AN ANALYTICAL APPROACH FOR ‘REQUIREMENTS SPECIFICATIONS’ TO ENLIGHTEN ‘DESIGN PRIORITIES’

S. S. Özsariyildiz, R. Beheshti, Ö. Ciftcioglu
Section of Design and Construction Processes, Department of Building Technology, Faculty of Civil Engineering and Geosciences, Stevinweg 1, 2628 CN Delft, The Netherlands.
E-mail: S.S.Ozsariyildiz@TUDelft.NL

ABSTRACT: This paper focuses on bridging the gap between inception and design stages in an analytic way (by using semantic and mathematical modelling) particularly enlightening design priority by using Requirements Specifications. The Requirements Specifications are context-dependent, i.e. a consequence of producing one-of-a-kind projects (typical of the BC industry). Sometimes due to the time constraints and missing information the requirements are ill-defined. The client lacks expertise and hence can be inconsistent regarding requirements decisions. This paper proposes a model that provides an analytical mechanism for dealing with problems that are context-dependent, ill-defined and inconsistent as well as priorities of the inception stage (a necessity currently missing in the BC industry).

Keywords – Inception, Requirements Specification, Brief, Design Priorities, GARM, AHP

1. BACKGROUND

During the last decades, the traditional linear Building and Construction (BC) processes remained unchanged or showed minor changes, leading to very few innovations. During the last few decades however clients, authorities and society are increasingly becoming unsatisfied with the BC industry’s performance, resulting in increased demand for better performance and competitiveness. These demands closely related to improvements in early stages.

Among the BC project lifecycle stages, the first stage where the client’s requirements are formulated (here called the inception stage where is covers a broader process), plays a crucial role in the success of a project. Inception process takes place at the early stage in the BC processes in which initial client’s needs transformed to the client’s requirements and written down in a formal document called the “Requirements specifications” or the “Brief”. This specification then provides a fixed reference for the subsequent design of the building. This traditional view of the inception stage is highly constraining in many ways for Large Scale Construction (LSC) projects.
2. INCEPTION AND BRIEFING

Traditionally, the requirement capturing and the briefing is a part of the task of the architects. However as stated by Pena et al. (1987) programming and designing are two separate processes, requiring different attitudes and different capabilities. Moreover, as they say "most designers’ lore to draw", and thus there is a push from architects to start designing before the brief is completed. However in large scale construction projects a team of experts from different domains (managers, engineers, architects, etc.) have to drive the entire process. The client, particularly the inexperienced client, cannot be expected to know everything that will be required at the beginning of the project. Requirement Specifications are only being developed in detail as the project progresses. This means that the client cannot be left out of the total processes after the initial Brief has been written and expect a satisfactory design to emerge without further development of the Brief. In addition it’s difficult to assess all the uncertainties and risks beforehand. Fixing the price and demands in an early stage of the project makes it difficult to respond to changing demands and circumstances. As a result, full participation of the client throughout the project is imperative. Whilst a clear Requirement Specifications can be a great asset, it is not the end of the story. It is important for clients to make appropriate decisions in particular stages of a project. Strategic decisions will need to be made during the lifecycle of the AEC project. Thus, the client should not be omitted from the total process once an initial Brief has been drawn up.

Furthermore it’s essential to bridge the gap between inception and design in an analytic way (by using semantic and mathematical modelling) particularly enlightening design priority by using Requirements specifications for Large Scale Construction projects. The requirements specifications are context-dependent as a consequence of producing one-of-a-kind projects (typical of BC projects). Sometimes due to the time constraints and missing information the requirements are ill-defined. The clients lack expertise and hence they can be inconsistent regarding the judgment of their requirements. The proposed model will provide analytical mechanisms to deal with problems that are context-dependent, ill-defined and inconsistent as well as priorities in the inception stage.

