Proceedings of International Structural Engineering and Construction
Holistic Overview of Structural Design and Construction
Edited by Vacanas, Y., Danezis, C., Singh, A., and Yazdani, S.

ISSN: 2644-108X

A FRAMEWORK FOR EMERGENT NEEDS ANALYSIS DURING FRONT-END DESIGN IN SOCIAL HOUSING

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Social Housing is increasingly a focus of debate in many countries because of the escalating need for affordable housing that has become intertwined with the needs of society both emergent and traditional. The delivery of social housing, however, is often complex from the many stakeholders involved resulting in design challenges on account of conflicting needs. This paper presents a conceptual model for Design Decision Support in the face of emergent needs from multi-use scenarios defined by the multiple stakeholders. The Brazilian government's Minha Casa Minha Vida social housing program is the basis for the framework's conceptualization. The model allows for analysis of emergent user and design needs during design using probabilistic Hidden Markov Modeling of requirements changes. This paper's novel contribution is to present a theoretical conception of HMM in the analysis of changes in social housing requirements and modeling their interdependencies in front-end design decision making. The paper, therefore, adds to knowledge of requirements forecasting in design of social housing in the face of emergent needs.

Keywords: Requirements management, Requirements modeling, Benefits realization, Design decision support model, Markov chain, QFD.

1 INTRODUCTION

The importance of social housing in transforming communities has been highlighted by many studies recently (Kassela *et al.* 2017, Scanlon *et al.* 2015). Scanlon *et al.* (2015) for example, points to performance pressures within the social housing sector on the one hand while on the other, policy and user expectations continue to evolve. Social Housing is, therefore, increasingly a focus of debate in many countries. The rising need for affordable housing has become intertwined with individual and societal needs both emergent and traditional. The delivery of social housing, however, is often complicated by the ever growing number of stakeholders involved in the realization of social housing benefits on the one hand; and ever more complex and changing user needs on the other. This combination results in design challenges on account of often ill-defined and conflicting needs.

Participatory design (Donetto *et al.* 2015) has been heralded as an essential step towards bridging this gap. Using this approach, research argues that better value co-creation can be generated in projects (Fuentes and Smyth 2016). The key element in participatory value co-creation is understanding of stakeholder requirements. Dick *et al.* (2017) observe that requirements understanding and modeling should first reflect the context to support problem understanding and only following this should the process turn the focus on the solution. This position by the authors reinforces the vital role of Front End Design (FED) in the project's lifecycle as it's in this stage that requirements can be modeled and transformed in design requirements. Social housing use, however, is not static and use changes over time often renders the designs unsuitable for end users which often reflects insufficiencies in the requirements management processes. This places the modeling of requirements to support benefits realization is social housing projects during FED for both current and emergent needs; as an essential process in requirements management.

Thus, this paper presents the Design Decision Support Model as a conceptual model based on Utility Theory and requirements modeling; for FED decision making that takes into account both current and emergent end-user needs. In drawing to the role of context in design decision making, the Minha Casa Minha Vida social housing program is set as the basis for the model conceptualization in facilitating decision making with a focus on the utility of design decisions. The model illustrates the importance of analysis of emergent user and design needs using probability theory in accounting for uncertainty in the evidence base and requirements forecasting using Hidden Markov Modeling (HMM). The paper, therefore, explores the theoretical underpinnings in social housing design with a focus on FED processes alongside uncertainty and requirements forecasting modeling. The latter two concepts demonstrate the application of quantitative analysis in design decision making which represents a step-change in design practice.

