Development of a Decision Support Tool for Bamboo Building Design

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ABSTRACT

The design process of a bamboo building is sometimes very complex for building designers, since there is no accepted design methodology for it. This process may be caused by a lack of relevant information provided to the designer. Based on this issue, this paper proposes a decision support system for application in bamboo building design that might be helpful for the designer in his/her design process. For this purpose, a decision support tool for bamboo building design process is being developed. The development of the tool uses approaches, i.e. a taxonomy of bamboo building to identify the design problems, IDEF∅ to model the decision support tool, and develops a dedicated tool for Bamboo building design process. This tool has been tested in an international bamboo-housing workshop, hence results, suggestions, and recommendations from the workshop will be analysed. With this tool, the bamboo-building designer can make a bamboo building design in a systematic way. This tool also helps the designer to be as best informed, explicit, correct, and complete as possible during the design process.

1 INTRODUCTION

Designing a bamboo building can be perceived according to its surrounding conditions, local bamboo species available in location, and user requirements in order to fulfil performance criteria given by the user (Mardjono 2000a). The surrounding conditions may consist of bamboo-building traditions, terrains, elevation of the location, climates, and type of natural disasters such as floods, storms, and earthquake. The local bamboo species are also important in this design, since building constructed with bamboo will quite often depend on characteristics of the bamboo as a building material. Bamboo culms have many characteristics that make them suitable for numerous building construction purposes such as pillars, walls, roofs and floors. When used for pillars, culms should have a large diameter with thick walls and relatively short internodes. For example: in South-East Asia species suitable for this purpose belong to Bambusa, Dendrocalamus and Gigantochloa (Widjaja 1995). It makes sense to provide the designer with such information.

Beside that, the designer sometimes has problems relating to start the design process. These problems can be described as: lack of relevant information provided to the designer, and lack of a systematic design guidance. In order to solve this problem, we propose a design decision support tool that might be valuable in helping the bamboo-building designer. This paper explains this decision support tool for bamboo building design. In the following sections we will explain the necessary characteristics of the decision support, selecting software to construct the tool, building the tool with the selected software, and evaluation of the tool.

2 SRUCTURING THE DECISION SUPPORT TOOL

In designing a bamboo building we sometimes face contradictions that seem to fly in the face of accepted factors, ideas or rules in decision-making. If we consider multiple factors in this process, we have to look those factors which design decisions have in common. In general terms, the decision making process consists of findings, a series of actions which will tend to an outcome and preferably to the best or optimum - outcome. The decision making process will find a set of possible outcomes, allocate to each possible outcome a degree of desirability and choose one which is as desirable as the rest. In scientific approach to problem solving, it can be done by problem observation, structuring the decision, identification of possible outcomes, evaluation of possible outcomes, and verification of all possible outcomes.

In order to solve the real design problem, we have to identify the real problem and not one of the symptoms (Negnevitsky 2002). If we have not identified the decision which must be made, we cannot expect to find a suitable possible outcome. Equally, if we have identified the decision wrongly, the wrong possible outcome is likely to be chosen.

Decision making in the design process of a bamboo building can be approached in an appropriate way by exploring problems of bamboo building design with theory of taxonomy of concepts in architecture, collecting and formulating all activities in the design process with IDEF∅ (Integration Definition for Function Modelling) scheme.

With all utilities of bamboo in a building, we use the taxonomy of concepts in Architecture (Bax and Trum 1993), to detect problems and also to find desirable solutions in an appropriate way, which is concerned on the whole lifecycle of bamboo as building material. Detected problems on the use of bamboo as a building material can be divided in many aspects (Mardjono 2000b) as follows:

1. Natural environment and bamboo building
2. Relation of the habit, economic, and life standard of the community, and bamboo
3. Bamboo Plantation as a material resource
4. Bamboo harvesting and preservation
5. Research and development on bamboo as building material
6. Bamboo building design activities
7. Bamboo building construction activities
8. Bamboo building maintenance activities
9. Living in a bamboo building, and
10. The end of the bamboo building lifecycle.