3. DYNAMIC PERFORMANCE CONTROL MODEL (DPCM)

As a framework for analyzing transactions in the BC industry, De Ridder (2002) introduced the Value-Price-Cost model (Figure 1).
The parameters in this model can be compared to the principles of neoclassical economics. Value relates to the willingness to pay for a certain object. In theory, the cost is the minimum amount a producer is willing to accept. The price lies somewhere in between value and cost, dividing the total benefit into a consumer surplus and a producer surplus [Dreschler, 2005].

The Dynamic Performance Control Model (DPCM) is as a contractual and organizational model for an optimal collaboration between Client and Contractor. [De Ridder, 2005] The DPCM can provide, in the event of some unexpected results, a new balance between the value on the one hand and the price on the other hand. The main condition for this freedom of choice is that the Contractor is financially compensated for the extra efforts done to reach the adjusted project result. Extra efforts are measured by a kind of bookkeeping system at different levels (unit prices, cubic meters, tones, man-hours etc.). The Dynamic Performance Control Model, however, is not only able to measure the performance, but can also link the financial compensation directly with the performance. Therefore, the Dynamic Performance Control concept is a very strong approach for decision making.
3.1 Requirements Model as a Part of DPCM

Information and knowledge processing during the inception stage requires the distinction between functional and technical perspectives, and the support for non-monotonic decision processes (for example, changing in a late stage the structural system from prefab concrete to steel without redoing all the work). These inception requirements are met by the General AEC Reference Model (GARM) developed by W. Gielingh (1988). This modelling approach is similar to real world practice and reflects the way experts work and make decisions.

The GARM as a reference model provides a semantic structure for requirements specifications. In the GARM, a product and each of its parts can be represented by a Product Definition Unit (PDU) which defines a certain context for requirements. A PDU holds the requirements specifications including definitions, functional requirements, possible technical solutions and required and expected characteristics. A PDU can represent a whole facility, but also includes its sub-systems, aspect systems, elements, components, parts, or features. This information is given as a collection of characteristics. Each characteristic of a PDU is related to an aspect. Examples of aspects are strength, cost, durability, quality, safety, etc. The GARM distinguishes two related views for a PDU: a functional view, and a technical view. In the functional view, the PDU is called a Functional Unit (FU) and in the technical view a Technical Solution (TS). The relations between FUs and TSs are defined as follows (Figure 3):

- A TS fulfils the requirements of one or more FUs
- A TS decomposes into a set of lower order FUs
A functional unit (FU) describes the product ‘as required’, i.e. the required functionality of the PDU (‘what’). A technical solution (TS) is a concept that may meet the requirements formulated by a FU. It describes (Figure 4) the product ‘as expected’ (‘how’). Many TSs are ‘standard’, such as standard components, connections, and features. Others are subjected to dedicated design and engineering efforts.

Decomposition describes how a product can be divided into smaller units (Grouped under sub-clusters). Decomposition can be semantically modelled in UML by words such as: ‘is-part-of’, ‘consists-of’. Often decomposition limits a model to only one view of a product. However, the GARM is not limited to one decomposition, but supports alternative TSs, FUs that are fulfilled by several TSs (a function, like stability, that is partly fulfilled by several TSs), or TSs that fulfil the requirements of several FUs (elements, such as wall, that play a role in several systems).
Fig. 4. FU, TS and Characteristics; the FU holds the required characteristics and TS holds the expected characteristics of a PDU.

