TOWARDS A PREDICTIVE METHOD FOR BENEFITS REALISATION THROUGH MODELLING UNCERTAINTY IN FRONT END DESIGN

IGLC 2019

DUBLIN, IRELAND

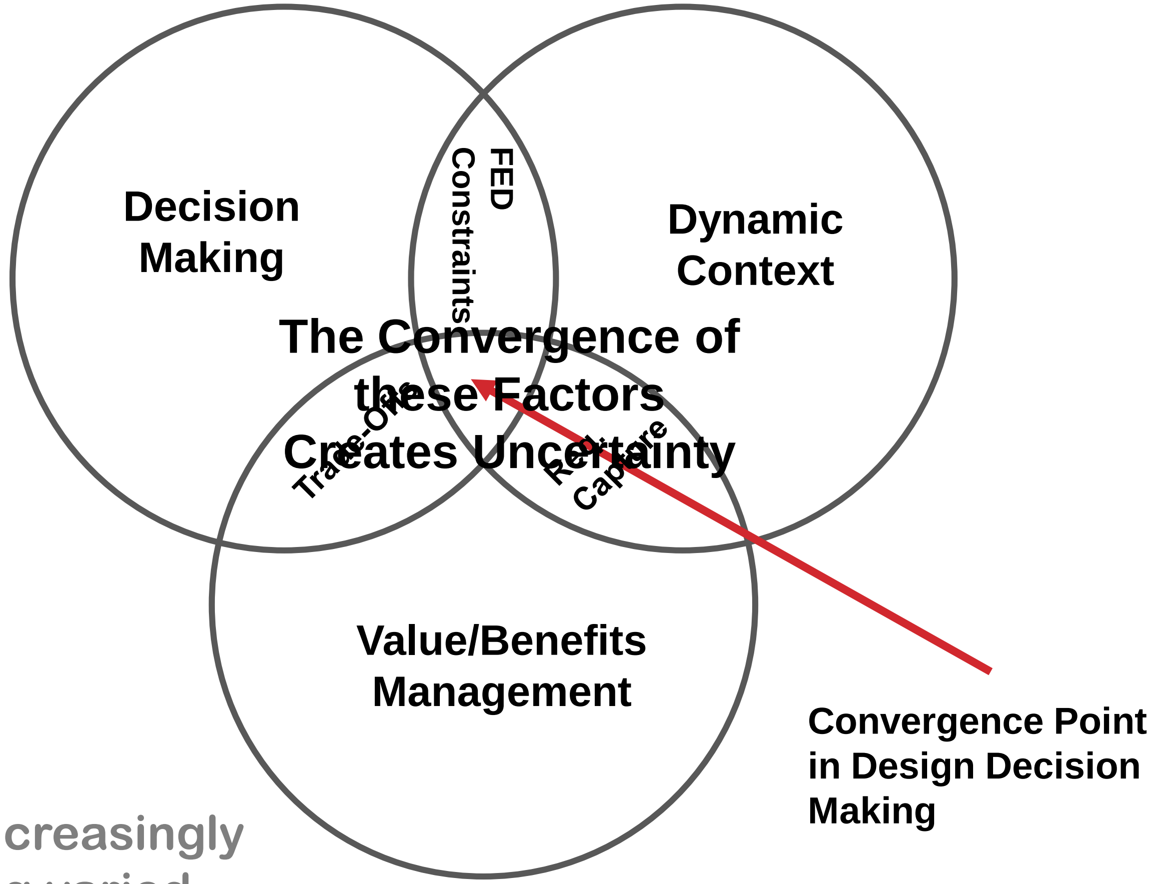
Joas Serugga, Mike Kagioglou, Patricia Tzortzopoulos

University of Huddersfield U.K.

CONTENTS

WHY THIS RESEARCH?