All those aspects can be described in taxonomy of bamboo building. This means if we concentrate on one aspect e.g. Bamboo building design activities, we also have to consider all other related aspects. Some examples of descriptions are given below:

“…**Usability concept**. User requirements - above all - are the key success factors for a good building design. They should be considered the basic guiding principles for the design of every bamboo building. People’s appreciation and conviction on the bamboo building design activity should regard to use the appropriate design techniques.
Durability concept. The stability of the bamboo building depends on the stability, safety, rigidity and durability of the building construction and the materials. Design criteria for stability, safety, rigidity and durability of bamboo building constructions should be formulated, agreed upon and applied.
Makability concept. The craftsmanship, skills, tools and equipment of the available construction workers, as well as the specification of the chosen bamboo material, the type of connections and the time needed for construction, influence and restrict the makability and the eventual quality of the bamboo building. Therefore these factors should be taken into account during design. The designer should not only produce a detailed design, but also a detailed construction plan or work plan, tailored to the characteristics of the construction workers….” (Mardjono 2000b)

The design decision tool described in this paper has been logically structured but it leaves the freedom of the designer fully in text. The IDEF∅ method is used to structure the tool and it will be explained in the following section.

2.1 IDEFØ Scheme of the Bamboo Building Design Activities

"….IDEFØ is a method designed to model the decisions, actions, and activities of an organization or system. Effective IDEFØ models help to organize the analysis of a system and to promote good communication between the analyst and the customer. IDEFØ is useful in establishing the scope of an analysis, especially for a functional analysis. As a communication tool, IDEFØ enhances domain expert involvement and consensus decision-making through simplified graphical devices, and as an analysis tool, IDEFØ assists the modeller in identifying what functions are performed, what is needed to perform those functions, what the current system does right, and what the current system does wrong. Thus, IDEFØ models are often created as one of the first tasks of a system development effort. The IDEFØ models can be drawn as "box and arrow" that show the function as a box and the interfaces to or from the function as arrows entering or leaving the box…." (KBSI 2000)

The basic syntax for an IDEFØ model is shown in the figure below

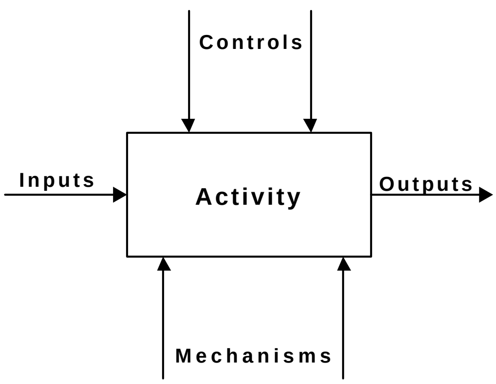

Figure 1: **IDEFØ Function Box and Interface Arrows (KBSI 2000)**

Provided activities in a conceptual design process of a bamboo building will be drawn in a scheme based on this IDEF∅ principle. Those activities can be described as follows:

1. Determine bamboo building design requirements
    - Transform intention into requirements for systematic bamboo building design
        - Show aspects of brief relevant for project
        - Show project requirements for systematic bamboo building design
    - Determine design requirements of bamboo building
        - Show list of bamboo building design aspects
        - Show additional information as user requests
        - Select bamboo building design requirements
        - Check user's satisfaction on bamboo building design requirements
2. Establish total bamboo building design
    - Select the space plan of bamboo building
        - Select total or aspects of space plan
        - Determine aspects of the space plan
        - Check user's satisfaction on the space plan
    - Select the structure of bamboo building
        - Select total or aspects of structure
        - Determine aspects of the structure
        - Check user's satisfaction on the structure
    - Select the skin of bamboo building
        - Select total or aspects of skin
        - Determine aspects of the skin
        - Check user's satisfaction on the skin
    - Select the services of bamboo building
        - Select total or aspects of services
        - Determine aspects of the services
        - Check user's satisfaction on the services
    - Establish the integrated bamboo building
        - Combine structure, skin, services and space plan
        - Specify control, construction, maintenance, dimensions, and materials
        - Check user's satisfaction on bamboo building
3. Evaluate (alternative) bamboo building design(s)
    - Show specifications total bamboo building design
    - If the designer is not satisfied, establish an alternative total bamboo building design
    - Select most appropriate total bamboo building design

Series of activities number two can be seen in Figure 2. The complete scheme of the IDEF∅ for bamboo building system will be published (Mardjono et al. 2002). By those aspects, the design process will use the design requirements and existing case bases as input of the activities, establish the design process of all building parts design, and evaluate the design at the end of the design process. End Results of the design process may be as a complete design, or it can be a trace back to the starting point of the design process.