3.2 Analytical Hierarchy Model

In the inception stage, the decision process to handle uncertainty, imprecision and subjectivity can be carried out basically by means of probability theory and/or fuzzy set theory. The former focuses on the random nature of the decision-making process while the latter concerns the subjectivity and imprecision of human behaviour. The other approach is the analytical hierarchy process (AHP) involving qualitative data and dealing with the uncertainty, imprecision and subjectivity. In addition, AHP models can provide a mathematical means to semantic decomposition and fulfilled by relations as discussed in previous section as well as giving priorities of possible technical solutions. The AHP method is a technique developed by Saaty (1980) to compute the priority vector, ranking the relative importance of factors being compared. The only inputs to be supplied by the expert in these procedures are the pair-wise comparisons of relative importance of factors, taken two at a time. This means, in an environment of complex relationships among the variables, one follows the principle of “divide and rule”. If we denote the expert input comparing the \(i\)th variable with respect to the \(j\)th variable by \(a_{ij} = \frac{w_i}{w_j}\), then the relative importance of the \(j\)th factor with respect to the \(i\)th factor is represented as \(\frac{1}{a_{ij}} = \frac{w_j}{w_i}\). Note that it is not easy to make a judicious relational assertion in an environment with high number complex relations. However, to make a simple comparison between any two attributes and to make a judgment is much easier for an expert. The \([n \times n]\) matrix obtained by arranging these pair-wise comparison ratios is termed the reciprocal judgment matrix and designated as \(A\) where \(n\) is the number of factors subjected to pair-wise comparison. The diagonal elements of \(A\) matrix are all unity. Since we take the reciprocals, we have to fill the upper diagonal elements which are altogether \(n(n-1)/2\).
The details of this technique are given by Saaty (1980, 2000) and a comparison and a highlighting its strengths are reported in the literature (e.g. Saaty and Vargas 1984). The principal 'eigenvector' $W$ of $A$ is computed by solving the 'eigenvalue' problem

$$AW = \lambda_{\text{max}} W$$

where $\lambda_{\text{max}}$ is the principal or largest real 'eigenvalue' of $A$. The normalized 'eigenvector' corresponding to $\lambda_{\text{max}}$ is the priority vector $P$. The beauty of the AHP operation can be appreciated by considering the tolerance of the method allowed during making the expert judgment. In this regard some deviations in the expert judgments do not critically affect the final outcome.

AHP is applied in many fields up to now, such as the economic analysis, urban or regional planning and forecasting (Vargas 1990), knowledge model validation (Ciftcioglu 2003), etc.

### 3.2.1. An Example

To exemplify the utilization of AHP for the relational attribute determination, as a first step, let us make expert judgment for the structural aspects. The project requirements are Cost ($w_1$), Value ($w_2$), Form and Space ($w_3$), Structural type ($w_4$), Structural behaviour ($w_5$).

Only for illustrative purposes, we might do expert judgments about ratio with general requirements considerations as follows:

$$w_2/w_1=0.9; \ w_3/w_1=0.7; \ w_4/w_1=0.5; \ w_5/w_1=0.7;$$
$$w_3/w_2=0.8; \ w_4/w_2=0.5; \ w_5/w_2=1.0;$$
$$w_4/w_3=0.9; \ w_5/w_3=1.2;$$
$$w_5/w_4=1.5;$$

The rationale about these ratios is due to expert judgment. For instance for $w_2/w_1=0.9$ is selected comparing the relevance of Cost to relevance of Value. Cost and Value are approximately equally important and therefore they have weights at the same order. However, Cost gets slightly higher priority because in the present case, it precedes the selection of the value. Therefore the ratio is asserted to be 0.9. For the ratio $w_3/w_1$ Cost is more important than the form and therefore the ratio...
is 0.7. The structural type is an optional process. Therefore it has less priority compared to the cost. Therefore $w_4/w_1=0.5$. Structural behaviour is an important consideration in the structure and its priority is comparable to the cost being slightly inferior to the cost. Therefore $w_5/w_1=0.7$. As to the cost and the form and the space, the cost is more prominent since the form is supposedly considered afterwards. Therefore $w_3/w_2$ is taken to be 0.8. As to value and structural type, the value is considerably given more weight relative to the structural type and therefore the structural type/value ratio, that is, $w_4/w_2$ ratio is asserted to be 0.5. As to the value and the structural behaviour, the ratio $w_5/w_2$ is asserted to be one since both aspects are competitively important in a construction. For the ratio structural type/form and space, the assessment is 0.9 due to more consideration to form and space relative to that given to structural design approach. However, contrary to this, structural behaviour/form and space ratio is taken to be 1.2, as the structural behaviour is more prominent compared to form and space. As to the ratio structural behaviour/structural type, structural behaviour is more prominent compared to structural type and therefore the ratio is asserted to be 1.5.

