other software's with the potential to integrate into a BIM platform. The gaol is to maximise the utility function of this attribute by minimising project time.

Utility for relationship quality Utility U(RQ): this attribute takes into account strategic alliances and benefits of working long-term with different parties (contractors in this case). It may be based on historical data and reputation of the parties in question, and the way that they have handled problems, conflicts and other stakeholders in their past projects. To some extent relies on independent investigation, collection of historical data and profiling of the prospective parties. This is a qualitative attribute and the goal would be to maximise its associated utility function by seeking maximum strategic relationship quality with a contractor.

Utility of sustainability U(S): this attribute considers the contractors experience and ability to work under sustainability regulations and codes of practice. It can be measured by waste management track records, energy consumption during the project and how much the built facility adheres to green and sustainable ratings. Also requires external data collection and profiling of the contractors. The contractors could also be asked to estimate waste and energy consumptions based on the preliminary conceptual design and propose initial structural systems and components for the project. However, this will be just a preliminary measure and based on the limited information available which will require detail information and specification once contract has been awarded. As a rough estimate a life cycle cost exercise can be performed within the BIM platform by potential contractors. The goal would be to maximise this utility function by seeking maximum sustainable solutions and outcomes.

Utility for Quality of work performed U(Q): this attribute takes into account the overall satisfaction of previous clients and stakeholders with the potential contractors. Does the final product or facility conform to the project specifications and whether the stakeholders are happy with the project delivery process. This would be another qualitative assessment and profiling may be required. The evidence and data could be hard to obtain; however, the overall reputation of the parties could be used as an initial indicator. The goal would be to maximise this utility function by seeking maximum quality of work.

6.2 mathematics formulation of model

The core assumption is that of Mutual Utility Independence:

"Utility for attribute X is independent of attribute Y if and only if

for any lotteries $[(X, y_i)]_1$ and $[(X, y_i)]_2$ over space of $X \times Y$ with Y fixed to value y_i, we have $[(X, y_i)]_1 \preccurlyeq [(X, y_i)]_2 \longrightarrow [(X, y_k)]_1 \preccurlyeq [(X, y_k)]_2 \; \forall \, y_k$ of Y"

The implication is that a change in preference order of any one criterion/attribute for instance sustainability does not change the rank of others such as relationship quality, cost profile, time profile and quality. Since the property of Preferential Independence assumption is weaker than Mutual Utility Independence it is also assumed to be true. Therefore, a multiplicative utility function is appropriate for this model:

$$U(x_1,x_2,\ldots,x_n) = \frac{1}{K}\left(\prod_{i=1}^{n}[Kk_iU_i(x_i)+1]-1\right) \qquad \textbf{(1)}$$

Where:

$$(1+K) = \prod_{i=1}^{n}(1+Kk_i), \quad 0 < U_i(x_i) < 1, \quad 0 < U(x_1,x_2,\ldots,x_n) < 1$$

The utility function comprised of all the contributing attributes is derives for the DSS as demonstrated in Formula 2. The aim would be to maximise this function by choosing the best fitting contractor.

$$U(CT, TP, RQ, S, Q) = \frac{1}{K}\left(\prod_{i=1}^{n}[Kk_iU_i(x_i)+1]-1\right) \qquad \textbf{(2)}$$

Where:

CT: Cost Performance; *TP*: Time Performance; *RQ*: Relationship Quality; *S*: Sustainability; *Q*: Quality of work

Using the equivalent lotteries method the utility function of different attributes can be evaluated and scaling factors are identified (Hillier and Lieberman, 2010; Jelodar et al., 2014). In order to do this first the best possible scenario and the worst possible scenario of utility functions are defined. For instance, the utility of minimum cost and time option plus maximum relationship quality, sustainability and quality of work should be the ideal choice and is assigned a utility of 1. On the contrary the utility of maximum cost and time with minimum relationship quality, sustainability and quality of work would obviously be the worst case and is assigned the utility of 0 as demonstrated below:

Best: $U(min\ CT, \min TP, max\ RQ, max\ S, max\ Q) = U(1,1,1,1,1) = 1$

Worst: $U(max\ CT, max\ TP, min\ RQ, min\ S, min\ Q) = U(0,0,0,0,0) = 0$

On the formation of equivalent lotteries demonstrated in Figure 1, alternative lottery 1 which is between the best and worst possible utility function is weighed against alternative lottery 2 with minimum cost [$U(CP) = 1$], and decision makers are asked at what value of p there choice would be indifferent between alternative lottery 1 and 2.