2 FRONT-END DESIGN

Authors such as Almqvist (2017) and George *et al.* (2008) are part of growing research to highlight the vital role of FED in the efficacy of benefits realization in Architecture, Engineering and Construction (AEC) projects. This research argues that FED is the starting point in the realization of project benefits. FED is thus seen as one of the most critical stages in a project lifecycle (Gibson *et al.* 2006). According to this emergent body of knowledge, vital decisions that impact on project performance are made in FED processes; while other research highlights opportunities for value co-creation. Its argued that costs borne out of any design changes at this stage are significantly a fraction of those in later stages of project implementation. At the same, however, Fuentes and Smyth (2016) highlight that in terms of benefits realization, more understanding is needed into the exact links between value co-creation and benefits realization. It is argued that continuing value underperformances in the AEC sector stem from limited collaboration, optimization and modeling of processes (Gibson *et al.* 2010) and insufficiencies in the body of evidence that guides design decision making (Almqvist 2017) among others. Essentially, research suggests underlying insufficiencies in the management of project requirements in as much as they account for contextual influences on FED processes.

Such insufficiencies according to Oh Eun *et al.* (2016) are what contributes to failures in later processes that manifest as waste. Authors such as Gibson *et al*. (2010) argue that there is a direct link between such wastes in downstream processes and insufficiencies in earlier FED processes as a result of ill-defined requirements; a position reinforced by later Kukulies and Schmitt (2018). This essentially suggests that preciseness in requirements management in FED is essential in the delivery of project benefits (Dick *et al*. 2017). Requirements understanding is a crucial element of the body of knowledge essential for FED; and structuring requirements management processes is therefore essential in the information flow and exchanges thereof (George *et al*. 2008). The study by George *et al*. (2008) highlighted how this structure impacted on project scope definition, process, resource and risk management and planning, and fostering of collaborative environments aspects which impact on project communication and information flow. It, therefore, appears that improving the requirements management processes in FED translates into improved value delivery for the end-user (Dick *et al*. 2017). This approach to improved FED also presents opportunities for the design process to uncover unknowns in the process of defining the solution in a structured way (Gibson *et al*. 2010); as well as to context-specific influences on designs (Jung 2008) drawing to the many benefits of a structured FED. While research in this area appears on the increase, there is a gap between this body of research and the intricacy of requirements management in practice, much of which remains rational mainly and inadequate for the rising complexity in design of social housing (Serugga *et al.* 2019).

3 REQUIREMENTS MANAGEMENT IN SOCIAL HOUSING

Pohl (2016) asserts that requirements for a proposed system cannot be assumed to exist before they are elicited. This is especially important in social housing design where contexts differ widely and influence how end-users perceive the derived benefits. It is therefore essential that the design process seeks to establish the context and any boundaries that define the design (Pohl 2016). This process should include assessing both inherent and emergent requirements (Dick *et al*. 2017). It is on this basis that Dick *et al*. (2017) propose that requirements modeling need to focus on the context first that espouses the problem space before moving onto the solution space. Understanding requirements that can be functional or nonfunctional do define the material and immaterial attributes impacting on benefits realization (Pohl 2016) are essential in the implementation of housing projects. Research continues to reinforce the inherent inadequacy in requirements elicitation and general modeling in AEC (Serugga *et al*. 2019). This appears to confound in social housing design where besides, there appears little evidence in to support analysis and modeling, verification and validation and management of requirements over time in practice. Current tools are also reported insufficient to support the complex modeling of emergent and complex and often conflicting requirements (Serugga *et al*. 2019). New tools and models are therefore needed to facilitate the better realization of benefits, particularly for FED processes.

4 METHODOLOGY

This paper presents an early theoretical conceptualization of a Design Decision Support Model. The model formulation is guided by the authors' research into contextual design influences in Brazil but merely relies on theory for the model development. Literature review from seminal works such as Keeney and Raiffa (1976) for example support a utilitarian perspective to requirements modeling. This includes defining the basis for decision analyzing requirements through (i) establishing the analysis goal through finding and understanding of stakeholder needs (ii) defining the variables of analysis such as bringing structure to the raw requirements, (iii) identifying and modeling any contextual constraints (both current and future) alongside transforming the raw needs into a computational form and, (iv) devising evaluation criteria to ensure the devised/modeled specifications correspond to end-user needs.

