OPTIMISED STRATEGY BY UTILISING BIM AND SET-BASED DESIGN : REINFORCED CONCRETE SLABS

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ABSTRACT

Considering the significant amount of material wasted in the construction industry there should be a business case for companies to pay more attention to reducing waste, which would also have a major impact on the environmental issues of the projects. Although structural engineers and architects have different roles in the design process in selecting construction systems and materials, they provide building information together. Building Information Modeling (BIM) could provide an opportunity for all relevant stakeholders to share their knowledge and experiences in the early stages of design and a platform for structural engineers to utilize Set-based Design in considering different alternatives for the optimal design of systems. This research suggests a conceptual strategy for enhancing an decision support model in parallel with stakeholders' participation to achieve the optimal final solution in terms of material waste, by narrowing down the structural alternatives. The example used in the paper is reinforced concrete slabs, but the same principles are applicable to all structures.
This research will focus on describing the BIM features, which could help the structural engineers to rank their criteria and select optimized design solutions.

Keywords: BIM, Set-based Design, structural engineering, waste reduction, concrete slab.

1. INTRODUCTION

The construction industry is an activity producing a significant quantity of material waste; the building industry consumes approximately 40% of the world's raw materials. (Koskela 1992) and in the UK from the 420 million tonnes of materials used annually 120 million tonnes, 28%, becomes waste (Network Waste UK 2012)Already in the construction phase the waste of materials can constitute 2-3% of the total construction costs, which is about the same as the typical profit margin in the industry (Network Waste UK 2012). Previous research has indicated that the main reasons for physical waste in the construction industry are inappropriate preparation, inaccurate processing of materials and incorrect decisions in the design stage (Ballard 2000).

The main reason for errors and delays in most processes is inconsistent and ambiguous information. Therefore, the construction industry requires explicit storage to share and exchange the project information between all participants (van Nederveen et al. 2010). It is commonly known that design and construction projects are too often running over budget and schedule because of errors and changes during the construction. BIM is expected to address some of the fundamental reasons for these problems by ensuring "getting the right information in the right format at the right time in the right place" (Tolman 1999)"BIM is a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's lifecycle" (Penttila 2006). reduction in mistakes and rework than material produced by a commercial vendor who is unlikely to be neutral (Autodesk 2011).

Eastman et al. (2008)examined three main impacts of BIM in the design phase: 1) Conceptual design, 2) Integration of engineering services, and 3) Construction-level modelling. Conceptual design determines the basic framework of the construction design in terms of general spatial layout, massing and structure, taking the site and other local conditions into consideration. The integration of engineering services can cover many factors of a building's performance, e.g. analysis of structural engineering, ventilation, temperature control, energy distribution, water consumption, waste disposal, lighting, acoustics and air flows. Construction-level modelling covers detailing, specifications and cost estimation, including composition and placement rules to expedite the generation of construction standards and construction documentations.

Danatzko (2010) highlighted some sustainable structural design methodologies including diminishing material use, material production energy and embodied energy creating lifecycle analysis/inventory and ensuring reuse. This research will examine the link between Set-based Design and BIM in selecting the most efficient system for pre-cast concrete slabs in structural design. At this point the research is in its early stages so the paper presents the initial framework for the future work.

2. SET-BASED DESIGN AND POINT-BASED

In the philosophy of design, the term of DTM (Design Theory Methodology) has been described as a study of determining the methods and thinking of designers to develop efficient structures for the design procedures (Wynn and Clarkson 2005). The design in structural engineering means the entire planning procedure for a new building or infrastructure including mathematical calculations, and the requirements usually come from the client's functional requirements and building codes defined by Government bodies. The structural design can be categorized in two stages: 1) a feasibility study involving a comparison of the alternative solutions for structures and selection of the most suitable types, and 2) detailed design of the chosen structure (Arya 2009).The main criterion in structural engineering is ensuring that the strength of materials and components at any critical point is sufficient for all stresses and loads affecting that part. The design principles would support a Point-based or Set-based system. Commonly engineers use Point-based Design, where a single option of feasible design will be selected based on the designer's experience and subsequently the design will be modified by more information (Lee et al. 2012).