Please insert Figure 1

For instance, in the above figure, if the decision maker is indifferent at p=33%, then $U(Cost) = U(1,0,0,0,0) = 0.33$ and consequently k_1=0.33.

Please insert Figure 2

Figure 2 demonstrates equivalent lotteries for maximum relationship quality [$U(RQ) = 1$] for scaling purposes and attaining k_3. The same process is require for $U(TP) = 1$, $U(S) = 1$ and $U(Q) = 1$ to obtain k_2 ,k_4 and k_5 as the required scaling factors for the utility function of Formula 2. Accordingly, K is obtained by including all the identified $k_i$into Formula 2 and solving it for the best possible utility scenario [$U(1,1,1,1,1) = 1$] as follows:

$$K = \prod_{i=1}^{n} [Kk_i U_i(x_i) + 1] - 1 \qquad \textbf{(3)}$$

All above process should be performed for the number of prospective contractor's whether in a bidding process or in negotiation. A matrix of all the scaling factors are created to assist the decision maker which structure and transforms the data require for the DSS (Table III). This allows for the calculation of individual utilities for each contractor; and the greater utility demonstrates the higher rank order and more fit for purpose contractor. This outcome can be integrated via programming language and as a plug-in to Autodesk Revit.

Please insert Table III

7. Integration and model Architecture

The question after conceptualisation and mathematical formulation of the model is how to integrate the DSS within the available BIM platform and popular applications such as Autodesk. Such integration will require a model architecture and generally information must be inputted, analysed weighed against criteria and output structured information obtained. According to this a conceptual illustration of model architecture is provided in Figure 3.

The model divided the decision-making process into two different stages of pre and post contract. The pre-contract stage is mainly about the contractor selection and uses the MAUT mathematical model developed in section 6 as its foundation. With the lowest detail of information during conceptual design, which is generally part of contract document, and with the aid of Autodesk Revit the early decisions could be made. In selecting a contractor certain profile data must be collected as inputs and weighed against the criteria. The recommended process of integration would entail acquiring data directly and indirectly from the potential contractors. Thus, during negotiation or tender stage an interview or survey questionnaire can be developed and used as a medium of collecting such data.

In cases where a preliminary conceptual design has been developed by the designer shared document through a BIM interface could also be used to get the necessary information from the prospective contractors. This approach revolves around the collaboration of client, designer (architect) and contractor. However, while all parties will contribute; the actual decision making is only performed by the client. An integrated interface can be designed which could be shared between clients and potential contractors. Often appropriate programming languages such as C# (C Sharp) which is quite popular are used. C# is and object-oriented language with significant versatility which great for developing windows desktop and mobile apps (Jalaei et al., 2015). The interface will generally collect and structure data on the five identified attributes of the developed DSS in section 6. All the inputs to the system are illustrated in Figure 3.

With the selection of a contractor and along with the analysis of design, structural systems and building components; more information emerges. This information can be also used to make further advance decisions in material and subcontractor selection. Different issues need to be considered which are possible with the involvement of the main contractor and the availability of alternative designs. In the selection of the material its cost effectiveness, durability, environmental impact, user wellbeing impact, suppliers, logistics, aesthetics and architectural appeal become important decisions to consider. The post-contract decisions have not been the focus of current study, however the model in Figure 3 explains how a modified version of the DSS could fit well and be integrated into the system. The amount of information will exponentially grow post contract and a broader and more in-depth matrix is required to capture all the data points. This would be a more advanced and extended interface of the pre-contract DSS. The TOPSIS method in combination with Entropy Weighting Approach will be a suitable mathematical foundation for such DSS (Jalaei et al., 2015). For the extended advance interface which will be used for material, supplier and sub-contractor selection the ability to import from multiple platforms and formats is crucial. This is because data with different output formats will be gathered from multiple Database Management Systems (DBMS) and software.

Please insert Figure 3

7. Conclusion

This study has recognised the need for more automated and facilitated decision support systems (DSS) specially through the uses of information technology and specifically based on the available BIM applications. However, such grand and versatile informatics infrastructure is extremely underutilised and not enough innovative systems have been derived for the construction sector. The current study has sought to develop a DSS for the often problematic and complex procurement phase in construction. Procurement decisions are fundamentally different at pre-contract and post-contract stages; hence a distinction has been made; with the current study mainly focusing on pre-contract decision making. This enables parties involved in the earlier conceptual and design phase of the project to make informed decisions based on available data. Therefore, enabling design for procurement as well as design for structural integrity and construction.