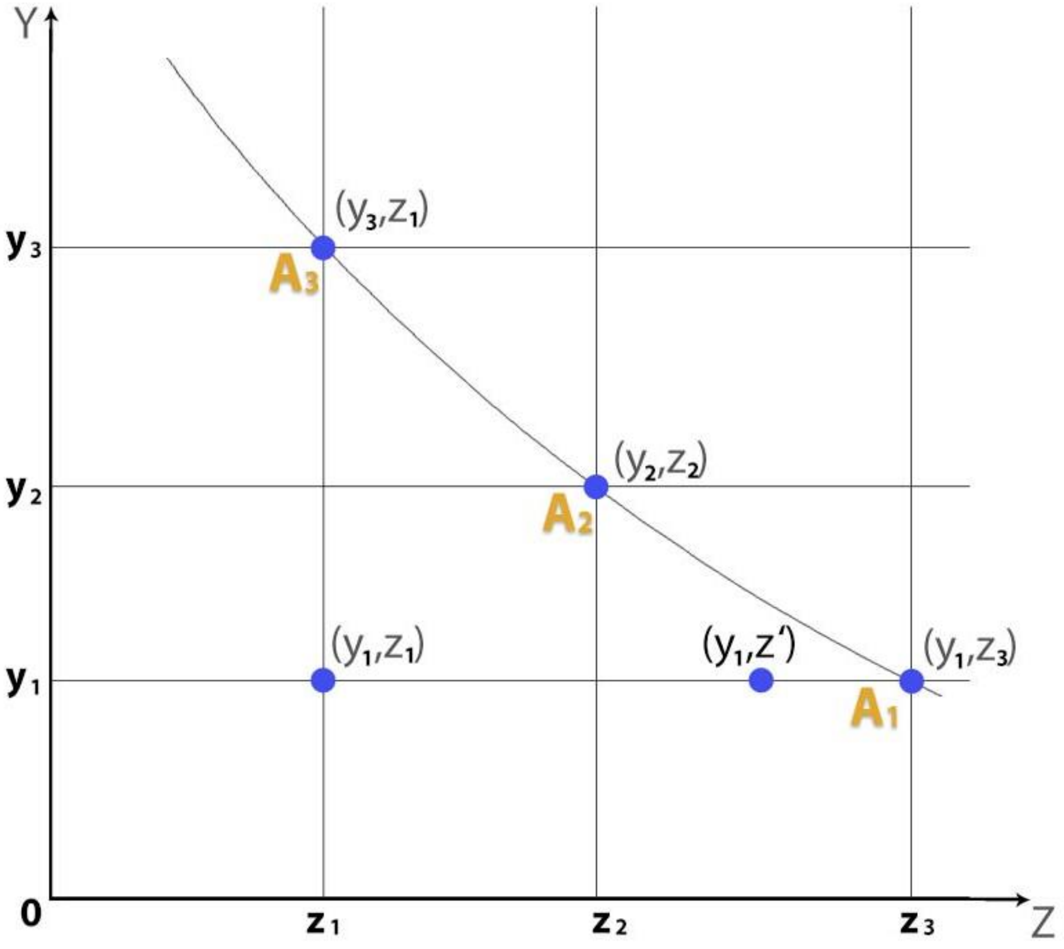
The Setting for this Research is in Social Housing Design Research. Social Housing Benefits stretch many stakeholder interests calling for contextual decision making.



The Delivery of Social Housing Benefits is increasingly a focus of many stakeholder interest creating varied expectations and bringing uncertainty to processes. Much of these benefits are determined during FED design processes. Yet FED decision making is Poorly Studied.

WHY THIS RESEARCH?

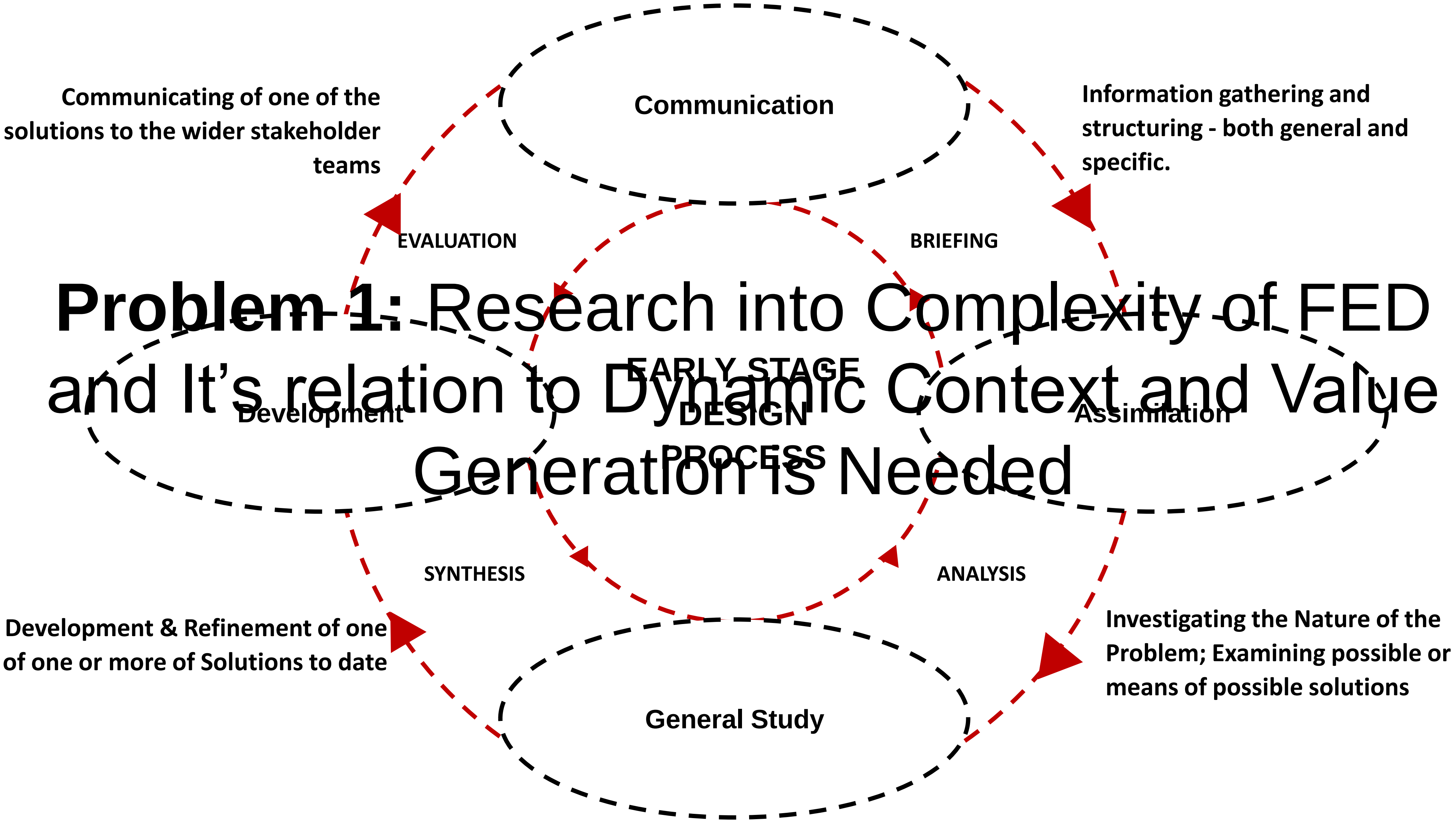
- Focus Usually on delivery of high-level goals such as enough social housing, within a given budget.
- K=Limited focus on how uncertainty is influencing design decision making processes to meet changing user use cases.
- A utilitarian perspective can focus decision making around their Utility function (UF) to harness Consistency $A_3\ (Y_3, Z_1)$,$A_2\ (Y_2, Z_2)$, $A_1\ (Y_1, Z_3)$ are of Equal Utilities so have to be explored with the DM)