5 MODELING EMERGENT REQUIREMENTS

Much of the current practice in requirements management adopts a rational approach. This has been noted to be insufficient in modeling the complex phenomena when end-user needs change as in social housing. An HMM approach is a probabilistic approach that models emergent future states based on current states by applying a state's transition and emission probabilities (Asadabadi 2017, Shieh and Wu 2009). Asadabadi (2017) illustrates that for a given conditional probability, the transition probability of X_t in state j given that $X_{t-1}$was in i is represented by the transition probability matrix (TPM) as can be seen in Eq. (1):

$$P[X_t = j|X_{t-1} = i] = P_{ij}^t \tag{1}$$

Given the condition states set $S = \{s_1, s_2 \ldots\ldots, s_n\}c$ and outcomes $O = \{o_1, o_2 \ldots\ldots, o_k\}$, $1 \leq i \leq n$ and $1 \leq j \leq k$. If $\{X\}$ is a representation of the Markov chain, $P_{ij}^{(0)}$defines the absolute probability for $s_1$is in t_0. Matrices A and B represent the transition and emission probabilities for s_i transits to s_1:

$$A = \begin{bmatrix} P_{s_1|s_1} & P_{s_1|s_2} & P_{s_1|s_3} & \cdots & P_{s_1|s_m} \\ P_{s_2|s_1} & P_{s_2|s_2} & P_{s_2|s_3} & \cdots & P_{s_2|s_m} \\ P_{s_3|s_1} & P_{s_3|s_2} & P_{s_3|s_3} & \cdots & P_{s_3|s_m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ P_{s_m|s_1} & P_{s_m|s_1} & P_{s_m|s_1} & \cdots & P_{s_m|s_m} \end{bmatrix} \quad B = C_{re} \begin{bmatrix} P_{o_1|s_1} & P_{o_1|s_2} & P_{o_1|s_3} & \cdots & P_{o_1|s_m} \\ P_{o_2|s_1} & P_{o_2|s_2} & P_{o_2|s_3} & \cdots & P_{o_2|s_m} \\ P_{o_3|s_1} & P_{o_3|s_2} & P_{o_3|s_3} & \cdots & P_{o_3|s_m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ P_{o_m|s_1} & P_{o_m|s_1} & P_{o_m|s_1} & \cdots & P_{o_m|s_m} \end{bmatrix} \tag{2}$$

For the observed phenomena o_j, the emission matrix B represents the current state s_i. Where the probabilities $P_{s_1|s_1}$and $P_{o_1|s_1}$are empirical data documented or through observation, survey or other data collection point and C_{re} represents the credibility factor applied to represent confidence in the empirical data sets. $\sum_{j=1}^{m} P_{s_j|s_i} = 1$ and $\sum_{k=1}^{m} C_{re} P_{o_k|s_j} = 1$. An HMM is thus the transition matrix A along with the probability $P_{ij}^{(0)}$ associated with the state s_j while the emission matrix B is that with the probability $P_{ij}^{(0)}$ associated with the observed outcome o_j. The transition of all i states through j states means that the sum of all transition probabilities sum to unity represented as $\sum_{j=1}^{m} P_{ij}^{t} = 1\ \forall i$. Iterating over several time-spaces, the probability at n steps is such that $P^n = P^{(0)} P_{ij}^{n}$ where $P^{(0)}$is the initial probability. It thus follows that given an initial probability and a transition probability as TPM, proceeding probabilities can be computed through raising the initial probability to the power n representative of the nth time state (Shieh and Wu 2009). It follows that for an $n\ steps$ transformation the matrix $B^{-1}AB_{kj}^{(n)}$ can be represented as can be seen in Eq. (3).

$$(B^{-1}AB)_{kj}^{(n)} = \sum_k (B^{-1}AB)_{ij}^{(n-1)} (B^{-1}AB)_{kj} = B^{-1}A^n B_{kj} \tag{3}$$

