# P1141

# Assessment of Buildability Information by a Bayesian-based Evaluation Model

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**Abstract:** Construction design is a process through which the designers render the client's needs into a practical solution. The processes during construction rely heavily on the availability and transfer of information between all stages and parties involved. The construction process is a fusion of several disciplines and so requires a multidisciplinary information flow. In the digital information age there is an urgent concern that the right information needs to be transferred in the right format and quantity at the right time to the right person at a reasonable cost over a multi-principles information platform. This paper aims to examine the optimum level of information quality and value for construction sites in order to minimise errors (e.g. human error, drawing error, and information interpretation error). A questionnaire survey was conducted among designers and site managers in the UK to collect their perspectives on the quality and value of information being produced by designers and its utilisation on site. An information evaluation model was developed on the basis of Bayesian network theory to evaluate the collected data. The result of the research indicated that information from the various disciplines must be integrated to enable collaborative design and production in construction; although it is clear that high value and quality information is needed, the interpretation of high quality and value information varies significantly among the stakeholders. This paper examines the attributes of information value and quality for use by designers and site managers. Further research is recommended into the costs and benefits of high value and quality information generation.

**Key words:** value, quality, evaluation, collaborative production.

## 1. INTRODUCTION

Construction design is a process through which the designers render the client's needs into a practical solution. Every activity within the construction process i.e. designing, planning and management, is done to ensure the smooth flow of activities in the future. The progression through construction stages depends on the availability and transfer of current information for future application. The main disconnection is the transformation of information from virtual to practical (Johnson, et al., 1998). The significance of information is known by every stakeholder from the start to the completion of the project (Mitchell, 2006). The construction processes as a whole, the information at every stage in each phase needs to be reviewed and as a result grows in maturity. It is processing and accumulating in maturity accordingly until the information being produced by the designers reaches a satisfactory level of maturity for its use.

The application of digital design tools, such as Building Information Modelling (BIM) breaks down certain information flow barriers and at the same time bridges communication between extended design and construction teams. It is recommended to adopt BIM to meet the demand on "new levels of quality in construction and new services in order to deliver the 40-year carbon reduction programme" (BIS, 2010). A mechanism for the justification (e.g. costs and benefits) on using BIM has to be provided (BuildingSMART, 2010). Commercial data from the UK construction sector also showed that a consistent reduction of 8-18% of cost associated with design stages C to E of RIBA, including concept, design development and technical design and 8-10% during pre-construction stages including production and construction stages, while the upside potential of saving could be as high as 40% (BIS, 2011).

This paper focuses on designers' and site managers' benefits from the utilisation of optimum level information being produced by designers, as designers and site managers directly utilise information during construction stage. In an ideal scenario, the value of information can be interpreted as the information capacitated to a level of optimisation where it can convert itself into practicality without any influence from external influence (Lee, et al., 2000). However as a construction process is an amalgamation of multiple disciplines, the information consists of the data from a range of disciplines (Isikdag, 2008). It is essential to understand the perspectives from designers and site managers about information value, to establish the link between the significances of diverse information attributes towards information value and quality. In this research, the perspectives were collected by questionnaire method addressed with designers and site managers. In order to examine optimum level of information (value of information) provided on site in a way that it minimises the scope of errors, an information evaluation framework was proposed by introducing Bayesian network method to evaluate the information value and quality (Friedman et al., 1997).

## 2. CONSTRUCTION INFORMATION

Information as an aspect of every action during construction process is a key unit for progressing, processing and understanding an activity (Engeström, 1999a and 1999b). Information generates from the data accumulated by the stakeholder, in construction the accumulated data becomes the information when it is mature enough to flow from one discipline to another, which is called mature information. Information that is not capacitated enough so that it will flow from one stakeholder to another is considered to be immature information. Figure 1 below presents the information generation among the stakeholders in a construction process.

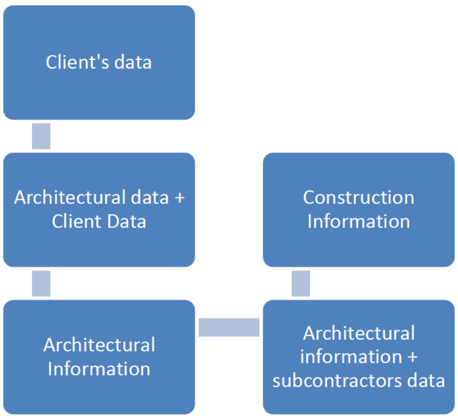


*Figure 1.* Information generation on construction

Construction is a unique discipline; it is a process, it cannot stay alone, and it is an amalgamation of different disciplines to create anything, everything, and sometimes nothing (Isikdag, 2008). The construction process is a way through which design gets synthesised into practical form. The most important process is the information flow from origin (client) to the end (user/product). Flow of information in business terms is known as communication. Communication is exceptionally a multidimensional flow of information as shown in Figure 2. In construction stage, stakeholders are dependent on each other for information exchange, because every action becomes practical, based on the information provided to them. Built form is a unique combination of different disciplinary information. All the information is uniquely designed, structured and applied to complete a project.

As for the increasing complexity if a contemporary construction project designers or site manager X has to communicate and work with different stakeholders A, B, C, D, E and F within the project (see as Figure 2), it is hard for designers/site manager X to bring out all the information for the resolutions against decision problems during construction stage, so they have to aid for help from other stakeholders, such as his/her colleagues or documents, drawings, models and databases. In other words the capacity of designers/site manager for retrieval and utilisation of high value and high quality information is vital to the success of the project during the construction stage.