In the Set-based Design, various design alternatives are considered by specific stakeholders at the same time and the information necessary for evaluating different options from multiple perspectives is transferred between these stakeholders. The main difference between Set-based Design and Point-based Design is that in the Set-based Design the engineer maintains several alternatives while in Point-based Design the selection is made in the earlier phase and the possible alternatives are not examined from several viewpoints in detail. "In particular, in the structural engineering phase, the design includes all permissible design options ranging from schematic design to construction detailing, and these could be modified and postponed until the decisive stage rather than materializing them before all of the requirements have been suggested" (Lee et al. 2012).

By using BIM the process does not only address the clashes between construction components but designers can produce and analyse alternative solutions faster than if they provide them separately (Parrish 2009).the research hypothesis is that this can make set-based design more efficient in the BIM environment than when using traditional methods, but this must be verified in the future research.

BIM provides tools for structural engineers to obtain models from architects and therefore easier access to correct information to define, for example, details of rebar conjunctions in concrete slabs. According to Arya (2009)"Most failures are as a result of poor detailing rather than incorrect analysis".

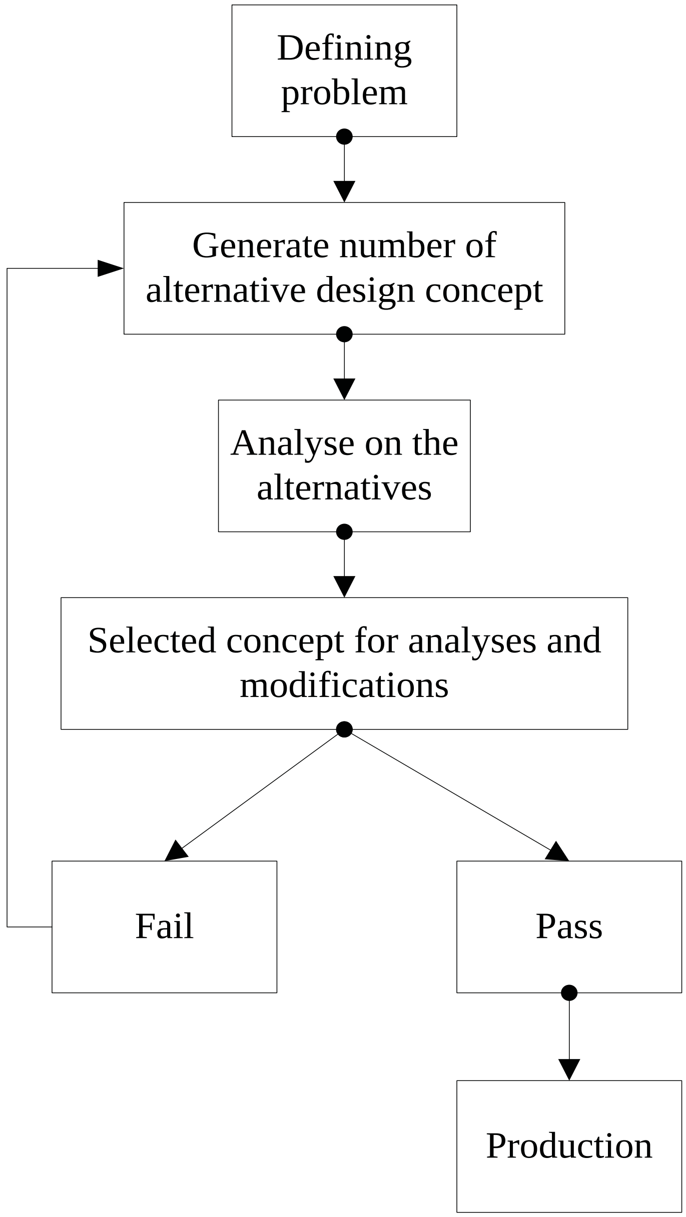

Figure 1: Point-based process

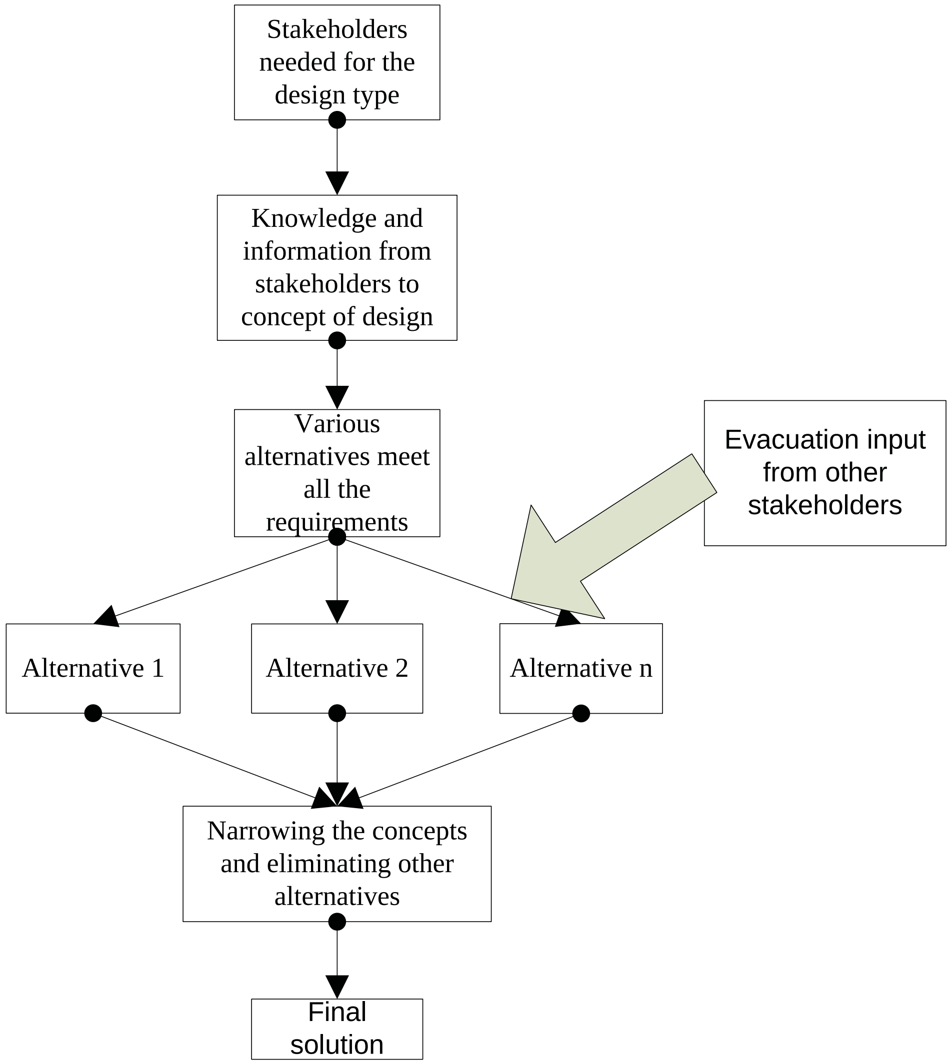

Figure 2 : Set-based design procedure