6 THE PROPOSED MODEL

An overview of a nine-step proposed model is presented in Figure 1. The stepwise approach aims to harness a typical FED process in supporting elicitation of requirements following the definition of project scope; followed by a concurrent process of categorization and transformation of requirements. The former step aims to group the different requirements into focus factors, while the latter is to interpret stakeholder needs into design requirements. Broad focus factors including such as things as economic performance or geopolitics or indeed family and among others are the basis for generating the important transition and emission matrices for proceeding HMM stepwise modeling. Quality Function Deployment (QFD) can then model any interdependences among the various requirements in a House of Quality (HOQ) matrix. Computations for the emission matrices and normalizations of the same are followed by analysis including sensitivity analysis to support optimization of input data in an iterative process.

The steps in the analysis are as follows: First step 1 that involves identifying an appropriate end-user to support the elicitation process. These are then tabulated in categories if appropriate in step 2. Stakeholder and expert groups are also identified to elicit corresponding design requirements followed by probabilities for the transition and emission matrices and thereafter capture the interdependences between Design requirements in steps 3, 4 and five respectively. Documentary evidence and any factual data that updates these for the probability and relationship matrices is important in this stage. These are then computed in an HMM analysis over the time-space required in step 6. The rating results feed into the HOQ end-user requirement for computing the relationship matrix in step 7. Then the HOQ matrix is computed for results in step 8. Sensitivity analysis and further data processing can be undertaken in step 9.

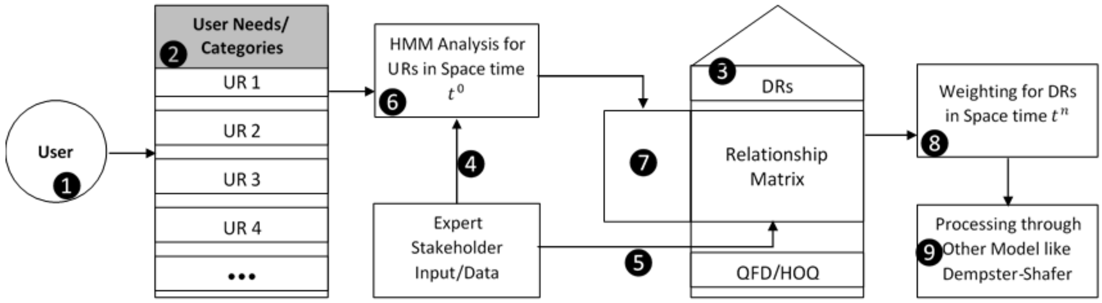

Figure 1. Hidden Markov analysis of end-user requirements using QFD for social housing.

7 DISCUSSIONS AND CONCLUSIONS

Utilizing the proposed HMM approach presents opportunities for informing FED processes of any future implications of design decisions. It is also is important in underscoring the role of the changing end-user and project context in the delivery of wider project benefits. As such the model presents opportunities in FED design planning and decision making on resource planning and benefits realization early in a project's lifecycle. The HMM analysis is initially based on obtained requirements, but importantly, the proceeding analysis is independent of these requirements something that gives the approach its robustness. This ensures that FED processes have a decision support tool to support insight into the future of a project that can run alongside current rational approaches. HMM also ensures the design process is focused on understanding the changing needs of the end-user as the approach allows design discourse to capture information on trends such as a change in family structures of aspirations something important in benefits perceptions. Capturing these intricate dynamics during design can mean that the design process stays in step and benefits realization processes stays relevant to the project purpose. The model also illustrates an iterative and collaborative benefits realization process in drawing out this information important not only for HMM but also for decision making. Another novelty in this approach is in addressing the time consuming and laborious process of requirements management. This means that if the requirements capture process is correct in the beginning, ongoing iteration, optimization and sensitivity analyses underpinning the wider project design processes can proceed without the need to repeatedly capture new requirements and assess how they've changed since. Modeling using HMM and QFD, therefore, presents a robust basis for design and data interdependences modeling while probabilities can be updated in the model if there is a significant event that impacts on design decision making to inform new understanding. Moreover, ongoing optimization and refinement of data including any probabilities or emergent requirements ultimately ensure that the rigor of the design process improves all the time to keep in pace with the changing project needs.