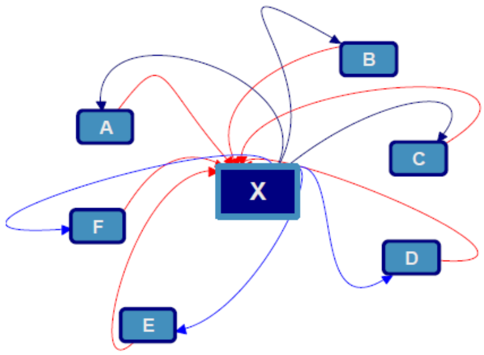


*Figure 2.* Information flow and communication among different stakeholders in construction stage

During communication process one of the difficulties is to predict the information, on which the future action of an individual or an organisation depends. This happens because information becomes mature and optimum along with the progression of practical activities taking place in the process, the greater the value and quality of information on which the practical activity depended, the greater the information maturity is, and therefore the greater the progress on information certainty.

## 3. DESIGN AND KNOWLEDGE MANAGEMENT IN CONSTRUCTION

The Latham (1994) report proclaimed that the main reason of poor communication between stakeholders in a construction project is the fragmented nature of construction industry, which in a way impedes delivering collaborative production or construction in constructional context. Management of any aspect is the business side of the said discipline. Similarly both design and knowledge management are the business side of design and knowledge respectively. Design management (DM) as a discipline acts on two different thoughts first being organising a design firm, and second aims to better understand the design process (its nature, stages and activities) in order to improve communication and coordination mechanisms (Tzortzopoulo, et al., 2007).

In terms of handling design, it is a complex activity which has various managerial issues. “Complexities lie within the technical knowledge, information availability, the uniqueness of design and interactions between different stakeholders” (Sebastian, 2005). Design and its management became a necessity when projects got more complex and the market competition pressure started playing major roles in deciding the fate of projects. DM is always seen through the eyes of design stakeholders and not all, that is a gap between design and construction professionals (Tzortzopoulos, et al., 2007). In the digital information age, designers and site managers get the information and data from the mediums including blue prints soft copies, telephonic conversation, email, intranet and so on. Knowledge in construction is available in abundance, the trick is to manage this wealth in a way that it is properly communicated and applied. Knowledge management (KM) is a process which helps in integrating different construction issues in a space containing people, process and technology.. Knowledge is personal and stays in people's head, while information needs to be recorded/codified and the processes of their transformation process called personalisation and codification. (Tang et al., 2007; Raisbeck and Tang, 2009; Tang et al., 2010). "It has been estimated that defects in the UK construction industry costs at least £1 billion to repair or rebuild every year (Crocker, 1990)". Most of this loss is due to the inefficient use and communication of information. It is very difficult to a balance or optimum point between these two processes

The basic difference between design and DM is that design is the information and DM is the process which gives meaning to that information. Similarly DM and KM cannot function in each other's absence. BSI[9] knowledge Management vocabulary (PD 7500) KM is defined as "The creation and subsequent management of an environment which encourages knowledge to be created, shared, learnt, enhanced, *organized and utilized for the benefit of the organization and its customers."*

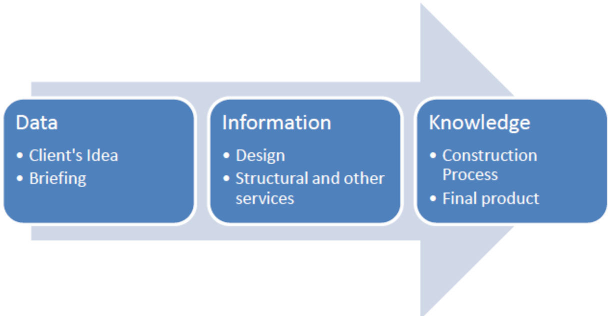


*Figure 10.* Data to knowledge transformation in a construction process: A DM and KM integrated perspective

Figure 3 shows the relation of design and knowledge. It is reflected that a construction project as a whole not only in the construction stage but in every discipline of construction process needs knowledge to be managed effectively so that products and services can be delivered successfully on time and under budget. There are different approaches being introduced for DM or KM in the construction sector, i.e. Adept (Austin, et al., 2001), Microsoft project and process protocol. Although some models like these are associated with streamlining information flow however there is no single approach which integrates KM and DM together to create a singular platform (Alavi, et al., 2001), in particular focusing on the value and quality of information. Management of design involves managing routine and non-routine design information produced by designers, in a way that it corresponds to further buildability stage. It strengthens information to a level where information is gathered and integrated from every discipline involved in the process to make it contactable (Alavi, et al., 2001). If the process, of knowledge management is analysed, then it resembles the similar path adapted by any management including DM. KM is about an environment, which facilitates knowledge, production, enhancement, learning and utilization to its complete benefit. So, DM and KM are the parts of an information-integrated system (Markus, et al., 2002).

## 4. VALUING INFORMATION

"When information needs to be valued – for example, in the calculation of either costs or benefits of information – the commonly used evaluation methods are inadequate because of its tangible and intangible characteristics" (Zhao, et al., 2008). Value is the essence of every action in today's information age wherein every action is judged and dependent on its value. Information is considered as a commodity and posses as an asset, it has become an element of commerce (Fenner 2002), e.g. a

[9] BSI: http://www.bsigroup.com

piece of physical product information goes through quality control before getting distributed. In today's world information is either purchased or exchanged with other information. Masterman et al. (1994) developed five significant customer wants or value in a construction process: final cost certainty, completion date certainty, value for money, and finally having the lowest possible tender for work. So it is difficult to set value for construction process itself, its unique to the project and stakeholders involved.