WHY THIS RESEARCH?

- New Analytical Approaches to uncertainty in Design Decision Making in Social Housing Need Now to be Explored using mathematical approaches.
- This Has to Be Focussed on the Front End Design Stages where changes can be quicker & Cheaper to make, yet with the Most Dynamism information exchanges.
- Drawing Context to the role of uncertainty in Design Processes can also help draw focus on utility of benefits for social housing.

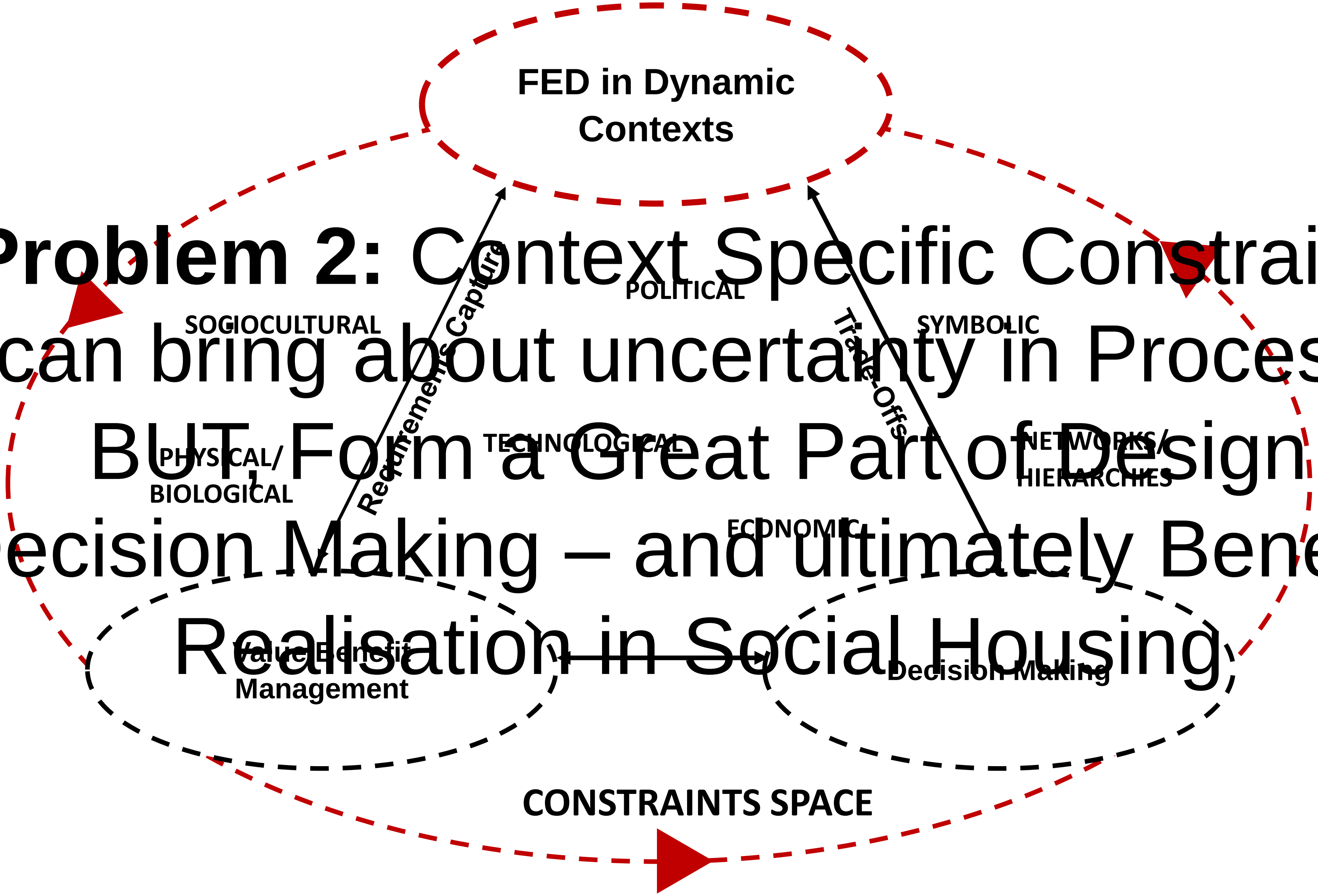
BACKGROUND – DESIGN PROCESS



Problem 1: Research into Complexity of FED and It's relation to Dynamic Context and Value Generation is Needed