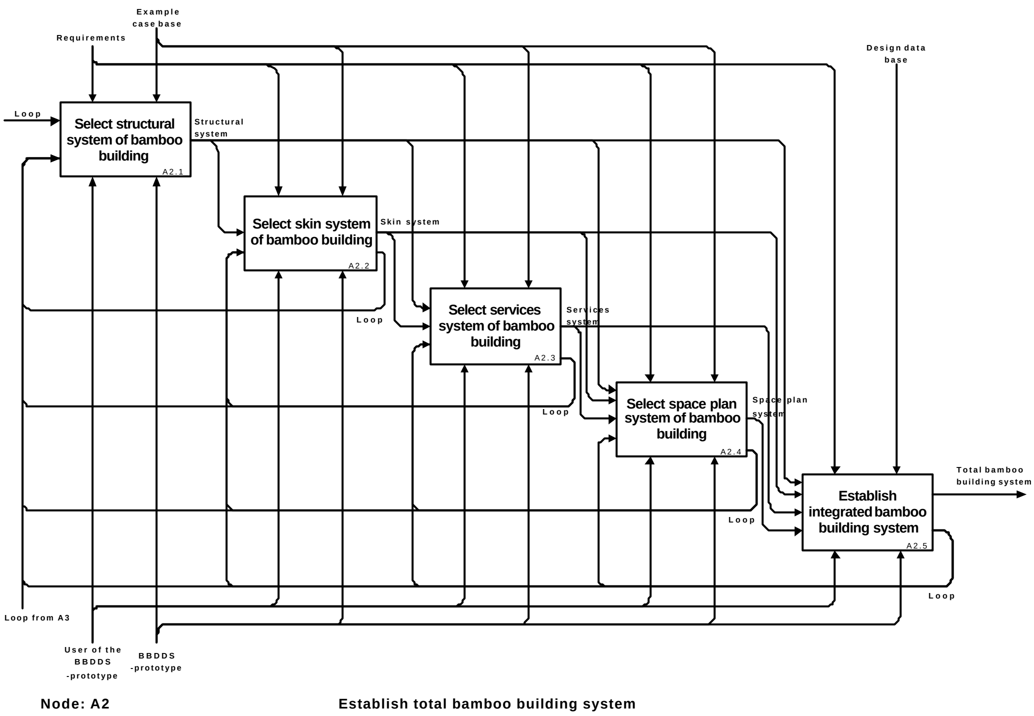

Figure 2: **An IDEFÆ Scheme for Bamboo Building Design**

2.2 Systematize the design process

The structure of all design activities built in the previous section then will be filled with knowledge related to each activity. This knowledge can be provided based on the developer of the tool, handbooks, experiments, and other related information. All collected information will be used and discussed to determine the decision. For this purpose we adopt a systematized process model of decision-making that is developed by Wiegeraad (1999). This systematized process is needed to provide appropriate decision-making during the design process and also to provide pattern of the design systematically.

Based on this process model we developed support for decision making at every noted of the IDEF∅ scheme. Every single decision in the structure can be reduced to a series of sub-decisions, sub-sub-decisions, etc. in which the possible outcomes and risks can be assessed. Each sub-decision can then be made individually and the possible outcomes of all the sub-decision can be combined together in some way to allow the overall decision to be made. All possible outcomes should be formulated simultaneously and then ranked according to their degree of desirability. For these purposes, a sub-decision may need attributes and attribute values. As an example, Figure 4 and 5 show the decision support for wall and wall-opening design process.

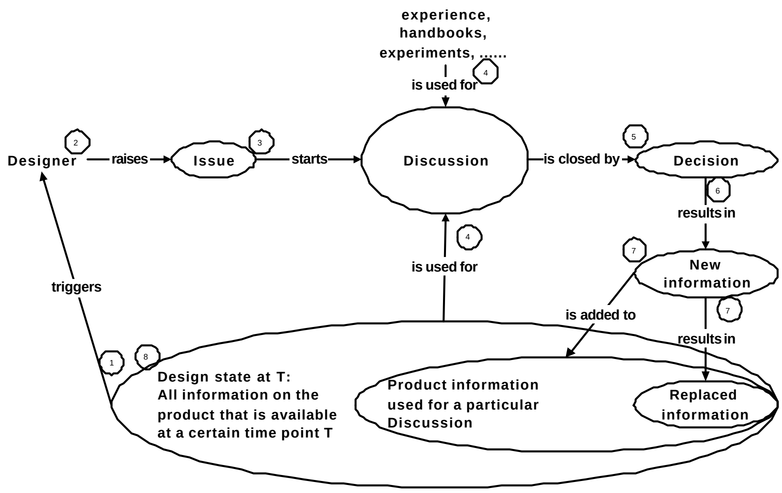

Figure 3: **Basic cycle of decision-making in a design process (Wiegeraad 1999)**