In general value is perceived in many ways, for example (Darlington et al., 2008; Zhao et al. 2008): Value = profit / loss, worth / cost, benefits / sacrifices etc. These relations are more general which everybody uses in their day-to-day life to make decisions. The decision of value is based on the expected reaction of that action. The expectancy factor introduces the important aspect of value which is probability. Probability of every expected reaction affects the value of any action or information. So equation 1(a) can be rewritten more correctly as: Value ≈ profit / loss, worth / cost, benefits / sacrifice. But it is very difficult to measure the value of information according to the cost system because of its explicit and implicit characteristics. Explicit information cannot stand-alone, it does not have any value singularly it must be accompanied by implicit characteristics in order to get processed. Information characteristics are also non physical in nature e.g. Information is not necessarily a physical product. Information can be produced at little or no cost. Each unit of information is different from every other. But buying the same product again and again does not include the cost of information because buyer already knows that. For a product based industry the majority of the information is hidden for the buyer. Further, "anything that makes it easier, faster and better value for money to find and deliver a relevant document adds value" (Philipp, 2005). By placing value on information a decision-making process gets quite evident. Questions like what to retain, discard and process start to have more meaning in any process. Many technologies came into being since last 20-30 years to achieve value on information i.e. concurrency management, new push technology, intelligent agents etc.

Although there are stresses on the needs of value on information in the construction industry, the characteristics of information flow during a construction process get numerous errors and gaps (see Figure 4). The act of converting the futuristic contextual information from virtual to real comprises of many steps and hence the probability of confusion and errors increases. Many different professionals are working in parallel on different facets of the same projects. The idea is to fill the gap and get rid of errors involved in order to make the process more efficient. The simplest example is client oriented design information (Leite, et al., 1995) for assembling furniture for ex-IKEA furniture. The cost of information is included with the product when customer is buying. So the principle of cost and benefit analysis can be tested in the programme. If one sees clearly in the product brochures of IKEA the integrated information is segregated accordingly and it is simple to understand by the user e.g. as shown in Figure 5.

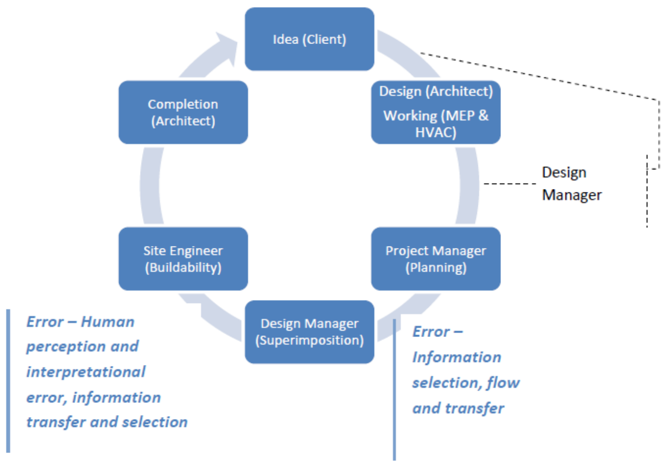


*Figure 4*. Occurrence of errors in the information flow

The information IKEA provides that are affixed with the features of high value information presented by Philipp (2005). The design information is published as 3D graphics that is in a form of pamphlets as the marketing strategy. Every product comes with detailed instruction documents, which is graphical in nature, which helps customers in assembling their respective products. These detailed instruction documents act as high value information documents to both customers and the company, which support an optimised approach of conversion between implicit and explicit knowledge (Tang et al., 2007; Tang, et al., 2010). As information is multidimensional and every action will have multiple effects on different aspects of value of information (VOI), interestingly this action of taking customers into the process has incorporated cost as well into the VOI.

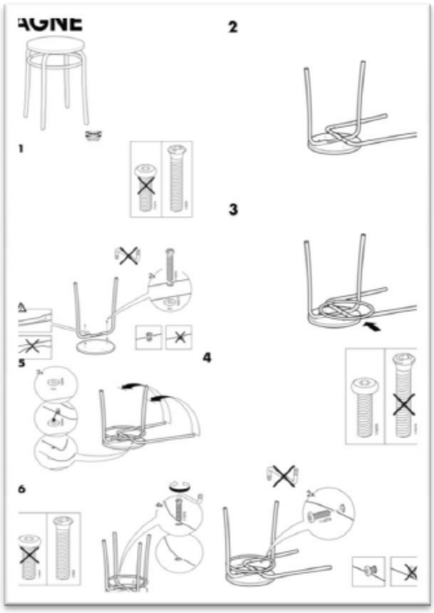

*Figure 5.* A high value information document (Source: IKEA Furniture's: http://www.ikea.com/gb/en/)

Similarly it seems like a plan for information flow (or a high value design plan) before the construction phase commences. The planning is needed to reduce the errors and cost overruns. Planning is a way through which a programme is formed to act on a particular project. It is a programme, which facilitates information to flow throughout different stakeholders for the on-going project. As for an adoption of IKEA added value information concept, the scenario working on a construction site would be, a designer/site manager X receives the design information published in a form of 3D effect manual, every activity or process at each stage comes along with this detailed instructive document, he/she or other associated stakeholders will get the ideas of what they are doing and going to do after at their respective work stage. Furthermore this high value information flow helps stakeholders to be aware of others' progress, this enables every stakeholder to have an overall picture on the underway project progress and work cooperatively. It also facilitates collaborative production that is relying on this high value information flow.

## 5. RESEARCH METHOD

Information value and quality analysis ensures any potential losses explicitly stay away from errors and uncertainties during a decision-making process (Mussi, 2004, Yokota, 2004, Cox et al., 2006, Pfiug, 2006). Knowledge, as from valuable and quality information, can be advantageous for companies, furthermore for the success of companies (Walters and Lancaster, 1999). However it can be negative to daily and even overall operation of company if the value and quality of information cannot be measured and managed properly and hence to select the optimised decision during the life cycle of a project. There are some researches in relation to the value and quality of information being undertaken by various scholars, such as Fenner (2002) who gave a summary about how to place value on information; Weissinger (2005) who raised a theoretical basis and analysed the perspectives and perceptions towards the evaluative nature of information, for instance its materialism, idealist and metaphysical; Oppenheim et al (2000) who focused on how to value information as an asset in companies from peoples' stand-point. The above methods covered issues and considerations and some of factors that need to be taken into account in this subject domain. Regretfully none of them provided specific technique that can be applied to the evaluation of construction design.