Conceptualisation of Front End Design Adapted from Lawson (1983 p.24)

BACKGROUND – DYNAMIC CONTEXTS



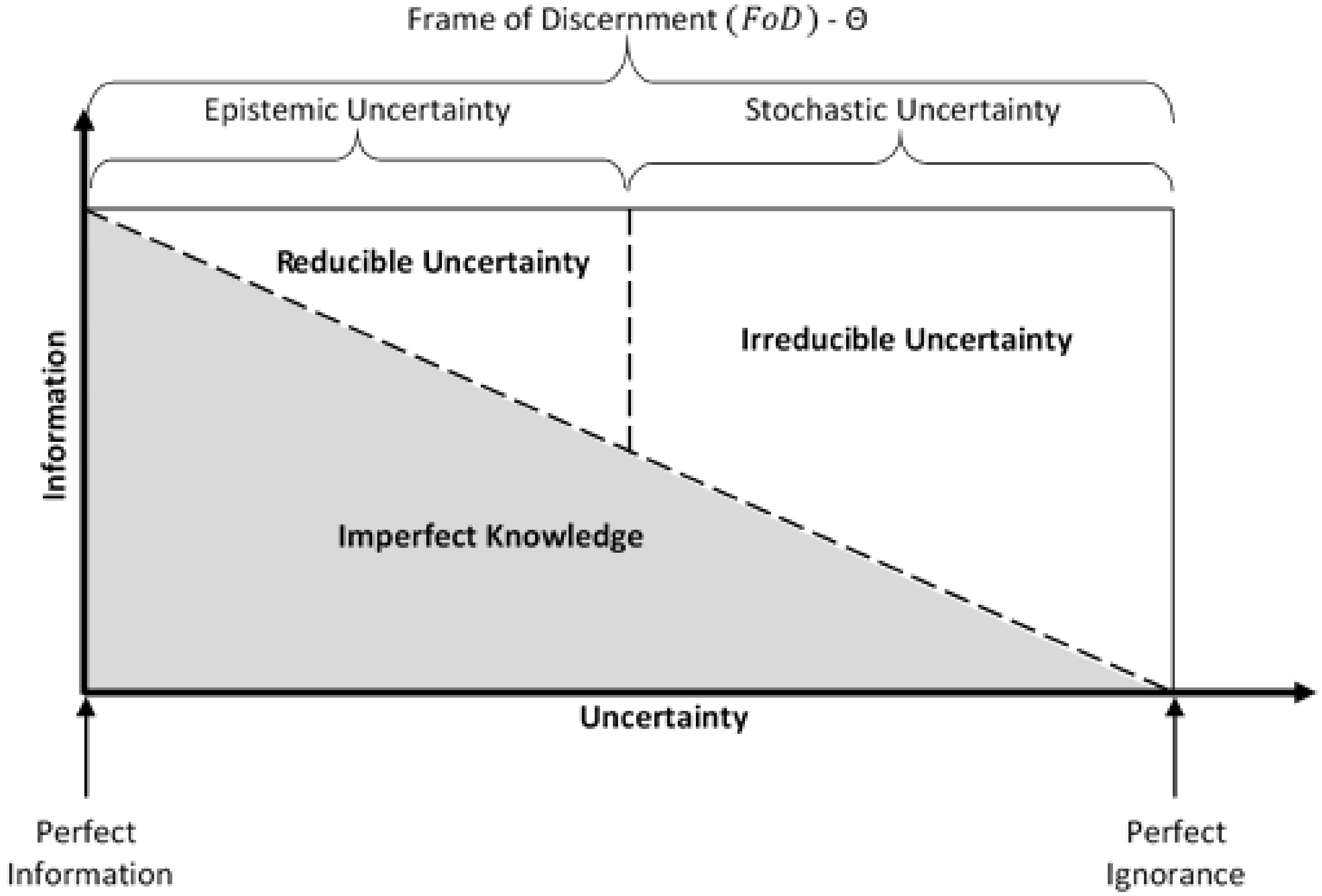
Problem 2: Context Specific Constraints can bring about uncertainty in Process; BUT, Form a Great Part of Design Decision Making – and ultimately Benefits Realisation in Social Housing;

RESEARCH METHODOLOGY....

- **A Mixed Methods Approach to Capture the Essential Heuristics, Subjectivity, Linguistics Adopted:** Set Basis for Context
- **Literature Review to Assess the Application of Probability Theory for Uncertainty and Predictive Modelling in the face of changing context studies –** a basis for theoretical validation of constructs and Architectural system (Evidence Based Design – EBD, Experience Based Design - ExBD)
- **Development of a Mathematical Model for Data Analysis -** based on Probability Theory (Using Dempster-Shafer Theory – to model uncertainty in design decision making; and Hidden Markov Modelling to model the changing user and design requirements) – in a utilitarian perspective.
- **Case study Research plus Action Research -** Opportunities for Evaluation of Model through data analysis for 3 housing models in 3 different contexts.