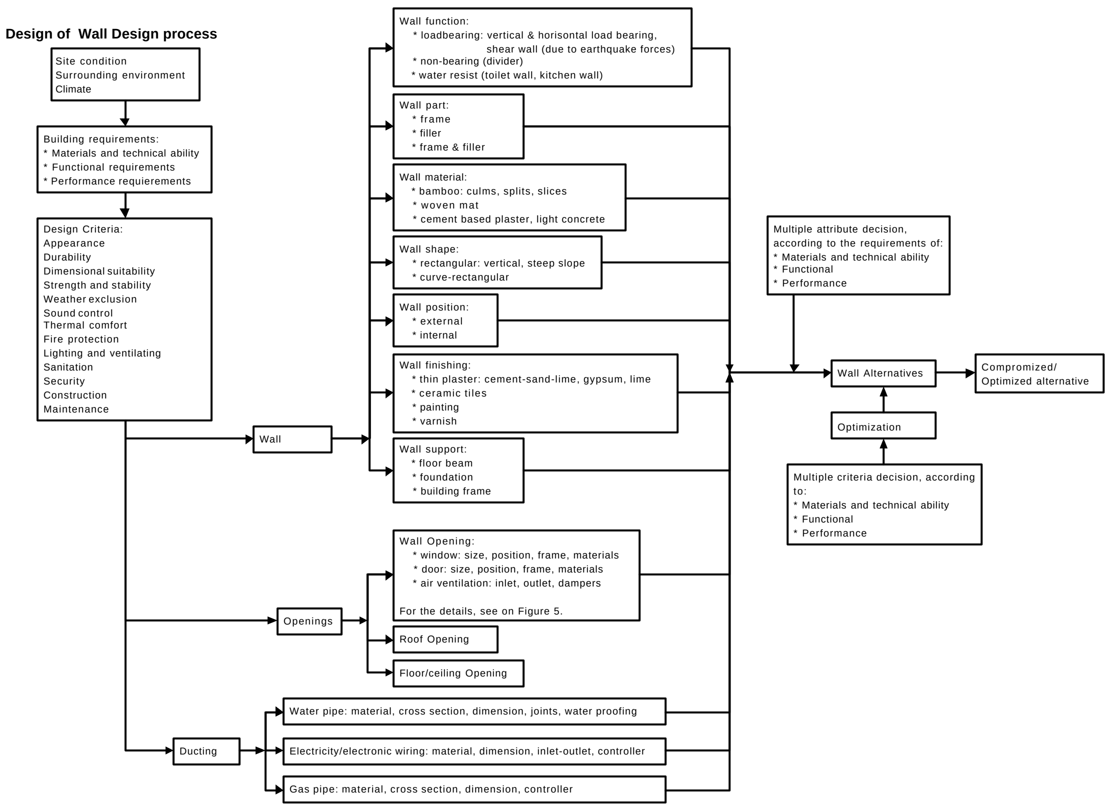

Figure 4: **A Decision support for wall design process**

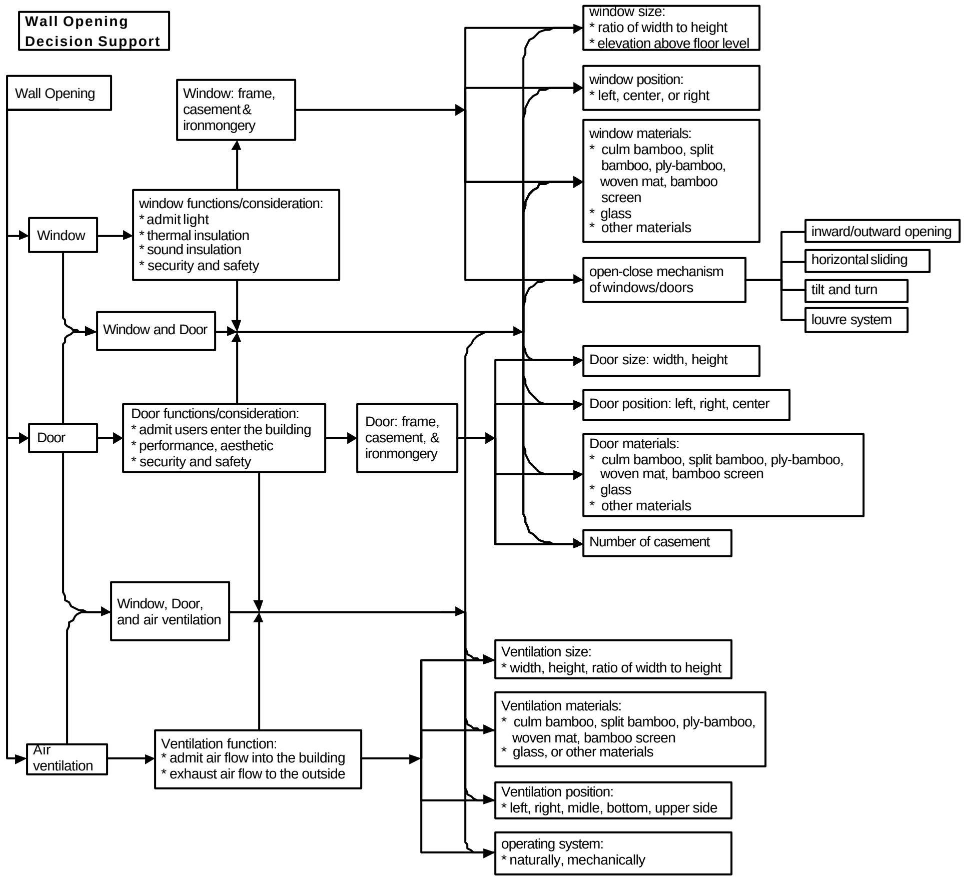

Figure 5: **Decision support for wall openings design process**

3 SELECTING A SOFTWARE PROGRAM TO CONSTRUCT THE DECISION SUPPORT TOOL

Selection process of a software program is a crucial step, so before we set this step, first we have to determine selection criteria for the decision support tool and examine some decision-support softwares available at this moment.

In relation with the decision support tool for bamboo building design, some criteria can be listed, i.e.: Platform, Performance, Functionality, Friendliness to the designer and user, Integrity with other program/language, Widely use, Future development.

Where do we start this process? If we assume that we have to select the main program of the decision support tool that is based on rule-based language, we have to compare all softwares available at this moment. Some available software programs are: *LISP, Active Agent X, Agent OCX, Eclipse, Rete++, CIA Server, Netweaver, and XpertRule Knowledge Builder*. Beside those aspects, we had tried to use each software and make an evaluation of each available software. At the end of this selection process we decided to use *XpertRule Knowledge Builder* software.

4 BUILDING THE TOOL

As we have seen in previous sections, sequence activities of the design processes had been determined with the IDEF∅ scheme, each decision that will be used in the tool has been formulated, and the software to build the tool has also been selected. Some advantages of the XpertRule Knowledge Builder software are:

> "…this software has a knowledge based decision-making engine that can use rules to decide the next task/action in a workflow system, based on current events and available data. The software supports a very broad range of knowledge representations rarely found in one single environment. This advantage enables developers to support a wide range of knowledge applications. Despite the richness of