A questionnaire, in this paper, is used as the core tool to collect data. A questionnaire has been shown to provide the sort of experimental understanding that the study aims to achieve, in the consideration of this the questionnaire was designed based on a previous study by Gunhan and Arditi (2005) which coincides with the aims of this research. Subsequently an information evaluation process model using Bayesian Network (Zhao et al, 2008) will be adopted and tailored which can help evaluate the information value and quality by metrics.

## 5.1 Model Training and Validation Pilot Sample

The measures for constructs in the research model are on the basis of Bayesian technique, which is adopted to extract knowledge from information by converting qualitative data into quantitative. It has several stages, which take researcher from data to the probabilistic results. This research focuses on benefits of buildability information being produced by designers to site managers (Heckerman 1996). The model training and validation tests comprise of a small sample of designers and site managers in construction teams within the UK. Based on Nueman's (2003) recommendation, a sampling frame was developed by searching various, including the designer firms, main contractors. 30 individual including both designers and site managers were invited directly because of the nature of work at the time of the study that was closely related to the context; it was at the time where designers handover design information to site managers. The survey was conducted from June to August 2010. A total of 30 questionnaire packages were sent by e-mail. In each pack, there was one invitation letter and one questionnaire (see section 5.3 below). When the survey was completed, a total of 10 questionnaires were received, producing a response rate of 30%.

## 5.2 Data Analysis

### 5.2.1 The Bayesian Network Model

The probability of the attributes to site manager's perspectives on information value and quality is derived from a developed Bayesian network. Zhao et al. (2008) explained the framework and information attributes interdependencies (see Figure 6).

Information quality can be assessed by breaking information down into its attributes. Information value to site manager needs to be analysed by measuring benefits. According to Zhao et al. (2008) the information evaluation framework evolved from an equation, which depends on two hypotheses considered in the engineering organization study.

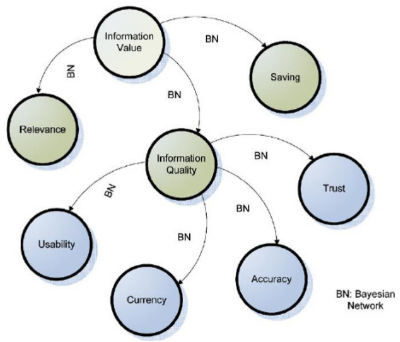


*Figure 6. Information evaluation approach (Source: Zhao et al. 2008)*

Two hypotheses were: (a) The context more specifically, the relevance is an explicit factor that affects the value, judged from the result of analysis" And (b) The information attributes in the model does not include costs because there are other losses such as time, effort, resources, opportunities as well as negative outcomes which are hard to get included in cost. Saving attribute of information is the inverse which is considered in place of cost as an attribute.

Equation 1 (Zhao, et al., 2008)

*(a) Information value = Benefits of Having Information / Resources Speding on Storing and (b) Retrieving information = (Quality + Relevance) x Saving*

"It's shown that BNs are directed acyclic graphs (DAG) with a set of probability tables" (Zhao, et al., 2008). This network establishes the dependency between each attribute and the combined dependencies with the respective parent attributes. These dependencies and interdependencies work on the probability of one attribute over the other. Zhao et al. (2008) explained the same with formulae; basically Bayesian roles are for any two events, A and B,

Equation 2

$$\boldsymbol{p}\left(\frac{\boldsymbol{B}}{\boldsymbol{A}}\right) = \frac{\boldsymbol{P}(\frac{\boldsymbol{A}}{\boldsymbol{B}}) \times \boldsymbol{P}(\boldsymbol{B})}{\boldsymbol{P}(\boldsymbol{A})}$$

Where *P(A) = Probability of A, P(B) = Probability of B, P (A/B) = the probability of A given that B has already occurred and similarly P (B/A) = the probability of B given that A has already occurred.* For example taking two attributes from information evaluation framework as shown in figure 6, i.e. value and accuracy, the probability of 'information value' (in the ranges of high, mid, or low), can be calculated from equation 1 as:

Equation 3

$$\boldsymbol{P}\left(\frac{\boldsymbol{Value}}{\boldsymbol{Accuracy}}\right) = \frac{\boldsymbol{P}(\frac{\boldsymbol{Accuracy}}{\boldsymbol{value}}) \times \boldsymbol{P}(\boldsymbol{Value})}{\boldsymbol{P}(\boldsymbol{Accuracy})}$$

So, the joint probability function will be:

Equation 4

$$P(X) = \prod_{i=1}^{n} P\left(\frac{Xi}{Parents}(Xi)\right)$$

For the above equations, a systematic model is designed on Bayesian network model basis.

## 5.3 Information Evaluation Model for Designers and Site Managers

The information evaluation framework for designers and site managers is tested in the Bayesian model to define the essential attributes of information value and quality. To achieve the objective a questionnaire technique is adopted because it acts as a basis of data collection to transform into Bayesian network system (Zhao, et al., 2008). The statistical data received is transformed in to CPT (conditional probability table) based on equation 4, which is the basis of BN model. Steps involved in defining information evaluation model are as follows:

Step 1: A questionnaire is prepared considering the established information attributes (see Figure 6), which affect information value and quality as shown in Figure 7. Questionnaire is designed such that all the answers received in the format of opinion (Agree, Disagree and neither of the two) for example 'the information provided on site has errors' can be answered as agree, disagree or neither of the two. This question indicates to the accuracy attribute of information. The relationship between the answers and variables of high, mid and low is done as follows: Agree = high, disagree = low and neither disagree or agree = mid. The data from the questionnaires is transferred and reorganised to summary sheet.