Such decisions revolve around main contractor selection and are of mulita criteria nature. A series of interviews and detailed case studies were performed to look at decision-making process during construction procurement (Table I and II). Accordingly, Cost Performance; Time Performance; Relationship Quality; Sustainability; and Quality of work were identified as main attributes for construction procurement decisions and contractor selection. The practical provisions of different procurement scenarios have been documented through three complex construction cases with higher level success criteria. These practical implications were seen in the actual DSS model formulation. Using Multi Attribute Utility Theory (MAUT) the utility functions were developed and disseminated as mathematical foundations of calculating utility values for potential contractors. This DSS allowed the clients to rank contractors based on their utility values and identify the most fit for purpose profile.

A conceptual model architecture is proposed for integration of the developed DSS with the available BIM platforms such as Autodesk Revit. A Plug-in is suggested for the DSS via programming through C#. The plug-in can provide a collaborative interface between main project stakeholders to input various information both pre and post contract. However, the pre-contract decision makers will generally be clients while post-contract DSS tools should be available to the project team which could comprise of clients, contractors and designers. These results may also be used to integrate the DSS outputs to nD models, cloud computing and potentially virtual reality facilities to facilitate better construction operations and processes.

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Table I: Classification of construction procurement decisions attributes and criteria

	Procurement Decisions		
	Contractor selection	**Material selection**	**Supplier and logistics**
Main attributes	Time performance Cost performance Strategic relationships (long term collaborations for business goals) Sustainability issues (waste management, energy consumption, life cycle costs) Quality of work	Quality and durability Lean and green Energy efficient Return on Asset Replacing and Maintenance Waste minimisation Supply chain performance	Handling Transportation Lead-time Cost Crew Customer services

Table II: Summary of case studies

Case studies	Project information	Specification and features		Procurement decision-making factors
Case1: Airport-departure terminal	• Demolish parts of the existing structure from the 1970s and 1990s; build some entirely new sections; some parts adaptive re-use • Doubled the size of the departure processing zone, New passenger lounge and duty-free shopping hub. • Early Contractor Involvement • With over 600 workers on site during peak times	Covered area Construction time Designed elements Budget Improve architectural design Data visualization BIM/3D modelling	32,000 m^2 additional floor space 3 years 15 large trusses, 4.5m deep, between 26m and 52m in length and weighing 12-32 tonnes; 2,000 m^3 concrete used; 2,000 tonnes of steel used $200 Million ✓ ✓ ✓	• The need to minimize impact on passenger movements and disruption to flight schedules (Time and schedule Constraints) • The airport has significant economic, commercial and logistical value and had to be operational during construction (Cost of closing) • Unreliable weather conditions (Time constraints) • Heavy load transportation (Time and Cost issues) • Use of landside storage for large pieces (Access and Time constraints)
Case2: Hospital redevelopment	• Design brief was collaboratively developed via key stakeholders • Future-focused inclusive planning and universal design • Low impact re-use of existing buildings, and waste strategies were adopted; recycling as much material as possible • Intensive use during construction and highly serviced nature	Covered area Construction time Design brief Contract value Improve functionality Data visualization 3D modelling	14,700 m^2 3 years Simple pitched/barrel-vaulted roofs; Post-tensioned ground floor slab; Polypropylene hot and cold pipework $35 million ✓ ✓ ✓ No BIM	• Long term collaboration of stakeholders, contractor and suppliers (strategic and key relationships) • Use of sustainable material (Cost implication) • Required special suppliers; reliable and high-quality material; especially for the hospital's finishes (costs due to sensitive functionality). • Operational use during construction was maintained (Time constraint and schedule issue) • Control of noise, dust and pollutants for the hospital environment (time and cost implications)
Case 3: University Multipurpose Building	• To house the faculty of science • Also Included refurbishment and seismic strengthening of two existing structures plus a link structure • Staged construction to ensure continuity of operations for the faculty • A state-of-the-art research and teaching facility • Use of sustainable material and design for sustainability functions	Covered area Construction time Designed elements Project Cost Improve functionality Data visualization 3D modelling	23,500 m^2 5 years upgrade A 13-storey building; steel-braced frame structure; 4,900m3 of concrete and; 960km of rebar 2,600 tonnes of structural Steel; 600 tonnes of cellular beams $290 million ✓ ✓ CAD-based 3D-modelling	• Academic calendar year influenced logistics, traffic and functionality of the site (Time and access restrictions) • Restricted urban area and limited storage (Cost of logistics and delivery) • Contractor and client working on multiple projects (strategic relationships and reputation) • The first building in NZ to procure Special Buckling Restrained Braces (BRBs) from USA, involved pre-qualification process (Cost and time issues) • Early input for local steel fabricators; strategic collaboration based on project complexity and others concurrent projects (Relationships).