the knowledge representation, the software retains the same graphical knowledge building blocks across representations. This consistency of knowledge representation ensures ease of maintenance and the ability to develop hybrid applications. Decision making in this software covers diagnostic, selection, recommendation, advice, assessment, monitoring, workflow and similar applications. Typically, the knowledge in such applications is represented by rules and/or decision trees. In these applications decisions or outcomes are derived from attributes. The attributes are captured from the user through dialogs, calculations or read from data files. The software represents decision-making knowledge using Decision Tree and Cases Table. A decision tree relates an outcome or decision to a number of attributes. A table of Cases contains a list of examples or rules each showing how an outcome or decision relates to a combination of attribute values…" (Attar Software limited 2001).

The main structure of the decision support for designing a bamboo wall can be seen in Figure 6. This main structure can be represented in an appearance screen at runtime program as seen in Figure 7. When the user runs the program, he/she can select his/her starting freely. In this process the user can attach any desired value. Inside the running process, the user can check whether he/she is satisfied with the result of decisions made during running the program, so he/she can go to the next decision in the process if he/she is confident with his/her decision result, or otherwise he/she has to trace back to the previous steps.

5 EVALUATING THE TOOL

All knowledge available in the tool needs to be verified and the structure of the decision process should be validated. For this purpose, we use decision tables (DTs) to verify the knowledge, and gave opportunities to a group of bamboo building designers and bamboo artisans to test and play with the tool during the International Bamboo Housing Workshop in Aizawl, Mizoram, India, on October 29 – November 11, 2001.