Step 2: The data from the summary sheet helps in building up the CPT. The CPT represents every linkage in Figure 6 mathematically.

| Information Attributes | Value to the site manager | Questions | Decisions | Comments |
|---|---|---|---|---|
| Accuracy | Degree of conformity of a measure to a standard or a true value. Level of precision or detail and closeness to reality. | · Information provided on site has errors<br>· Information cited is by recognised authority<br>· Information is reviewed before handing over to site | Agree<br>Disagree<br>Neither agree or disagree | |
| Trust | The confidence level of the information. | • Information authorising organisation is identifiable.<br>• Author's qualification, position, rank and experience increase the credibility of information.<br>• Purpose and reputation of the organisation increases the credibility of the information. | Agree<br>Disagree<br>Neither agree or disagree | |
| Usability | To be user friendly in all aspects. | · Information provided is clear and descriptive.<br>· Graphics of the information adds value to the understanding.<br>· Information is readable, legible and complete.<br>· Information is structured appropriately and logically. | Agree<br>Disagree<br>Neither agree or disagree | |
| Currency | The quality or state of being up-to-date or not outdated. | · Information is structured appropriately and logically. | Agree<br>Disagree<br>Neither agree or disagree | |
| Quality | The totality of features that fulfil stated or implied needs. The correspondence to specifications, expectations or usage. | · Information is good in general terms. | Agree<br>Disagree<br>Neither agree or disagree | |
| Relevance | The overall closeness that the information can be fitted into the context. | · Information is relevant to your needs.<br>· Content of information is suitably general/detailed.<br>· Content of information is novel/accepted.<br>· Coverage if the information is sufficiently broad for your needs. | Agree<br>Disagree<br>Neither agree or disagree | |
| Saving | The time or money that can be saved by using the information. | · Information provided is of a standard that it save money, time and can be archived. | Agree<br>Disagree<br>Neither agree or disagree | |
| Value | Benefits/Sacrifices | · Information is valuable to me and my department. | Agree<br>Disagree<br>Neither agree or disagree | |

Figure 11. A sample questionnaire for collection of designer and site manager's perspective on information being produced by designers

Step 3: CPT data is then transferred to BNs to get an information evaluation assessment model as shown in Figure 8.

Figure 8 shows the full process of getting an information assessment model through 10 designers and site managers. The value judgement of the attributes relies on all the attributes. Similarly the value for designers and site managers depends on the attributes for which the information is being analysed. Figure 9 shows the frontal evaluation model before any judgement has been made. All data from the CPT is transformed to BNs and dependencies can be analysed by changing the variables of any attributes. If accuracy variables are increased or decreased then the effect on value and quality increases or decreases respectively. For example as shown in the latter model in Figure 10, the 'accuracy of information' attribute reaches 'mid value' that is increased to 100%, simultaneously its information quality of 'mid value' is changed to 64.5 %. While before doing this sensitive analysis, 'accuracy of information' is on 61.3 % and its quality is on 52.8 %. This phenomenon indicates that every attribute of information works together to yield an optimum value and also the quality of information as the designers and site managers perceive.

Figure 9 indicates that if the 'accuracy of information' is 61.4 % then the probability of information being qualitative and valued to the designer or site manager is only 52.8 % and 33 % respectively. As Figure 9 shows that information value is not directly affected by context-independent attributes including 'accuracy of information', 'trust of information source', 'currency of information' and 'usability of information', they do affect but via information quality. So there are only three context-dependent attributes which are 'savings', 'relevance to the decision problem' and 'quality of information' whose changes will affect information value. Please note that in this case, the numbers in Table 1 shows that site managers are not completely sure about the information they are getting on site.