3. DESIGNING REINFORCED CONCRETE SLAB USING SET-BASED DECISION MAKING

In the course of structural designing, engineers are faced with several alternatives due to skill and experience of each designer lead to different design and complexity of the treated structure make several re-analysis and redesigns (Mahfouz 1999). Designing concrete slab would be an example of structural designing process which has been considered in this research to illustrate the overview of the conceptual platform thinking in set-based design and selecting optimum alternatives. In reinforced concrete construction, slabs are providing useful surfaces and flat and. Slabs might be supported by reinforced concrete beams, by masonry or reinforced concrete walls, by structural steel members, directly by columns or continuously by the ground. Slabs might be supported on to opposite sides only (one-way) or might be supported by beams an all four sides (two-way), if the ratio of length to width of one panel be longer than 2, therefore, one-way action is achieved due to most of the load will carry by the short way, even all supports be provided on all sides (Nilson et al. 2004). In some cases concrete slabs are supported directly by columns and those are called flat slabs and these types of concrete slabs utilize where spans are not large and loads not so heavy. In the course of slab concrete designing, the main criterion is safety, punching failure in high stress at the supports is a key aspect in designing structure of slabs however, normal slabs with column drops or edge beams do not suffer punching shear (Arya 2009). To avoid this failure engineers must take into consideration deep slabs and large diameter columns, and therefore the designer must consider several integrated design alternatives.