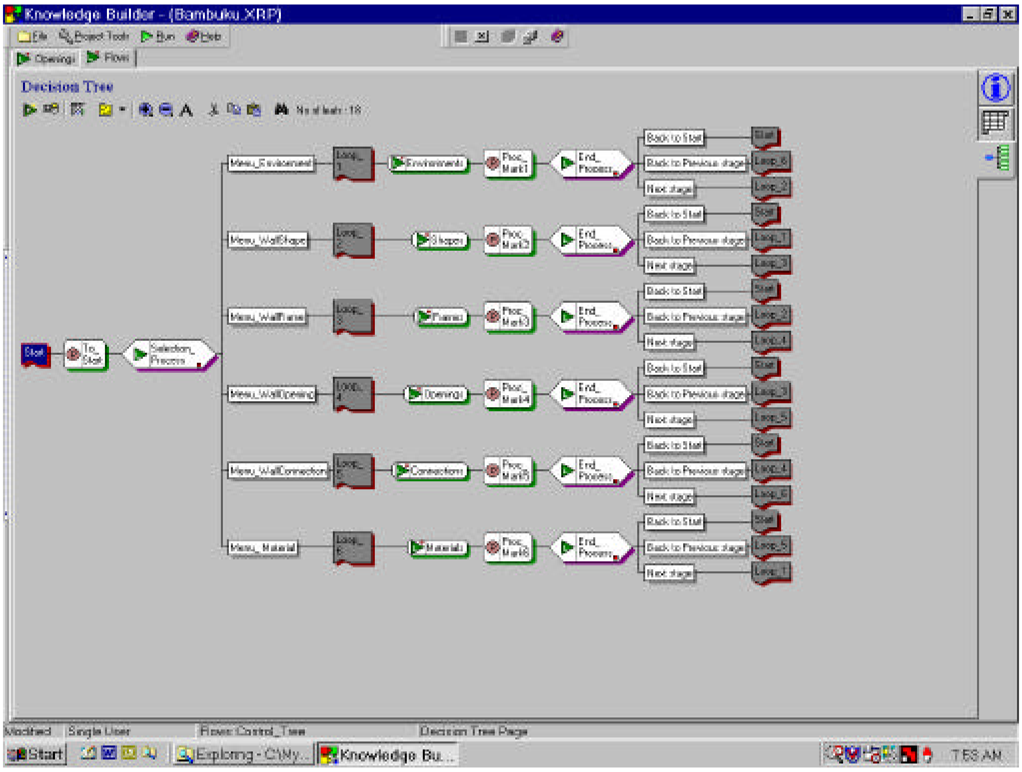

Figure 6: **Main structure of the decision support tool**

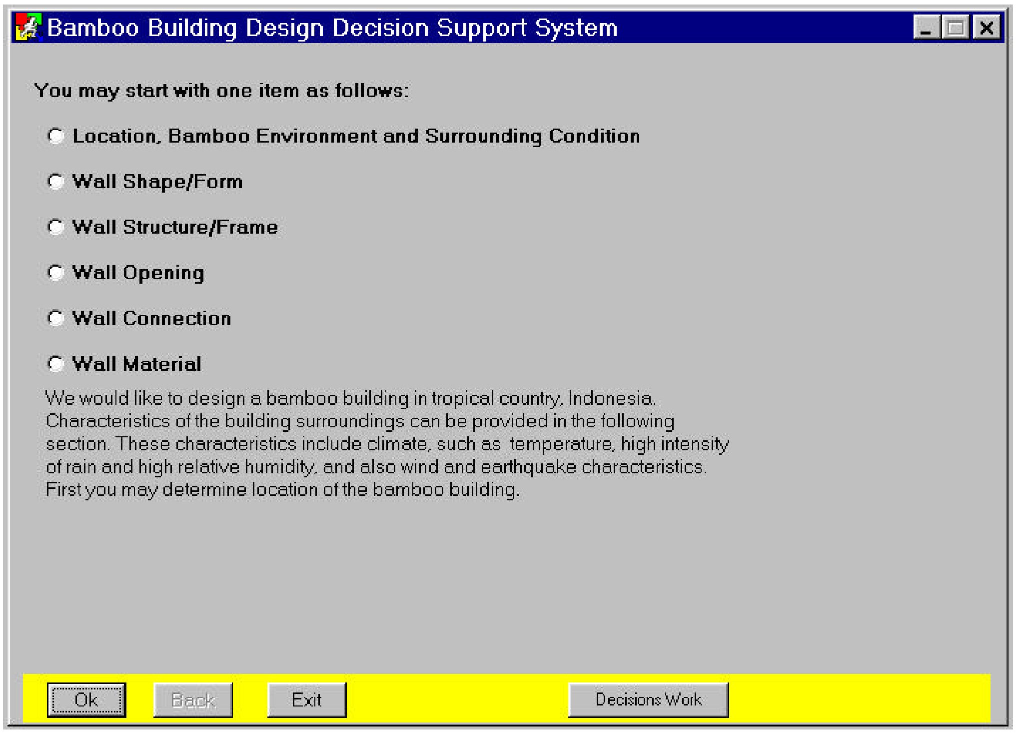

Figure 7: **A user interface in the tool**

5.1 **Verification**

A theory of DT can be found in Lucardie (1994), Wets (1998) and Witlox (1998).

> "…A DT is known as *Abstract*, refers to a fictitious domain and has two components. First component is on the left of the double vertical line that is called the *stub*. The first part of the stub, the part that is located above the double horizontal line, contains *condition subjects*. The second part of the stub, located below the double horizontal line, contains *action subjects*. The component to the right of the double vertical line displays conditional statements about the domain. These statements are called *Decision Rules* (DR's). They are pictured by means of columns. DR's describe the connection between condition subjects and action subjects. Above the double horizontal line the DR's contain a *condition alternative* for each condition subject. Below the double horizontal line the DR's contain an *action alternative* for each action subject. A DT must be *exhaustive* and *exclusive*. Exhaustiveness means that, within the domain of the DT, every possible combination of condition alternatives should be accounted for. Exclusiveness means that no situation is permitted to be described in more than one DR…" (Lucardie 1994).

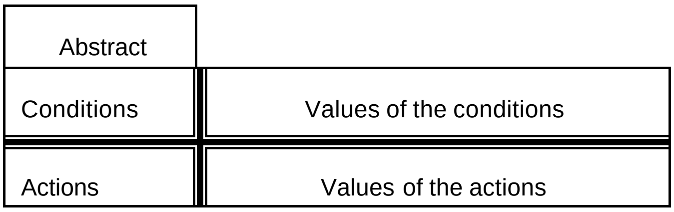

Figure 8: **Representation of a DT (After Lucardie 1994)**

As an example of verification using DTs in selecting or showing detail of a connection is described. These DTs have conditions and conditions values that are available in the tool (Figure 9). If we look at Figure 9, we provide seven conditions, and if we construct a DT based on these conditions and their values, we will provide 8640 columns of action alternatives. This amount of columns cannot be drawn in one table, and this means we have to split up in sub tables that can be seen in the following figures.