KEY CONCEPTS IN MODELLING UNCERTAINTY

Adapted from Kukulies and Schmitt (2018)



DEMPSTER- SHAFER THEORY

- **Multi Attribute Decision Making (MADM) during design such as in Social Housing involves uncertainty or use of incomplete information.**
- **Current tools and practice however are unable to account account for this uncertainty of the effect of 'making do' during FED processes** (Hua et al., 2008, Beynon et al., 2001)
- **Bayesian theoretic of conditional probability and adaptations such as Dempster-Shafer theory (DST) are able to model uncertainty within a body of evidence (BoE) -** (Dempster, 2008, Shafer, 1976, Altieri et al., 2017, Wang et al., 2016, Awasthi and Chauhan, 2011, Hua et al., 2008, Beynon, 2005).

DEMPSTER- SHAFER THEORY – CONT…

- DST allows for modelling of uncertain and unknown knowledge areas within a BoE through providing the Frame of Discernment (FOD) and a basic probability assignment (BPA) (Denœux et al. 2018, Zhou et al. 2017, Tang 2015)

FOD = denoted as $\Theta = \{S_1, S_2, \ldots, S_i, \ldots, S_n\}$

- The use of DST also helps reduce indeterminacy in decision making as argued by (Chen et al. 2018)
- In an action space, an incomplete BoE is assigned a basic probability assignments (bpa) for its describable and partially describable focal elements and the indescribable/FOD all assigned as DS mass functions [m(.)] (Denœux et al., 2018).

DEMPSTER- SHAFER THEORY – CONT…

In a BoE with n as set of focal elements in a BoE $m(.)$ defined as $s_1, s_2, \ldots, s_n$, with corresponding weights of $b_1, b_2, \ldots, b_n$ respectively, according to Beynon (2005), the BoE could be represented as:

$$m(s_i) = \frac{b_i p}{\sum_{j=1}^{d} b_i p + \sqrt{n}}, j = 1,2, \ldots, n \; and \; m(\Theta) = \frac{\sqrt{n}}{\sum_{j=1}^{d} b_i p + \sqrt{n}} \qquad (1)$$

Where p is the weighting for the criteria and Θ the FoD. The basic probability assignment (bpa) can also be represented by a belief function $Bel\ (A) = \sum_{\emptyset \neq B \subseteq A} m(B)$ and a Plausibility function $Pls\ (A) = \sum_{B \cap A \neq \emptyset} m(B)$. For two independent mass functions $m_1 and\ m_2$, the Dempster rule of combination can in this case be used to combine the two as follows:

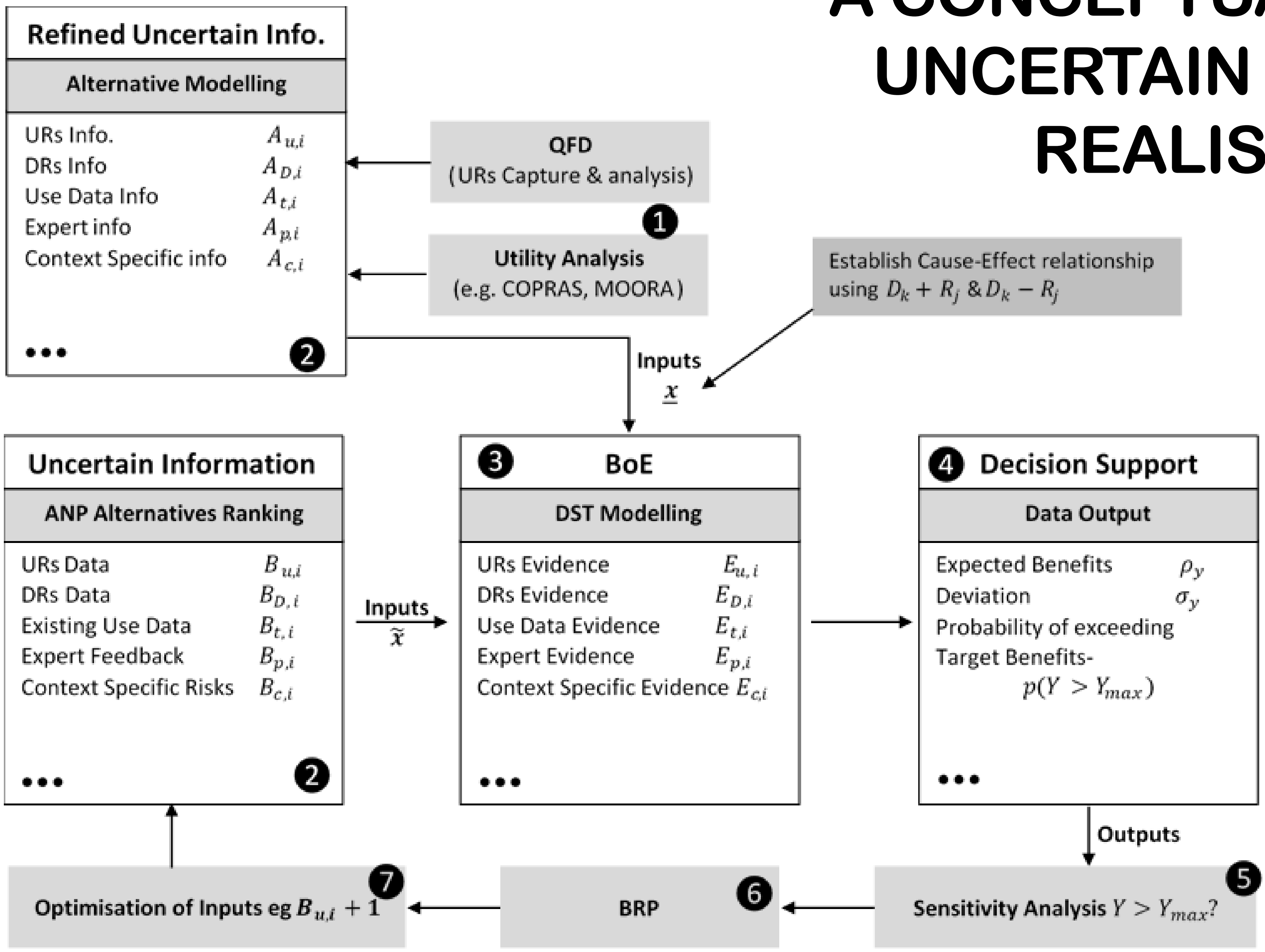
$$m(A) = m_1 \oplus m_2(A) = \begin{cases} 0, & A = \emptyset \\ \frac{1}{1-k} \sum_{B \cap C = A} m_1(B) m_2(C), & A \neq \emptyset \end{cases} \qquad (2)$$

