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MULTI-CRITERIA DECISION MAKING IN EARLY STAGE DESIGN: CAPTURING THE DYNAMICS USING UTILITY THEORY

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This paper introduces a conceptual framework that captures the key processes in early stage design (ESD) processes mapping out Decision Making (DM) to support value delivery using utility theory. A lot of construction waste in downstream processes can be traced back to the design stage according to research. Yet there's currently little research into interdependences key to value generation in this most dynamic of construction processes. This research identifies the role of the end-user as a key element in the process of value generation in ESD. Understanding the user requirements is just as important a step as it is for the design process to engage in requirement forecasting. This paper explores new ground in understanding of DM processes in ESD in defining and understanding value. The research first explores the theoretical concepts in multi-criteria DM, UT and value generation in ESD. Design science research methodology is used to review literature to inform the framework that's validated with case studies in two design firms.

Keywords: Front end design, Complexity and uncertainty, Value design.

1 INTRODUCTION

There's an increasing need for new paradigms to deliver improved value in construction projects. Yet at the same time, construction continues to be dominated by a lot of the waste both in the physical and process spaces (Bølviken and Koskela 2016). Halttula *et al.* (2017) attribute a lot of this waste to the limited integration in construction processes. Specific focus has been drawn to the role of early stage design (ESD) processes in value management (VM) as a result (Kpamma *et al.* 2017). VM in ESD is information intensive and dominated by a lot of decision making (DM) in the process of devising design solutions. Much of the waste at this stage is process based though ultimately, this translates into material waste if decisions have to be changed. DM shapes the whole process of value generation from (1) defining the project purpose and objectives, (2) establishing the project attributes (3) trading off attributes by weighing their consequences, (4) defining utilities of attributes and finally, (5) value definition and requirement forecasting. Moreover, DM in this case will be influenced by the project's context including sociocultural, economic, political, technological or environmental constraints. The compounding constraining effect added to the nature of the decision maker does influence the nature of decisions that underpin value delivery in addition to the often conflicting nature of design requirements (DR). On this basis, understanding and underscoring the process of DM is needed. Design typically utilizes attributes (design goals transformed into requirements) and alternatives (models and solutions) to design problems. Good decisions can contribute to value generation through reducing waste. Won *et al.* (2016) traced a lot of waste in construction processes back to DM in ESD through errors or need for reworks among other wastes. Multi Attribute Decision Making (MADM) theory of which Utility Theory (UT) is one, has been used successfully in supporting DM in arriving at decisions among alternatives in many industries processes including construction in value generation (Turskis and Juodagalvienė, 2016). However, none of the applications have been specific to ESD to date. Moreover, UT extends the MADM conceptualization by mapping the expected utility value (EUV) of choice decisions of the DM among the many alternatives (Mintz 2016). This is especially important in ESD when decisions made impact on processes later on in the project cycle. The use of UT therefore presents a step change in the understanding of stakeholder DM during design as design decisions drawn from user goals can be assessed on their EUV. Value can be mapped from UT conceptualization. This paper therefore contributes towards knowledge of ESD DM by presenting a framework that maps value using UT.

2 VALUE MANAGEMENT (VM) AND DM IN EARLY STAGE DESIGN (ESD)

According to Trevisan and Brissaud (2016) process dynamics and interaction of the various constructs that underpin value generation can be understood from system down to subsystem level for the purpose of value definition. The importance of such an approach is the ability to identify any gaps in processes that either are merely non value adding (in which any mitigations or management can be devised); or sheer waste (in which case they have to be addressed). This sets a useful basis for process level analysis in ESD to any improvement propositions. The conceptual basis by extension is important in capturing any dynamics in the flow of tasks and activities that constitute value definition in relation to DM.