Sub table 1 has seven results (n2) that will be continued in sub table 2.1 through sub table 2.7. or sub table 2.n2. Each sub table 2 has some determined values for two attributes i.e. Connection Type and Connection Form.

In the same way, we can continue to structure the DT until the last condition is arrived at. For this decision, it will provide sub table 5.1 through sub table 5.n5. Each sub table 5 has some determined values for three attributes i.e. Connection Type, Connection Form, Member Material, Structure Type, Connection Force(s), and Connection Filler.

Connection Type	One Dimension	Two Dimension	Three Dimension			
Connection Form	I	II	III			
Member Material	Full Culm	Half Culm	Laminated Bamboo	Ply-bamboo		
Connection Force(s)	Compression	Tension	Shear	Bending Moment	Don't Care	
Connection Filler	Wood OR Laminated bamboo OR Ply-bamboo	Full Culm Bamboo	Half Culm Bamboo	Steel Plate		
Connection Material	Wood pin OR bamboo pin	Steel bolt	Natural ropes	Glue	Nail OR Screw	Combination
Structure type	Truss structure	Frame structure				

Figure 9: **Conditions and their values**

Sub table 1									
Connection Type	One Dimension			Two Dimension			Three Dimension		
Connection Form	I	II	III	I	II	III	I	II	III
Proceed existence of the connection	X	-	-	X	X	X	X	X	X
Result	1.1			1.2	1.3	1.4	1.5	1.6	1.7
Next sub table	2.1			2.2	2.3	2.4	2.5	2.6	2.7 (2.n2)

Figure 10: **Sub table 1 of the DT**

Sub table 5.1						
From result	4.1					
Condition of the connection existence from previous sub table	X					
Connection Material	Wood pin OR bamboo pin	Steel bolt	Natural ropes	Glue	Nail	Combination
Proceed existence of the connection	X	X	-	-	-	X
Show Image	X	X	-	-	-	X
Result	5.1	5.2				5.3

Figure 11: **Sub table 5.1 of the DT**

From the sub table 5.1 through sub table 5.n5 we will provide n6 actions result. All of these results should be verified and validated whether the results and all knowledge in the DT are valid, complete, accurate, and consistent.