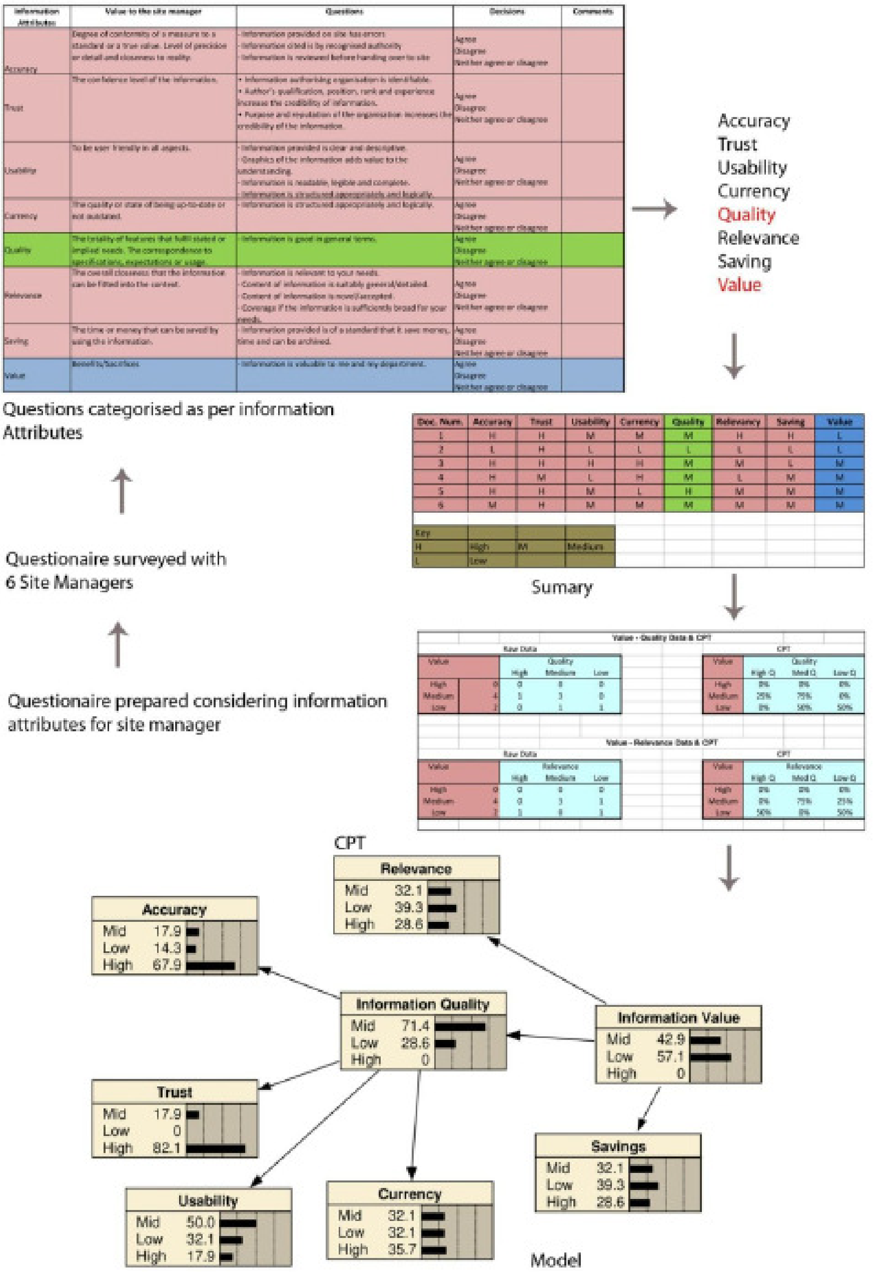


*Figure 8.* Process for the information evaluation model (running with the first 6 site mangers)

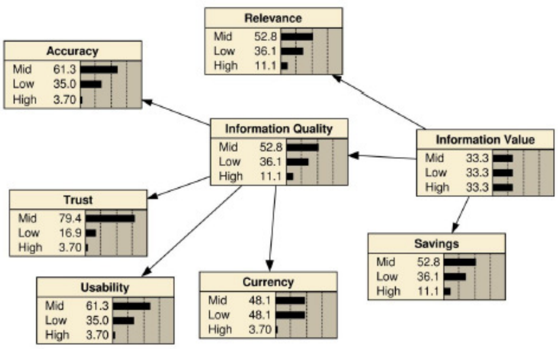


*Figure 9. Frontal information evaluation model*

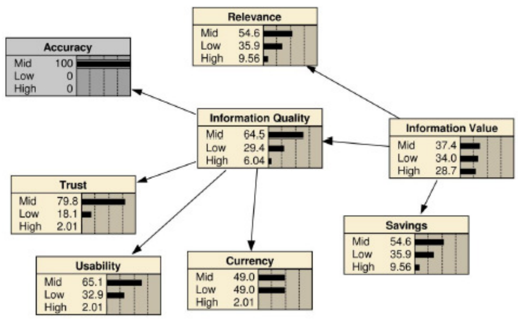


*Figure 10. Latter information evaluation model*

# 6. COST AND BENEFIT ANALYSIS

As said, the scenario of applying IKEA information flow theory shows that information in forms of readable, visible, sensible and accessible can bring certain benefits to different stakeholders. The relation of value to stakeholders, such as information providers and information users, is displayed in Figure 11. It clarifies that information value means differently to different stakeholders, which can be measured by two main factors, benefit and cost.

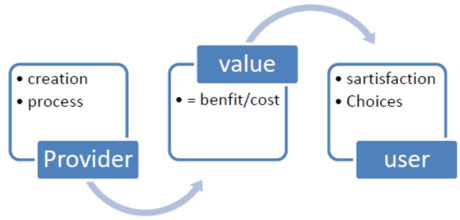


*Figure 11*. Value relations between the information provider and user

In this paper, one of the focuses is on information cost at the construction phase. All clashes like, stakeholders' interests, clashes in information provided and misuse of personal knowledge and so on are taking place at this stage. Suitable cost estimations against its associated benefits received are necessary. This comparison must be executed to assure an optimised decision is made for a decision problem on site. In practically designer or site manager uses two types of tools to do estimation (Jones, 2010), one is top down estimate and the other one is bottom up estimate. Table 1 shows the comparison of these two approaches.

*Table 1*. Comparison of cost estimate approaches

| | Top down estimate | Bottom up estimate |
|---|---|---|
| Advantage | It's done early in the project, so quite broad | It is often considered as the most accurate technique because it is based on WBS (work breakdown structure). Work is broken down to smaller work packets. The individual packet is then estimated and the entire estimated are added together to have a bigger picture of the project. Each work packet is estimated by looking forward to its requirements which are needed to complete that work packet. So, accuracy is more as compare to top down estimate. |
| Disadvantage | The limitation of the technique is that often lower level of employee and stakeholders are not accounted while estimating | It is much tedious and time consuming job because it becomes more complex in mega projects where work scope is much bigger in scale and to break that into smaller work packets will be a difficult job to complete |
| Suitability of project type | • top down planning is often done by senior management<br>• This is generally done by referring archived projects estimates and applying them to the current project. | • It suits for the project which needs accurate detailed estimates to make sure the project runs smoothly.<br>• The project must be affordable to time consuming and cost spending. |