Table III: Scaling matrix for the outcome utility functions

	K_{CT}	K_{TP}	K_{RQ}	K_S	K_Q	**Overall K**
Contractor 1	k_1	k_2	k_3	k_4	k_5	$K_{Contractor\ 1}$
Contractor 2	k_1	k_2	k_3	k_4	k_5	$K_{Contractor\ 2}$
Contractor 3	k_1	k_2	k_3	k_4	k_5	$K_{Contractor\ 3}$
Contractor 4	k_1	k_2	k_3	k_4	k_5	$K_{Contractor\ 4}$

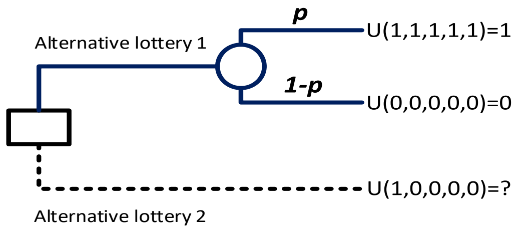

Figure 1: Equivalent lotteries for scaling factors of $U(CP)$

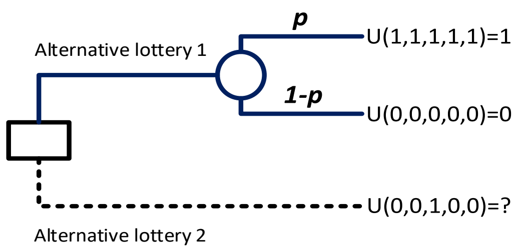

Figure 2: Equivalent lotteries for scaling factors of $U(RQ)$

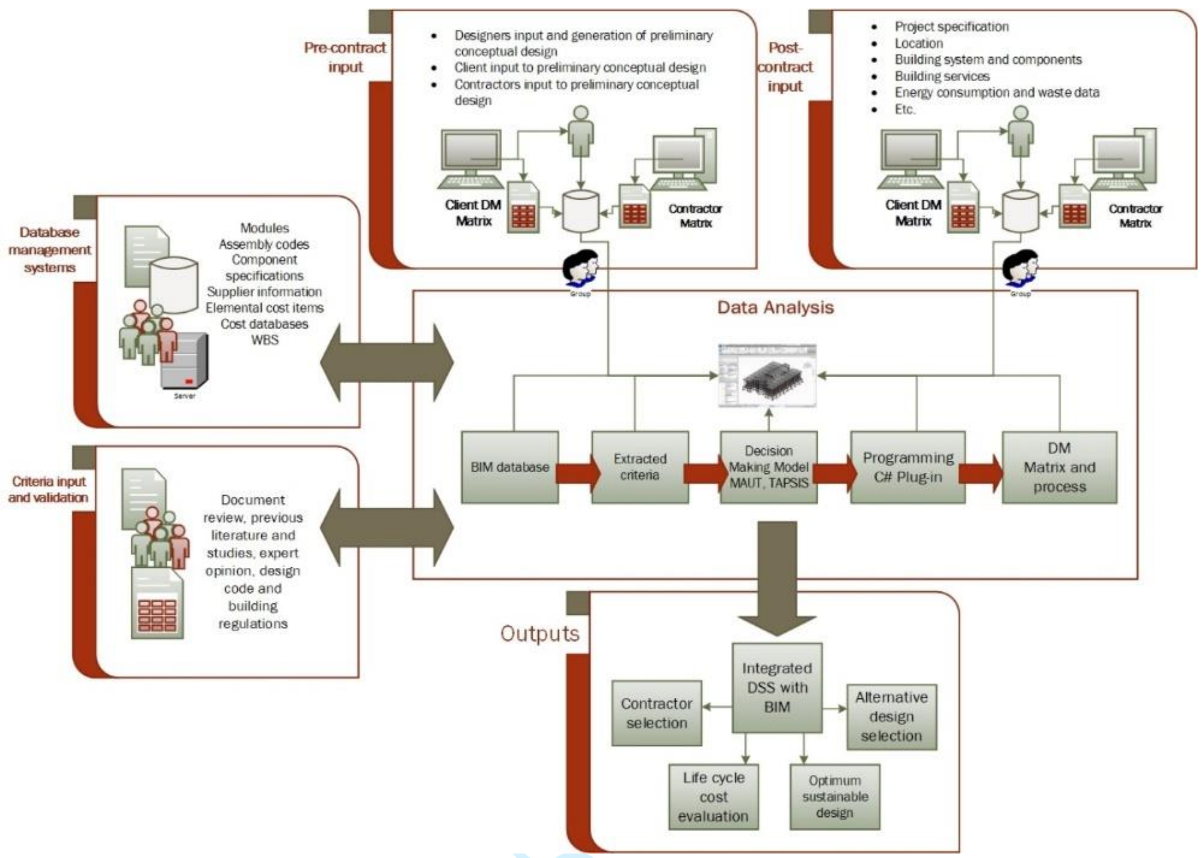

Figure 3: Model architecture for the integrated DSS with BIM

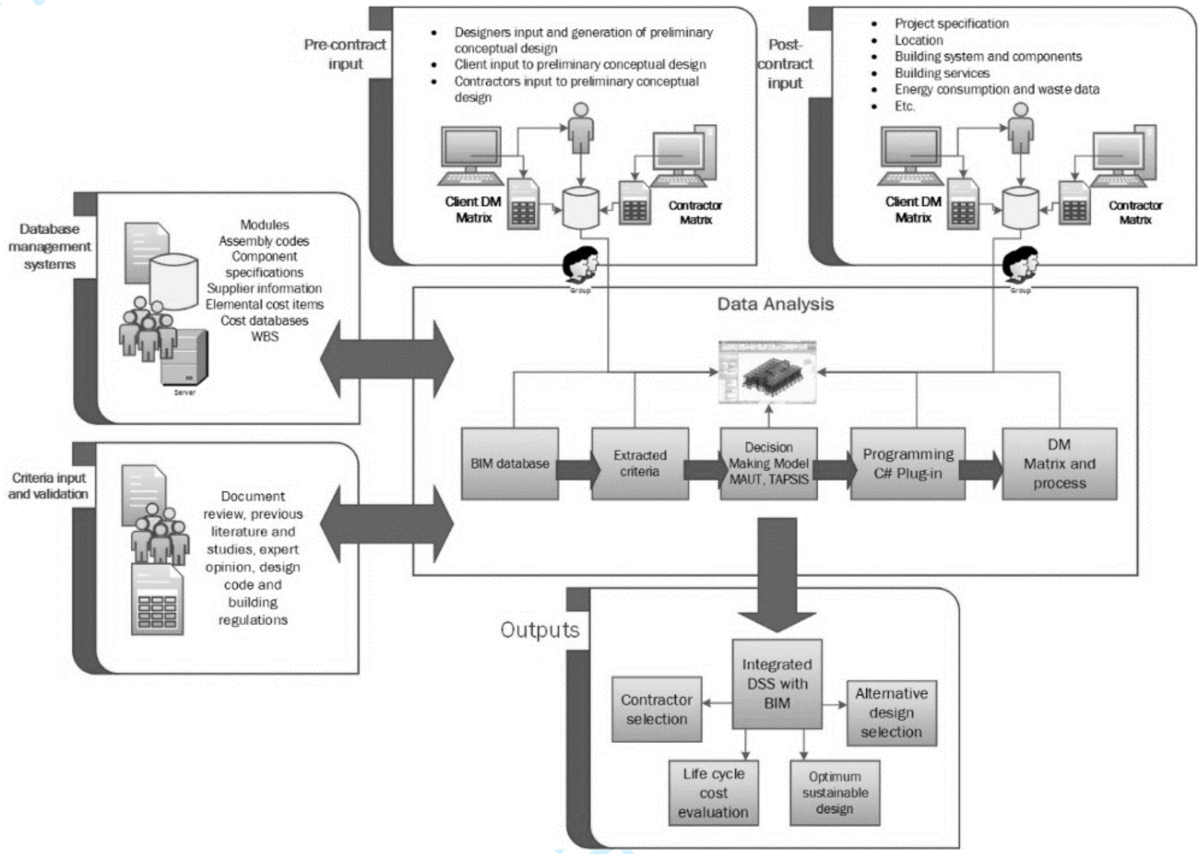

Figure 3: Model architecture for the integrated DSS with BIM