During the designing of concrete slabs, structural engineers can select the applicable building code through a variety of software. In designing concrete slabs deflection is a critical factor in addition to the ultimate limit state of bending and shear. The choice of slabs would begin with solid or precast, and afterwards for each main choice there are large numbers of alternatives. For a Reinforced Concrete slab alternatives are divided in geometric and non-geometric (Sacks et al. 2000). The geometric are related to Slab parameters such as length, width, dept. of slab and the width and depth of each four beams. And the non-geometric alternatives consider general aspects of successful project such as cost, time, quality and sustainability. All key stakeholders should rank these alternatives considering their different aspects. A new possibility in the BIM environment could be to use some advanced decision-making method, Parrish (2009) has highlighted some Decision making approach in set-based design in the choice of reinforcing bars in concrete design, such as; AHP, Choosing by Advantage, Multi-attribute Utility Theory or Robust Decision Making - to choose the optimal solution considering safety, economical and waste aspects.

By considering Set-based Design, based on BIM, the type of final slab would not be selected until last phase of design. The procedure of Set-based Design is categorized in Mapping Design Spaces, Finding Compatible Combinations of Design, and Making Commitment (Parrish et al. 2007). In the Mapping Design Spaces phase there are three main factors; the first is the minimum depth of slab (d_{min}), second is the minimum area of bars (A_{Smin}) and the third is the minimum and maximum clear distance between bars (S_{bmin} & S_{bmax}) (Arya 2009). All these factors impact on material usage in reinforced concrete slabs. The factors which can change the outputs can be categorized in two groups. The first category are factors, which are related to resistance or quality of materials, such as yield tension of steel(f_y) and maximum size of aggregate in concrete(h_{agg}). By increasing the values of these factors the minimum total area of bars in the slab section (A_{Smin}) will decrease and the minimum clear distance of the bars (S_{bmin}) will increase, which means that the total amount of steel in the slabs will be reduced according to the following equations from Euro code (Arya 2009).

$$A_s \geq 24\ \%\ A_c \text{ When } f_y = 250 \text{ N/ } mm^2$$

$$A_s \geq 0.13\ \%\ A_c \text{ When } f_y = 460 \text{ N/ } mm^2$$

$$h_{agg} + \text{Bar Diameter} \leq S_b \leq 3\text{d or } 750 \text{ mm}$$

The second category is related to factors, which designers can control, and they have a key role in minimising waste of material and in finding compatible combinations of design. In the designing of reinforced concrete one of the significant parameters is the amount of steel in the section area of concrete (ρ), and there are large numbers of potential combinations using bars with different diameters which can fulfil the requirements. Hence in the last phase of Set-based Design all these alternatives will be narrowed down to the final optimal concrete slab which is determined by the optimal depth of concrete, the optimal number of bars, the optimal clear distance between bars and finally the optimal span (one way slab or two way slab).

According to Howard (1988)"Decision analysis stands on a foundation of hundreds of years of philosophical thought about uncertainty and decision-making". The decision analysis is a process of understanding the problem, evaluating and solving. In the decision making, to find an optimal solution for a structural component, BIM-based system could improve the process by narrowing down the alternatives and supporting stakeholders' negotiation. It could be obtained from Figure 3 which has described the optimised conceptual strategy in structural design that, the two various conceptual thinking; BIM and Set-based design are integrated together. in the set-based design concept all the criteria depends on project conditions are ranked by the all project stakeholders from initial to final stages of project lifecycle and Information are transferred between Participants on the base of BIM concepts (information are machine readable (Eastman 2007)) and the all BIM tools aid participants to make the model more visualised for multi criteria decision supports based on advantages.