A proposed relation developed in accordance with the cost estimate approaches for the project are:

$$\begin{bmatrix} Ce = Be \\ Ce > Be \\ Ce < Be \end{bmatrix} \triangleq \begin{bmatrix} Ca = Ba \\ Ca > Ba \\ Ca < Ba \end{bmatrix}$$

Where, *Ce = Cost estimated, Ca = Cost achieved, Be = Benefit estimated, Ba = Benefit achieved*. The most ideal situation is therefore:

$$[Ce < Be] \triangleq [Ca < Ba]$$

But in reality the cost estimated (*Ce*) is different from the cost achieved (*Ca*). So it is essential to keep a check on this relation on every stage of the project. Generally every project has three significant costs available for every activity i.e. the estimated cost, the processed cost and the final cost. These costs are different by default for every project because of project specifications being altering in every aspect e.g. Client requirements changes, unavailability of material, and force majeure and so on. Cost and benefit are two sided of the same coin. In informational context of construction, benefit is the value of information provided to an individual working in that context. Cost is the straightforward cost of producing and delivering that information to that individual. To conduct this in the construction sector, it is necessary to break down the information cost from every discipline and then combine the segregated costs for particular information. That is a tedious job and there are no tools available to do such informational costing while it has been addressed in this paper. The model presented herewith can provide feedback information for the designers to improve the value and quality of production of design information. There is a necessity to carry further development of the tools along the life cycle of a project e.g. in the post-construction, use and facilities management stages with more real case studies which is the major future work of the research. This further contributes to the tool development on the justification on using digital design models e.g. BIM throughout the life cycle of a project.

## 7. CONCLUSIONS

Construction is a process that is multi disciplinary in nature. The call for collaborative production in construction gives pressures to the industry to have an integrated platform. This paper found that the way for construction process integration is to have integrated information for construction productivity based on design and knowledge management perspectives. Information earns its value or adds its value after the application when it is converted from virtual to practical. Construction process is an information flow process; the information becomes mature or optimum along with progressing construction activities, an improvement of information will increase the information maturity and its optimisation level. It is always the certain, high value and high quality information upon which successful practical activities depend. Information is also an aspect of every decision or activity, the relationship of design and knowledge shows that the construction project as a whole not only in the construction stage but in every discipline of a construction process needs knowledge to be managed effectively and efficiently. An efficient working process facilitates a communication environment which the creation of environment encourages the process of creating, sharing, learning, enhancing, organising and utilising information. As shown in Figure 10 accuracy variables are increased or decreased then the effect on value and quality increases or decreases respectively, the ‘accuracy of information’ attribute reaches ‘mid value’ that is increased to 100%, simultaneously its information quality of ‘mid value’ is changed to 64.5 %. While before doing this sensitive analysis, ‘accuracy of information’ is on 61.3 % and its quality is on 52.8 %. This phenomenon indicates that every attribute of information works together to yield an optimum value and also the quality of information as the designers and site managers perceive.

In this paper, the study of IKEA information flow concept showed that the significances and benefits of establishing an integrated high value information platform helps reducing the errors or misinterpretations during the conversion of contextual information at the construction stage and improving the conversion of personal knowledge and codified knowledge.

Although the application of high value information created by the concept of IKEA information flow, shows that how information in forms of readable, visible, sensible and accessible can bring certain benefits to different stakeholders, however information cannot be meant as high value as the same for every stakeholder in a general terms because every stakeholder has a function to perform. So the high value information towards each stakeholder they are looking for, in a document is always different. Hence the value of information to everyone is different from the other.. Figure 9 indicates that if the ‘accuracy of information’ is 61.4 % then the probability of information being qualitative and valued to the designer or site manager is only 52.8 % and 33 % respectively. As Figure 9 shows that information value is not directly affected by context-independent attributes including ‘accuracy of information’, ‘trust of information source’, ‘currency of information’ and ‘usability of information’, they do affect but via information quality. So there are only three context-dependent attributes which are ‘savings’, ‘relevance to the decision problem’ and ‘quality of information’ whose changes will affect information value. Please note that in this case, the numbers in Table 1 shows that designers/site managers are not completely sure about the information they are getting on site.

Questionnaire undertaken in this study focus on designers’ and site managers’ benefits from using high value information. Questionnaire was prepared around pre-identified information attributes to collect the perspective of a site manager on the completed design information from designers. The Bayesian network technique is adopted to convert qualitative into quantitative data in order to identify which information attributes play a significant role in enhancing information value for the site managers from designers as there are no available tools that help extracting the cost information attribute. Essentially this approach gave users an information analysis framework to analyse whether the information they are getting is of any use to them in terms of construction productivity. Recently there is a trend of application on digital building information modelling (BIM) in the industry, this framework should support BIM to provide high value information through addressing its defects

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## 9. REFERENCES

Alavi, M. and D. Leidner, 2001, ”Review: knowledge management and knowledge management systems: conceptual foundations and research issues”, *MIS Quarterly,* 25(1), p. 107-136.

Austin, S., A. Baldwin, J. Hammond, M. Murray, D. Root, D. Thomson, and A. Thorpe, 2001, *Design chains: a handbook for integrated collaborative design*, Thomas Telford, Kent, U.K.

BIS (Department of Business, Innovation and Skills), 2010, *Low carbon construction IGT: Final Report*, Department for Business Innovation and Skills, U.K.

BIS (Department of Business, Innovation and Skills), 2011, *A report for the government construction Client group: Building Information Modelling (BIM) working party strategy paper*, Department for Business Innovation and Skills, U.K.

Cox, L.A., D.A. Popken, J.J. VanSickle and R. Sahu, 2006, “Optimal Tracking and Testing of U.S. and Canadian Herds for BSE: A Value-of- Information (VOI) Approach”, *Risk Analysis,* 25(4), p. 829-840.

Crocker, A., 1990, *Building failures : recovering the cost*, BSP Professional, Oxford.