Where k is defined as:

$$k = \sum_{B \cap C = \emptyset} m_1(B) m_2(C) \qquad (3)$$

k is also a normalisation constant reflecting the degree of conflict between $m_1 and\ m_2$

A CONCEPTUAL APPROACH TO UNCERTAIN BASED BENEFITS REALISATION PLANNING



MODEL FOR UNCERTAINTY MODELLING - INTRODUCED

- **First Step is Requirements Management including raw data on user needs as basis for Design Decision Making -** using quantitative approaches such as QFD, Utilitarian COPRAS, MOORA - (Yazdani et al., 2017)

Key Step in Quantification of Requirements is to capture interdependences between them Using this Matrix.

$$B = \begin{bmatrix} 0 & y_{12} & \cdots & y_{1j} & \cdots \\ y_{21} & 0 & \cdots & y_{2j} & \cdots \\ y_{31} & y_{32} & \cdots & y_{3j} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ y_{n1} & y_{n2} & \cdots & y_{nj} & 0 \end{bmatrix}$$

$$A = \begin{bmatrix} c_1 & c_2 & \cdots & c_t & \cdots \\ b_{11} & b_{12} & \cdots & b_{1t} & \cdots \\ b_{21} & b_{22} & \cdots & b_{2t} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ b_{r1} & b_{r2} & \cdots & b_{rt} & \cdots \end{bmatrix}$$

A Utilitarian focus on decision making further establishes the trade-offs in decision making using cost-benefit analysis with this Matrix

MODEL FOR UNCERTAINTY MODELLING – CONT…

- **STEP 2:** Model Input data as refine-able and uncertain variables ready for DS/ANP modelling.
- **STEP 3:** Define the Uncertainty Modelling parameters and Model the variables in the DS/ANP model

$$u(\{b_i\}) = Pls\ (\{b_i\}) - Bel\ (\{b_i\})$$

- **STEP 4:** Produce and Analyse Preliminary Results.
- **STEP 5:** Carry out Sensitivity Analysis
- **STEP 6:** Define the Benefits Realisation Planning (BRP) program from the sensitivity analysis.
- **STEP 7:** Iterate over uncertain information for results that do not meet criteria

CONCLUSIONS & LOOKING AHEAD

- Research represents a first step in the mathematical understanding and modelling of uncertainty in design.
- Research will aim to apply this understanding to the dynamic and uncertain process of social housing design.
- The application of mathematical uncertainty modelling represents a foundation for decision support filling gaps in current tools and applications for design decision making.
- Integrating the process of Requirements forecasting using Hidden Markov Modelling based on probability theory bring together complementary tools in focussing design process on utility of decision making

HIDDEN MARKOV MODELLING (HMM)

- User requirements in social housing change with time affected by such factors as technology, environment, sociocultural influences, geopolitics and physical/biological and societal/family/individual factors (Bolar et al., 2017).
- Current approaches in social housing design decision making however do not attempt to predict these changes; merely attempting address current needs.
- There is need for mathematical models for prediction of changing user needs during social housing design decision making.

HIDDEN MARKOV MODELLING (HMM)

- Probabilistic Hidden Markov Modelling (HMM) allows for integration with QFD’s requirements management process with automated prediction of changing use situations using emission and transition probabilities (Bolar et al., 2017).
- Current approaches in social housing design decision making however do not attempt to predict these changes; merely attempting address current needs.
- There is need for mathematical models for prediction of changing user needs during social housing design decision making.