Sub table 5.n5						
From result	4.n5					
Condition of the connection existence from previous sub table	X					
Connection Material	Wood pin OR bamboo pin	Steel bolt	Natural ropes	Glue	Nail	Combination
Proceed existence of the connection	-	X	-	-	-	-
Show Image	-	X	-	-	-	-
Result		5.n6				

Figure 12: **Sub table 5.n5 of the DT**

Evaluation of the tool can be started with verifying the DTs built in the tool. According to Wets (1998) after Lucardie (1994) give an explanation about verification as follows:

> "… verification of the DTs can be done by checking some factors, such as consistency, exclusivity, and completeness…. …A DT is consistent if there exist no columns in the DT for which the condition part intersects while the action part differ, while exclusivity of a DT can be detected if in the DT at least one element of condition part in a column does not intersect with the corresponding element in the condition part of another column… …A DT is complete if every *condition entry (CE)* that is included in the DT and for each combination of condition values at least one action is specified…". (After Lucardie 1994)

Based on these criteria, it seems that the above DTs are consistent, exclusive and complete.

5.2 **Validation**

Validation is more complex, since in validation, we have to prove the system that has been built meets the requirements of the user. Actually a system will never completely satisfy the user, nor it will completely dissatisfy him. We can only detect if the system contains anomalies such as incompleteness, and inconsistency.

That is why we have to validate the system in the same sequence process after verification process has been completed. Since we use the IDEF∅ scheme to construct the structure of decision support in this process, we will have some advantages because sequence of activities in the design process can be determined in a proper way. With this scheme we can exactly construct the structure of design process through the ExpertRule Knowledge Builder. When we have built a decision support system with this software that is based on the scheme of design process of a bamboo building, the validation of this system can be focussed on the IDEF∅ scheme. We have to prove that the system meets the requirements of the user of this system. An activity in this system will contain a design decision task that is defined in the DTs. So the validation will check that all decision tasks match with the activities in the IDEF∅ scheme, and prove that these activities can be found in the IDEF∅ structure of the software. Activities found in the IDEF∅ scheme always start with a global activity and finish with detail activities. This scheme will guarantee that the structure of design process is constructed correctly according to the user's specification, all of the decision tool can be found in the system, and output of the decision tool built with this structure will be the same output provided with the DTs. To fulfil these requirements we have to accommodate all decision activities in the program and we may use all of the software decision capabilities, such as with cases table, decision trees, backward chaining, and forward chaining processes.

So what are characteristics of validity in this system? This is a difficult question to be answered, but it can be detected when we run and test the system, since outputs of the system can be detected whether they are same with the predicted outputs in the DTs or not, and also whether the outputs can satisfy the users. To eliminate subjectivity of the validation, we may use test cases and or delivering a questioner to the prospectus users.

A prototype of this tool has been tested during the workshop, and after a participant tested the prototype, we delivered a questionnaire that should be filled in. The questionnaire contains some needed information from the participant and his/her responses according to usability, makability, and friendliness of the prototype. There were thirty-six participants who tested the prototype, some of them (seven persons) have an educational background as building designer or architect, eleven persons have an educational background as construction worker or bamboo artisan, ten persons are social workers (NGO) or motivators in rural areas, and the others came from public officers of some departments from Mizoram government. Participants feel that the prototype really help to his/her design process of bamboo building, they are satisfied with the layout of prototype, and they are 'agree more than disagree' that the prototype improves the result of design process. They also gave opinions and suggestions after using the tool. These opinions and suggestions have been used to improve the prototype. Their responses after using the tool indicate that they are satisfied with the knowledge contents in the tool and the structure of the decision process available in the tool.

6 CONCLUSION

We have presented a design decision tool for bamboo building design process that is currently tested by the workshop participants. Even we did not use the DTs to build the tool, the verification of the knowledge available in the tool with the DTs gave a systematic tables and the result of this verification also supports the completeness, consistency and exclusivity of the knowledge and the decision-making process. Besides this, the response from the participants at the workshop was very positive and their feedback has been implemented in the coming tool.

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