Darlington, M., S.J. Culley, Y. Zhao, S.A. Austin and L.C.M. Tang, 2008, “Defining a framework for the evaluation of information”, Special *Issue of the International Journal of Information Quality on "Information Quality and Usability*, 2(2), p. 115-132.

Engeström, Y., 1999a, “Activity theory and individual and social transformation”, in Y. Engeström, R. Meittinen and R.-L. Punamäki (eds) *Perspectives on activity theory*, p. 19-38, Cambridge University Press, Cambridge.

Engeström, Y., 1999b, “Expansive visibilization of work: An activity-theoretical perspective”, *Computer Supported Cooperative Work,* 8(1), p.63–93.

Fenner, A, 2002, "Placing value on information", *Library Philosophy and Practice*, 4(2), p. 6.

Friedman, N., D. Geifer and M. Goldszmidt, 1997, “Bayesian network classifiers”, *Machine Learning*, 29(2-3), p. 131-163.

Gunhan, S., and D. Arditi, 2005, “International Expansion Decision for Construction Companies.” *Journal of Construction Engineering and Management*, 131(8), p. 928 – 937.

Han, I.X., W. Zhou and L.C.M. Tang, 2011, "The development of model-based life cycle cost and assessment tool for sustainable building design decision", in: *Proceedings of The 4th International Conference on Construction Engineering and Project Management*, Sydney, Australia.

Heckerman, D, 1996, "A tutorial on learning with Bayesian network. Technical report", *Microsoft Research Advance Technology Division*, Redmond, WA 98052, p. 1-58.

Isikdag, U., J. Underwood and G. Aouad, 2008, "An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes", *Advanced Engineering Informatics*, 22(2008), p. 504-519.

Johnson, R.E. and M.J. Clayton, 1998, "The impact of information technology in design and construction: the owner's perspective", *Automation in Construction,* 8(1), p. 3-14.

Jones, J. 2010, *Project Management Cost Estimating*, available at: http://www.suite101.com/content/project-management-cost-estimating-a249020 .

Latham, M., 1994, "Constructing the team : joint review of procurement and contractual arrangements in the United Kingdom construction industry: final report", HMSO, London.

Lee, H.L., K.C. So and C.S. Tang, 2000, "The value of information sharing in two level supply chain", *Management Science,* 46(5), p. 626-643.

Leite, J.C. and A. Oliveira, 1995, "A Client Oriented Requirements Baseline", *in Proceedings of the Second IEEE International Symposium on Requirements Engineering (RE'95)*, p. 108-115, IEEE Computer Society Press.

Markus, M.L., A. Majchrzak and L. Gasser, 2002, "A design theory for systems that support emergent knowledge processes", *MIS Quarterly,* 26(3), p. 179-212

Masterman, J.W.E. and R.N. Gameson, 1994, "Client characteristics and needs in relation to their selection of building procurement systems", *CIB W92, Procurement Systems East Meets West Symposium Publication (No 175)*, Hong Kong.

Mitchell, V.L., 2006, "Knowledge integration and information technology project performance," *MIS Quarterly*, 30(4), p. 919-939.

Mussi, S., 2004, "Putting value of information theory into practice: a methodology for building sequential decision support systems", *Expert Systems*, 21(2):, p. 92-103,

Neuman, W. L , 2003, *Social work research methods: qualitative and quantitative approaches*, Allyn and Bacon, Boston.

Oppenheim, C., J. Stenson and R.M.S. Wilson, 2000, "Valuation of information assets in UK companies", *Managing Information*, 7(3), p.56- 59.

Pflug, G.C., 2006, "A value-of-information approach to measuring risk in multi-period economic activity", *Journal of Banking & Finance*, 30, p. 675-715.

Philipp, M., 2005, "Why pay for valued-added information", *World Patent Information* 27(1), p. 7-11.

Raisbeck, P. and L.C.M. Tang, 2009, "Humanistic and scientific knowledge management: a comparison of design practice between architects and engineers", *in Proceeding of The 25th ARCOM Annual Conference 2009*, 7-9 September 2009, Albert Hall, Nottingham, UK. (Awarded research paper - The 'Rod Howes' Commemorative Award)

Sebastian, R, 2005. "The interface between design and management." *Design Issues*, 21(1), p. 81-93.

Tang, L.C.M., Y. Zhao, S.A. Austin, M.J. Darlington and S.J. Culley, 2007, "Knowledge and information evaluation practice: An exploratory study in a construction firm", *in Proceeding of CIB W102 3rd International Conference - Information and Knowledge management - Helping the practitioner in planning and building*, Stuttgart, Germany.

Tang, L.C.M., Y. Zhao, S.A. Austin, M.J. Darlington and S.J. Culley, 2010, "Codification vs personalisation: A study of the information evaluation practice between aerospace and construction industries", *International Journal of Information Management*, 30(4), p. 315-325.

Tzortzopoulos, P. and R. Cooper, 2007. "Design Management from a Contractors Perspective: The Need for Clarity." *Architectural Engineering and Design Management* 3, p. 17-28.

Walters, D. and G. Lancaster, 1999, "Value and information-concepts and issues for management". *Management Decision,* 37(8), p. 643-656.

Weissinger, T., 2005, "Information as a value concept: reconciling theory and practice", *Library Philosophy and Practice*, 8, p. 1-12.

Yokota, F. and K.M. Thompson, 2004, "Value of information analysis in environmental health risk management decisions: Past, present, and future", *Risk Analysis*, 24(3), p.635-650.

Zhao, Y., L.C.M. Tang, M.J. Darlington, S.A. Austin and S.J. Culley, 2008, "High value information in engineering organisations", *International Journal of Information Management*, 28(4), p. 246-258.