HIDDEN MARKOV MODELLING (HMM)

- According to conditional probability the transition probability such that the probability of X_t being in state j given that X_{t-1} was in i for the transition probability matrix (TPM) is defined as (Asadabadi, 2017)

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

- A predictive mechanism for user requirements changes is thus as follows:

HIDDEN MARKOV MODELLING (HMM)

If the condition states set is such that $S = \{s_1, s_2 \ldots\ldots, s_n\}$ with corresponding observed parameters $O = \{o_1, o_2 \ldots\ldots, o_k\}$, $1 \leq i \leq n$ and $1 \leq j \leq k$. If $\{X\}$ is the representation of the Markov chain $P_{ij}^{(0)}$ is defined as the absolute probability such that s_1 is in t_0. The transition probabilities so that s_i transits to s_1 is then represented by:

$$A = \begin{bmatrix} P_{s_1|s_1} & P_{s_1|s_2} & P_{s_1|s_3} & \cdots & P_{s_1|s_m} \\ P_{s_2|s_1} & P_{s_2|s_2} & P_{s_2|s_3} & \cdots & P_{s_2|s_m} \\ P_{s_3|s_1} & P_{s_3|s_2} & P_{s_3|s_3} & \cdots & P_{s_3|s_m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ P_{s_m|s_1} & P_{s_m|s_1} & P_{s_m|s_1} & \cdots & P_{s_m|s_m} \end{bmatrix} \quad (4)$$

The corresponding emission matrix for the output o_j given that the current state is s_i is as below

$$B = C_{re} \begin{bmatrix} P_{o_1|s_1} & P_{o_1|s_2} & P_{o_1|s_3} & \cdots & P_{o_1|s_m} \\ P_{o_2|s_1} & P_{o_2|s_2} & P_{o_2|s_3} & \cdots & P_{o_2|s_m} \\ P_{o_3|s_1} & P_{o_3|s_2} & P_{o_3|s_3} & \cdots & P_{o_3|s_m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ P_{o_m|s_1} & P_{o_m|s_1} & P_{o_m|s_1} & \cdots & P_{o_m|s_m} \end{bmatrix} \quad (5)$$

Where the probabilities $P_{s_1|s_1}$ and $P_{o_1|s_1}$ are empirically determined and C_{re} is the credibility factor applied to represent confidence in the empirical sets and $\sum_{j=1}^{m} P_{s_j|s_i} = 1$ and $\sum_{k=1}^{m} C_{re} P_{o_k|s_j} = 1$. A HMM is thus the transition matrix A along with the probability $P_{ij}^{(0)}$ associated with the s_j state while the emission matrix B is that with the probability $P_{ij}^{(0)}$ associated with the observed outcome o_j.

HIDDEN MARKOV MODELLING (HMM)

- **Case example is a typical family probabilistic states of social housing use such as income cycles of low, medium, high and very high;**
- **Each of these states can determine the benefits realisation in these changing use cases of a social housing.**
- **These states *1,2,….,m* can be captured and recorded at different times t**
- **In HMM, state i for low income at $t-1$ is represented by X_{t-1}.** (essentially, at any given time t, i or j can exhibit one state among $1,2, \ldots, m$)

LOOKING AHEAD

The Mathematical Model Employs Quality Function Deployment in Requirements Management that are modelled using Probability theory - Dempster-Shafer Theoretic and Hidden Markov Modelling to model changing user and design Requirements to support design decision making in meeting utility of social housing amid use and process uncertainty.

THE END

Questions Please Welcome

REFERENCES

AKBAŞ, H. & BILGEN, B. 2017. An integrated fuzzy QFD and TOPSIS methodology for choosing the ideal gas fuel at WWTPs. Energy, 125, 484-497.

ASLESEN, S., KRISTENSEN, E., SCHANCHE, H. & HEEN, P. I. Winning the Bid – A Step-Wise Approach Using BIMto Reduce Uncertainty in Construction Bidding. 26th Annual Conference of the International Group for Lean Construction, 2018/07/18 2018 Chennai, India. Chennai, India, 68-78.

AUSTIN, S., STEELE, J., MACMILLAN, S., KIRBY, P. & SPENCE, R. 2001. Mapping the conceptual design activity of interdisciplinary teams. J Design studies, 22, 211-232.

BATAGLIN, F. S., VIANA, D. D., FORMOSO, C. T. & BULHÕES, I. R. Application of Bim for Supporting Decisionmaking Related to Logistics in Prefabricated Building Systems. 25th Annual Conference of the International Group for Lean Construction, 2017/07/09 2017 Heraklion, Greece. Heraklion, Greece, 71-78.

BEYNON, M. J. 2005. A method of aggregation in DS/AHP for group decision-making with the non-equivalent importance of individuals in the group. Computers & Operations Research, 32, 1881-1896.

BOLAR, A. A., TESFAMARIAM, S. & SADIQ, R. 2017. Framework for prioritizing infrastructure user expectations using Quality Function Deployment (QFD). International Journal of Sustainable Built Environment, 6, 16-29.

BRADLEY, G. 2016. Benefit Realisation Management: A practical guide to achieving benefits through change, Routledge.

BURGER, K., WHITE, L. & YEARWORTH, M. 2019. Understanding front-end project workshops with Social Practice Theory. International Journal of Project Management, 37, 161-175.

CHESBROUGH, H., LETTL, C. & RITTER, T. 2018. Value Creation and Value Capture in Open Innovation. Journal of Product Innovation Management, 35, 930-938.

CORTES, J. P. R., PONZ-TIENDA, J. L., DELGADO, J. M. & GUTIERREZ-BUCHELI, L. Choosing by Advantages; Benefits Analysis and Implementation in a Case Study, Colombia. 26th Annual Conference of the International Group for Lean Construction, 2018/07/18 2018 Chennai, India. Chennai, India, 636-646.

DEL ÁGUILA, I. M. & DEL SAGRADO, J. 2016. Bayesian networks for enhancement of requirements engineering: a literature review. Requirements Engineering, 21, 461-480.