In reality however, Kpamma *et al*. (2017) remark on the limited participation of the end user in DM of ESD processes. Additionally, Luo *et al.* (2017) say that understanding the project context is a crucial part of this DM. Zhu and Mostafavi (2017) add that such understanding has to build with it any emergent properties relating to *'absorptive, adaptive, and restorative capacities'* of the project. This requires a structured decision support mechanism. It's important to point out that indeed there has been a proliferation of decision support tools aimed at supporting complex decision making (Nielsen *et al.* 2016). The conceptual UT considered is that by Keeney and Raiffa (1976).

During requirements capture many attributes will present potential for many alternatives in the process of design DM. Mapping the nature of DM on one hand while defining the user benefits on the other is therefore an important part of VM. UT affords both these benefits (Keeney and Raiffa, 1976). Transitivity in UT is a key element in ensuring consistency in the process. UT transitivity during DM therefore provides further support in the way decision makers go about capturing user requirements and the value propositions. The adoption of UT for this research therefore strongly supports efforts for wider need for support tools to bridge the gap in decision support in current dispensations. This paper forms part of the wider research into DM in ESD processes to understand how this contributes to value delivery. The discussion that follows establishes a framework integrating the key concepts of DM, UT and value generation in ESD from a utilitarian perspective; with firstly, a look at the methodological approach.

3 METHODOLOGY

A mixed methods approach of case studies and literature review is adopted Guetterman and Fetters (2018). Design science research was adopted where knowledge was built to inform the design and implementation of the framework (Van Aken *et al.* 2016). A detailed literature review was first carried out across a section of relevant journals and academic articles to develop the conceptual basis of the framework in terms of design practice. The literature from some seminal works like Keeney and Raiffa (1976) supported the conceptual basis of UT. Two general spaces in design process were identified i.e. – the integrated front end design (FED) and implementation/post implementation space. In the former, literature helped identify the attribute definition/requirement capture and tradeoffs spaces. In these stage, information is gathered, outline designs developed, requirements analyzed and alternatives can be compared. In the latter stage, there are opportunities for requirement and utility forecasting, evaluation of attribute utilities that ultimately define the value space. Two architectural firms in Porto Alegre in Brazil dealing in a cross section of housing products, from small residential to public and commercial design were choice selected for the action research. The choice in Brazil presented the element of a dynamic context a key part of the wider research. Through a series of interviews with senior designers, the processes mentioned above were cross examined with ongoing design work to validate the processes integrated in the framework.

4 DECISION MAKING IN UTILITY THEORY

Design processes capture user goals to transform these into design requirements. These effectively are high level goals that are essentially difficult to quantify (Keeney and Raiffa, 1976). The goal of utility theory (UT) is in part to interpret these high level goals into measurable attributes; in manner represented by a Utility function (UF) to support any tradeoffs process. A goal of *'nice views'* or *'quality workspace'* for an office space is qualitative. UT allows each attribute to be considered for its utility by defining a UF; essentially a representation of a DM's preferences when presented with a series of consequence trade-offs. EUV is the aggregation of all expected utilities of a given criterion. It's suggested that defining a UF for any given criterion takes the following three steps for an attribute X; i.e., 1) determining the upper and lower scales of the criterion (X, X_L). A minimum of two is needed for a function to be derived, 2) determining the threshold (X_T) - the neutral point between the two which is given a value zero; and the most preferred (X) point that's set to 1. i.e. $U(x_r)_j = 0 \, and \, U(x_M)_j = 1$ and finally 3) anchoring the points to define a cardinal utility and connecting the points to define a UF either with a straight line as $U_j(x_j) = A_j y_j + B_j$ or exponential function in Eq. (1).

$$U_j(x_j) = A_j e^{B_j y_j} + C_j \tag{1}$$

Where; $U_j(x_j) =$ utility of the criterion j while $A_j, B_j \, and \, C_j$ are constants.