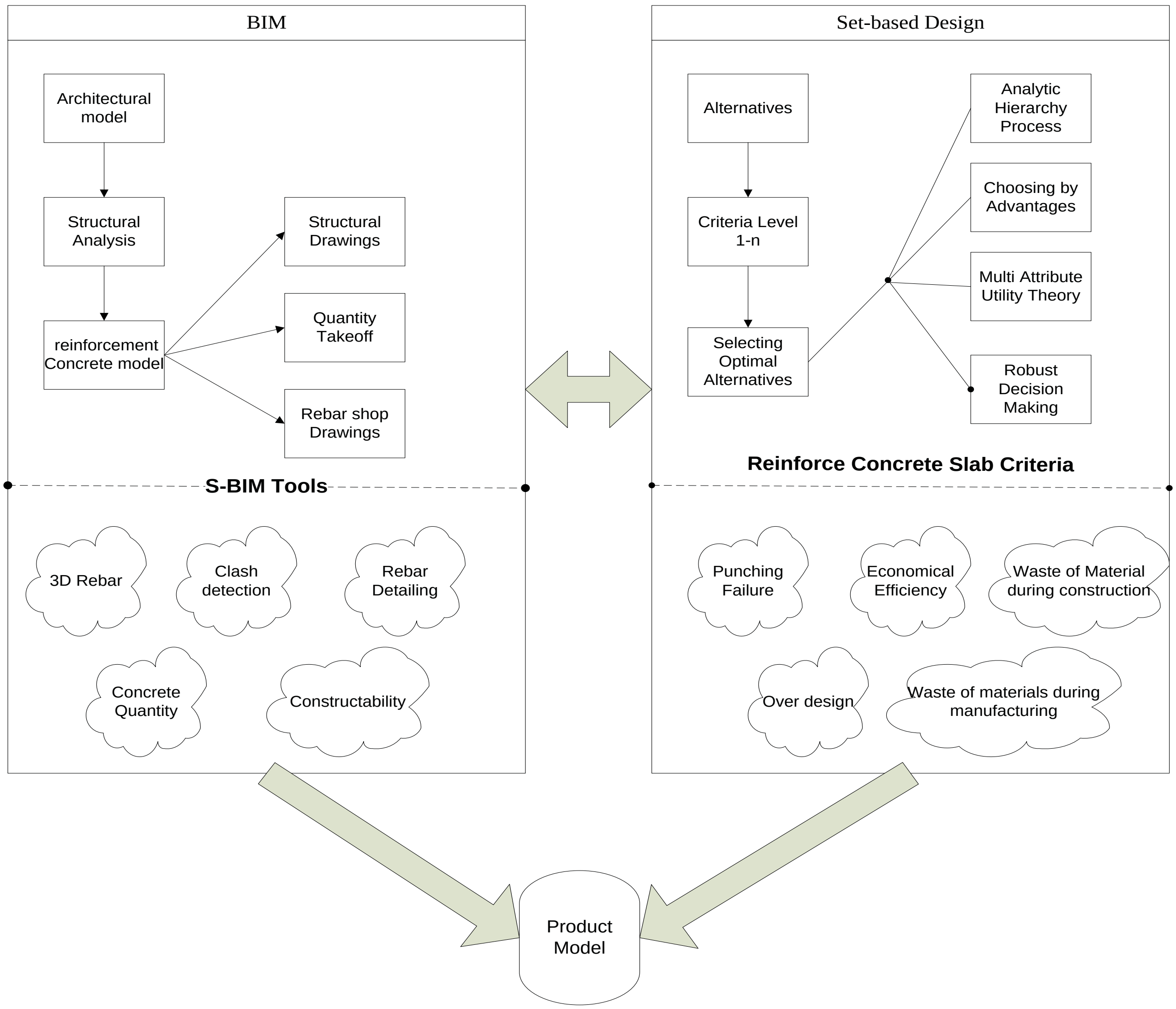

Figure 3: S-BIM in contingence with set-based design to select optimum alternatives.

Key stakeholders can input their weighing on different factors by considering the current customer requirements and potential future requirements (resource and material) for such a system, and the system could first narrow down the alternatives and at the final stage “find the total value for each alternative” (Cariaga et al. 2007) by formulating the ranking based on various intelligent decision-making methods, such as the Analytic Hierarchy Process, Choosing by Advantages, Multi-attribute Utility Theory or Robust Decision Making.

4. CONCLUSION

In addition to safety and durability of concrete slabs, minimizing material usage will be a critical factor for sustainable building design. To achieve this goal, Set-based Design has been suggested as an opportunity for all key stakeholders in the design phase, "Set-based design makes it possible to maintain feasible solutions for longer in the design process" (Parrish et al., 2007) to collaborate and utilize their knowledge and experiences in the decision-making. The combined use of BIM and Set-based Design will enable development and evaluation of a large number of alternative structural models. For reinforced concrete slabs those alternatives could be a combination of various materials with different resistances and various space designs. In parallel with determining various structural concrete slabs by key stakeholders, an intelligent decision-making system would support the evaluation of material optimization thus making the process of narrowing down alternatives in a more intelligent and efficient way.

The next step of this PhD research will be to examine appropriate intelligent decision-making processes in the integrated BIM environment for optimized structural design.

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