Based on the expert ratio judgments given above, the reciprocal judgments altogether are shown in Table 1.

Table 1. Reciprocal ratios of expert judgments for the attribute relations among Structural Aspects attributes

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Value</th>
<th>FS</th>
<th>ST</th>
<th>SB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>1</td>
<td>1/.8</td>
<td>1/.8</td>
<td>1/.5</td>
<td>1/.7</td>
</tr>
<tr>
<td>Value</td>
<td>.8</td>
<td>1</td>
<td>1/.8</td>
<td>1/.5</td>
<td>1</td>
</tr>
<tr>
<td>FS</td>
<td>.8</td>
<td>.8</td>
<td>1</td>
<td>1/.9</td>
<td>1/.9</td>
</tr>
<tr>
<td>ST</td>
<td>.5</td>
<td>.5</td>
<td>.9</td>
<td>1</td>
<td>1/1.5</td>
</tr>
<tr>
<td>SB</td>
<td>.7</td>
<td>1</td>
<td>.9</td>
<td>1.5</td>
<td>1</td>
</tr>
</tbody>
</table>

The reciprocal ratio judgment matrix, then, is given by

$$A = \begin{bmatrix}
1 & 1/.8 & 1/.8 & 1/.5 & 1/.7 \\
.8 & 1 & 1/.8 & 1/.5 & 1 \\
.8 & .8 & 1 & 1/.9 & .9 \\
.5 & .5 & .9 & 1 & 1/1.5 \\
.7 & 1 & .9 & 1.5 & 1
\end{bmatrix}$$

The largest 'eigenvalue' $\lambda_{\text{max}}=5.03$ and the corresponding priority vector is

$$pT= [0.262, 0.224, 0.187, 0.134, 0.193]$$

Another essential property of AHP method is the inbred consistency check in the method. Namely, for fully consistent expert judgment $\lambda_{\text{max}}$ is the
same as the number of variables being considered. In the above illustrative example the number of variables is $n=5$, and the largest 'eigenvalue' is $\lambda_{\text{max}}=5.03$, which indicates the almost ideal consistency of the judgments, though this is a mere illustrative example. Note that this is not a contrived example.

4. IMPLEMENTATION OF DPCM

The system has being developed in Java. The main reasons for using Java are: (1) Java is an agreeable Object-based and Object-Oriented programming language, (2) Java is platform independent and (3) Java supports distributed computing through the Internet. The tool enables semantic requirements formulation as discussed in previous sections. The requirements are associated with the cost and the value. Therefore in real-time, early design priorities are determined by AHP method by using experts’ judgment.

5. CONCLUSIONS

This work aims at pointing out that inception support can benefit from the interaction with the exact sciences and to exemplify this. It addresses the 'Requirements Specifications' (or the 'Brief') to enlighten ‘Design Priorities’ for Large Scale Construction (LSC) projects. In this context, definitely mathematics plays an essential role to establish firm foundations for analytic inception support.

The requirements specifications are context-dependent as a consequence of producing one-of-a-kind projects (typical of BC projects). Sometimes due to the time constraints and missing information the
requirements are ill-defined. The clients lack expertise and hence they can be inconsistent regarding their judgment of requirements. The proposed model will provide analytical mechanisms to deal with problems that are context-dependent, ill-defined and inconsistent as well as priorities in the inception stage.

In this respect, the analytical hierarchy process method has deep implications in real-time supervision for enhanced inception support as well as early design priorities by processing multidimensional complex building project information. The present work aimed to highlight the method and explained its potential use in inception stage of BC projects. Additionally, the work demonstrates a strong interaction of the BC industry with the methods of exact sciences and potential use of these methods for early design analysis and/or enhanced design.

The adopted model seems to be ideal for the inception and very early design support by determining the design priorities. It provides a means to judge and evaluate the requirements and priorities based on successful earlier designs, thus providing a mechanism presently missing in the building and construction industry.

6. REFERENCES