Figure 1 an illustration of such two attributes x, y. Keeney and Raiffa (1976) have demonstrated that the UF (Figure 1) marks interface of attribute points with equal utilities. The UF is equally important in informing the nature of DM; whether the decision maker's risk averse, prone or neutral. Their work is quite important in underscoring DM in ESD when design solutions have to be drawn from a raft of alternatives and from sometimes conflicting attributes. Firstly, they describe a decision maker's risk premium as $X_i - \widehat{X_\iota}$ to support the decision makers risk position. Secondly, they demonstrate that the optimum quantifiable and qualitative variables for the objectives for example can better be captured by understanding the intricate nature of the DM process via the UF. In ESD for example, it's as much important to understand the underlying expectations of the stakeholders as it is to map the DM processes that defines the value. In Figure 1, the utilities of A_3 (Y_3, Z_1),A_2 (Y_2, Z_2), A_1 (Y_1, Z_3) are equal.

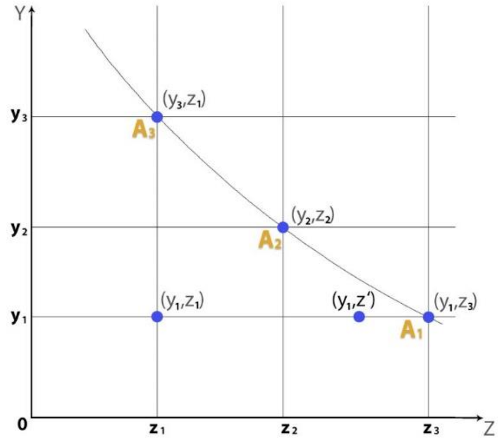

Figure 1. Mapping the decision maker's DM with UF.

In an effort to bring about convergence of DM, a stepwise process is proposed by Keeney and Raiffa (1976) as; drawing up any preliminaries of an assessment that draws focus between process analysis and DM. Fully defining the relevant qualitative parameters relating to the project such as – time frames, cost structures and any incentives; quality or environmental requirements that define the intended objectives and specifying quantitative limits based on lower level attributes relating to these broad high level goals/objectives. Finally, the analyst chooses a UF of the parameters and carries out consistency checks to ensure any results align with not only the objectives but also DM. Again Keeney and Raiffa (1976) suggest a five step process for analysis of a UF as; 1) pre analysis involving examining the nature of the functions, 2) structuring a problem, 3) Assessing the judgmental probability distributions, 4) Carrying out an assessment for all consequences relating to the DM process and preferences and 5) Harnessing opportunities in maximizing the EUV. The basis of UT is thus shown in the attributes S, Q, R, T, W (see Figure 2). The attribute space is bounded by specifying the limits of the attribute X in terms of X_0 and X^*, such that the expected utility X is reflected by $X_0 \leq X \leq X^*$. As buildings are elements of space and time requiring trade-offs during DM, the role of the end-user is important right from the process of purpose of definition from Figure 2. For example, attributes S, Q, R, T, W can be traded off taking into account the costs and benefits of each. This delicate process if integrated with all stakeholders, including the end-user is key in supporting value generation through the attribute utility transformation seen in Figure 2. Defining user requirements – Q - great views – R-optimal workspace, S - Ease of maintenance – T – low energy use, Q – flexible space; and that Utility (U)assumes an additive function defined in Eq. (2).

$$U_{Q,R,S,T,W} = U_Q(Q) + U_R(r) + U_S(S) + U_T(T) + U_W(W) \quad (2)$$

This can be summarized in Eq. (3).

$$U_{Q,R,S,T,W} = \sum_{i=1}^{n} U_i(X_i) \quad (3)$$

5 DISCUSSION AND CONCLUSIONS

The major part of ESD DM is in fact the process of resolving the often conflicting requirements. Collyer and Warren (2009) discuss the sources of these conflicting goals and purposes as stemming from defining design parameters, interpreting design needs and defining concept processes.