DEMPSTER, A. P. 2008. Upper and lower probabilities induced by a multivalued mapping. Classic Works of the Dempster-Shafer Theory of Belief Functions. Springer.

DENŒUX, T., LI, S. & SRIBOONCHITTA, S. 2018. Evaluating and comparing soft partitions: An approach based on Dempster–Shafer theory. IEEE Transactions on Fuzzy Systems, 26, 1231-1244.

FUENTES, M. & SMYTH, H. Value co-creation at the front-end of project management: a service-dominant logic perspective. 2016. Association of Researchers in Construction Management.

HORKOFF, J. & YU, E. 2016. Interactive goal model analysis for early requirements engineering. Requirements Engineering, 21, 29-61.

HUA, Z., GONG, B. & XU, X. 2008. A DS–AHP approach for multi-attribute decision making problem with incomplete information. Expert systems with applications, 34, 2221-2227.

REFERENCES

JAVANMARDI, A., ABBASIAN-HOSSEINI, S. A., HSIANG, S. M. & LIU, M. Constraint Removal and Work Plan Reliability: A Bridge Project Case Study. 26th Annual Conference of the International Group for Lean Construction, 2018/07/18 2018 Chennai, India. Chennai, India, 807-817.

KAGIOGLOU, M., COOPER, R., AOUAD, G. & SEXTON, M. 2000. Rethinking construction: the generic design and construction process protocol. J Engineering, Construction Architectural Management, 7, 141-153.

KAGIOGLOU, M. & TZORTZOPOULOS, P. Benefits realisation: an investigation of structure and agency. Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA, 2016. IGLC, 183-192.

KEENEY, R. L. & RAIFFA, H. 1993. Decisions with multiple objectives: preferences and value trade-offs, Cambridge university press.

KIM, Y.-W. & BALLARD, G. 2010. Management thinking in the earned value method system and the last planner system. J Journal of Management in Engineering, 26, 223-228.

KLIR, G. J. 2004. Generalized information theory: aims, results, and open problems. Reliability Engineering & System Safety, 85, 21-38.

KOSKELA, L. Making-Do — the Eighth Category of Waste. In: BERTELSEN, S. & FORMOSO, C. T., eds. 12th Annual Conference of the International Group for Lean Construction, 2004/08/03 2004 Helsingør, Denmark. Helsingør, Denmark.

KOSKELA, L., BØLVIKEN, T. & ROOKE, J. Which Are the Wastes of Construction? In: FORMOSO, C. T. & TZORTZOPOULOS, P., eds. 21th Annual Conference of the International Group for Lean Construction, 2013/07/31 2013 Fortaleza, Brazil. Fortaleza, Brazil, 3-12.

KUKULIES, J. & SCHMITT, R. 2018. 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.

MUÑOZ-FERNÁNDEZ, J., KNAUSS, A., CASTAÑEDA, L., DERAKHSHANMANESH, M., HEINRICH, R., BECKER, M. & TAHERIMAKHSOUSI, N. Capturing ambiguity in artifacts to support requirements engineering for self-adaptive systems. 2017.

NGUYEN, H. V., LOSTUVALI, B. & TOMMELEIN, I. D. Decision Analysis Using Virtual First-Run Study of a Viscous Damping Wall System. In: CUPERUS, Y. & HIROTA, E. H., eds. 17th Annual Conference of the International Group for Lean Construction, 2009/07/15 2009 Taipei, Taiwan. Taipei, Taiwan, 371-382.

SAATY, T. L. 2001. Decision making with dependence and feedback: The analytic network process, RWS, Pittsburgh.

SAHU, A. K., MAHAPATRA, S. S., CHATTERJEE, S. & THOMAS, J. 2018. Optimization of surface roughness by MOORA method in EDM by electrode prepared via selective laser sintering process. Materials Today: Proceedings, 5, 19019-19026.

SALAZAR, L. A., BALLARD, G., ARROYO, P. & ALARCÓN, L. F. Indicators for Observing Elements of Linguistic Action Perspective in Last Planner® System. 26th Annual Conference of the International Group for Lean Construction, 2018/07/18 2018 Chennai, India. Chennai, India, 402-411.

SHAFER, G. 1976. A mathematical theory of evidence, Princeton university press.

SMYTH, H. 2018. Projects as creators of the preconditions for standardized and routinized operations in use. International Journal of Project Management, 36, 1082-1095.

SMYTH, H., LECOEUVRE, L. & VAESKEN, P. 2018. Co-creation of value and the project context: Towards application on the case of Hinkley Point C Nuclear Power Station. International Journal of Project Management, 36, 170-183.

REFERENCES

SWEENEY, J. C., PLEWA, C. & ZURBRUEGG, R. 2018. Examining positive and negative value-in-use in a complex service setting. European Journal of Marketing, 52, 1084-1106.

TORP, O., BØLVIKEN, T., ASLESEN, S., FRITZSØNN, L. P., HAAGENSEN, Å., LOMBARDO, S. & SALTVEIT, T. Is Integration of Uncertainty Management and the Last Planner System a Good Idea? 26th Annual Conference of the International Group for Lean Construction, 2018/07/18 2018 Chennai, India. Chennai, India, 658-668.

YAZDANI, M., CHATTERJEE, P., ZAVADSKAS, E. K. & ZOLFANI, S. H. 2017. Integrated QFD-MCDM framework for green supplier selection. Journal of Cleaner Production, 142, 3728-3740.