References

Almqvist, F., *The Fuzzy Front-End and The Forgotten Back-End: User Involvement in Later Development Phases*, The Design Journal, 20(sup1), S2524-S2533, 2017.

Asadabadi, M. R., *A Customer Based Supplier Selection Process That Combines Quality Function Deployment, The Analytic Network Process and a Markov Chain*, European Journal of Operational Research, 263(3), 1049-1062, 2017.

Dick, J., Hull, E., and Jackson, K., *Requirements Engineering*, Springer, 2017.

Donetto, S., Pierri, P., Tsianakas, V., and Robert, G., *Experience-Based Co-Design and Healthcare Improvement: Realizing Participatory Design in The Public Sector*, The Design Journal, 18(2), 227-248, 2015.

Fuentes, M., and Smyth, H., *Value Co-Creation at The Front-End of Project Management: A Service-Dominant Logic Perspective,* 2016.

George, R., Bell, L. C., and Edward Back, W., *Critical Activities in The Front-End Planning Process,* Journal of Management in Engineering, 24(2), 66-74, 2008.

Gibson, J. G. E., Bingham, E., and Stogner, C. R., *Front End Planning for Infrastructure Projects,* Construction Research Congress 2010: Innovation for Reshaping Construction Practice, 1125-1135, Alberta, Canada, 2010.

Gibson, J. G. E., Irons Kyle, T., and Ray Michael, P., *Front End Planning for Buildings*, Building Integration Solutions, 1-14, Omaha, USA, 2006.

Jung, Y., *Automated Front-End Planning for Cost and Schedule: Variables for Theory and Implementation*, AEI 2008: Building Integration Solutions, 1-10, Cololrado, USA, 2008.

Kassela, K., Papalexi, M., and Bamford, D., *Applying Quality Function Deployment to Social Housing?,* The TQM Journal, 29(3), 422-437, 2017.

Keeney, R. L., and Raiffa, H., *Decisions with Multiple Objectives: Preferences and Value Trade-Offs*, Cambridge University Press, 1976.

Kukulies, J., and Schmitt, R., *Stabilizing Production Ramp-Up by Modeling Uncertainty for Product Design Verification Using Dempster–Shafer Theory*, CIRP Journal of Manufacturing Science and Technology, 23, 187-196, 2018.

Oh Eun, H., Naderpajouh, N., Hastak, M., and Gokhale, S., *Integration of the Construction Knowledge and Expertise in Front-End Planning*, Journal of Construction Engineering and Management, 142(2), 2016.

Pohl, K., *Requirements Engineering Fundamentals: A Study Guide for The Certified Professional for Requirements Engineering Exam-Foundation Level-IREB Compliant,* Rocky Nook, Inc, 2016.

Scanlon, K., Fernández Arrigoitia, M., and Whitehead, C. M. E., *Social Housing in Europe*, European Policy Analysis, (17), 1-12, 2015.

Serugga, J., Kagioglou, M., and Tzortzopoulos, P., *A Predictive Method for Benefits Realisation Through Modelling Uncertainty in Front End Design,* 27th Annual Conference of the International Group for Lean Construction (IGLC), 1121-1132, Dublin, Ireland, 2019.

Shieh, J. I., and Wu, H.-H., *Applying a Hidden Markov Chain Model in Quality Function Deployment to Analyze Dynamic Customer Requirements*, Quality and Quantity*,* 43(4), 635-644, 2009.