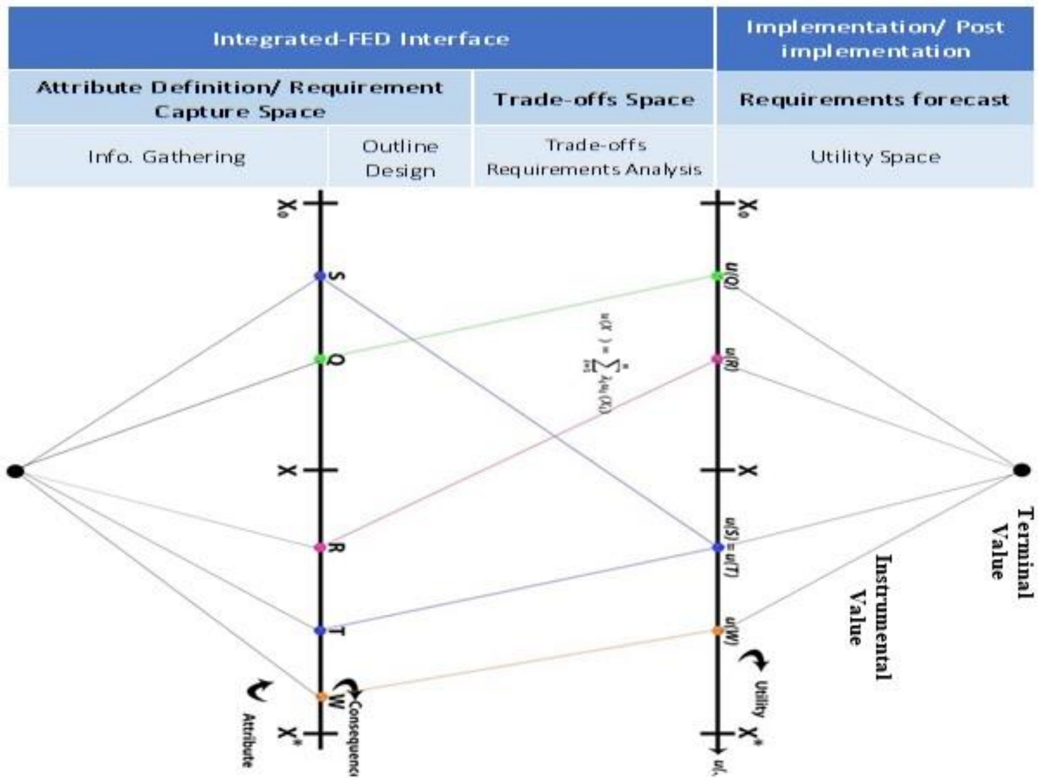

Figure 2. Framework to map value evolution and capture in ESD.

In the framework in Figure 2, this mismatch between interpretations is seen with the utilities of transformed attributes $Q\ and\ R$ on one hand and S on the other; so that in the former, their utilities $(U_Q\ and\ U_R)$ were lower than what was captured in the attribute space and interpreted in the trade-off space. Similarly, the attribute S is seen to have a higher utility (U_S), equal to $T, (U_T)$, than could supposedly be assumed in the previous spaces. According to Pich *et al.* (2002), DM has to adopt some level of ambiguity in this case built around a core purpose, so that any uncertainty arising out of these misunderstandings can be accommodated. Zhu and Mostafavi (2017) reinforce this position arguing that the right approach should be *'absorptive, adaptive, and restorative'* so as to have any change capacity. This stage seeks to reinforce the capacity of the DM process to accommodate any changing needs in the design process.

From the foregoing, UT provides a strong basis for analysis of the decision maker's propensity to risk which can influence their ability to make decisions in ESD. It's important to underscore the decision maker's preference structure from Figure 1 if various decisions carry the same utility especially if that decision is key to value definition. Perhaps some previous criticisms of UT do not adequately reflect the fact that in some settings, value trade-offs are a fundamental part of DM like it's illustrated crucially in this ESD framework. Some of these criticisms relate to transitivity, one of the central tenets of UT. Critics argue that transitivity may not necessarily be present in some real world DM scenarios such as expecting a professional boxer A to beat boxer B simply because boxer C beat boxer B. This perhaps is important in supporting further investigations into the limits of UT as a MADM tool by looking dynamic contexts in a more detail study as part of the wider research.

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