A Bamboo Building Design Decision Support Tool

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PROEFONTWERP

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door

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geboren te Boyolali, Indonesië

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PREFACE

Motivation

I still have vivid recollections of the housing conditions of rural people in my hometown in Boyolali, Indonesia around 1970. There was no electricity or telephone lines, and most of the people built their houses using bamboo, wood, and sometimes brick. They used natural resources, like bamboo and wood, as these materials were available on their own land or they could obtain them from the surrounding area. People who used bricks did so because they had access to clay; almost every family could produce bricks using the clay that was available near their home. These people felt that they lived in harmony with the surrounding nature. This was a familiar picture in the rural areas until the Indonesian government initiated a rehabilitation programme for rural housing. The grand design for this programme was actually a good idea. It aimed to improve housing conditions by improving the health conditions, increasing the air circulation in the house, allowing sunlight to enter the house, etc. However, the implementation of this programme had different results, such as removing bamboo walls from the houses and rebuilding them with brick.

In an improvement programme, the government ordered an increase in the added value of the people's land to increase its economic value. During this programme the government officials authorised the removal of bamboo plantations in almost every rural plot, and changed it into some other plantation that they felt had a higher added value. This made me wonder whether bamboo was actually bad as a building material and whether brick was better.

Finally, about 10 years ago, I started doing research into bamboo as a building material, and started to find out about this material. I started by making some specimens for tensile and compression tests. The results from these experiments revealed an important fact: that some bamboo species have a greater maximum tensile stress than hard wood of the type available in Indonesia. Not many people are aware of this fact. People who still use bamboo as a building/housing material also think that bamboo is not as strong as wood. I also found that they still use traditional methods in the construction of their bamboo houses, such as using natural fibres as connecting materials, and using non-preserved bamboo. This construction tends to reduce the durability of the bamboo.

General View

For centuries the Indonesian people have accepted bamboo as a natural resource. They use bamboo in almost all aspects of their life: for cooking utensils, working tools in the field, furniture, and of course as a building material. Since bamboo is a natural product, we have to view bamboo as a natural resource, which has the potency to contribute to sustainable development. In recent years, people have started to become concerned with global issues about using natural resources for houses or buildings. People also consider bamboo to be an old fashioned building material; something made of bamboo has the image of being of colonial style. Therefore when people think of a colonial style, they always associate it with bamboo housing/buildings.

I am very glad to have done my PhD-design project at this university on bamboo building design. I was given enough time to search through all the existing literature on bamboo from around the world. This is when I discovered that there are huge problems related to the design of bamboo buildings, construction methods, bamboo preservation, the maintenance of bamboo buildings, and so forth. There are enough open topics that interest me, one of which is designing bamboo buildings.

The designers of bamboo building designers still do not have any handbooks with norms or guidelines. They usually use their own experience to design a bamboo building. If we ask people how they design a bamboo building, they often answer that they can do it because they have some experience, but they have no specific knowledge. Those who have experience with designing bamboo buildings are confident of their design capabilities.

Designing something means making a concept of a thing based on experience, knowledge, capabilities, instinct, and intention. Other requirements can be added to this design, such as being able to transfer user requirements to the design process and being able to satisfy the user. Of course, there has to be a series of discussions between the designer and the user of his/her product during the design process. During this design process the designer has to make many interrelated, difficult decisions and needs support for his/her[1] decisions. It is therefore relevant to find alternative solutions to help the bamboo-building designer by providing a decision support tool for bamboo building design, based on knowledge of bamboo and design. This tool will be used as a guide for designers and practitioners when making decisions in their design, construction and maintenance activities.

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[1] we are referring both to male and female designers; for simplicity's sake we will only use *she* or *her* to represent a designer in the remainder of the document.

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Chapter 1

INTRODUCTION

1.1 Aim of the PhD-design project

This project is concerned with the development of a decision support tool for the design of bamboo buildings, to help bamboo-building designers especially in the early stages of the design process. One problem is that hardly anybody can design a building in bamboo. This statement might seem a bit exaggerated, but in fact it is true. There are certainly many places in the world that have good examples of traditional building techniques, but these solutions are limited to use in a single and specific region and climate. It is impossible to directly transfer these traditional building techniques to different regions, climates or cultures. The available knowledge also lacks any system. Books like Dunkelberg (1985) and Oscar-Hidalgo (1974) give an endless series of details, but are without any system or coherence. These two facts really are a constraint for building in bamboo.

Recent research on bamboo and bamboo buildings can be found in several publications such as those on bamboo as a material for building structures in tropical countries (Janssen, 1981), fundamentals of the design of bamboo structures (Arce-Villalobos, 1993), and a house design method using plybamboo sheets as structural elements in prefabricated construction (González, et al. 2001). These research areas are about bamboo structures and constructions. Another publication in bamboo design is about the added value of hybrid technology to improve bamboo products (Larasati, 1999). It formulates design requirements of bamboo products based on the use of hybrid technology, to improve the quality of the bamboo product and the benefits for bamboo craftsmen.

It is the author's conviction that accessibility and application of modern bamboo knowledge and technology can be improved by supporting the bamboo-building designer. For this kind of support a useful category of support tools exists, as can convincingly be found in the proceedings of numerous Design Decision Support Systems (DDSS) conferences (e.g. Proc. of the 6th International Conference: DDSS, Ellecom, 2002). However, every developed DDSS so far, is a dedicated tool for specific support in solving a design problem in a particular field. This means that for an application in a new field, a new DDSS should be devised.

The main problems and research issues covered by the study reported on in this thesis are the development of a design decision-support tool for bamboo building based on knowledge of bamboo. This basic development relates to such properties as the surrounding conditions of the building site, bamboo species available in the location, and user requirements. Our general project objective can therefore be formulated as follows:

- Develop an appropriate design decision-support tool for a bamboo building.
- Implement and apply the appropriate requirements for a tool.
- Test the tool to see whether it is suitable for the early design stages of a bamboo building. Later on this tool can be applied to support the bamboo design.

1.2 **Design of a bamboo building**

The design process of a bamboo building starts with determining problems, stating the design goal, finding the constraints, and giving the criteria. These requirements then must be analysed, synthesized and evaluated to provide solutions. In this process we sometimes have to optimise to obtain the best solution. The activities need to be described until we have the final design that is ready to be applied in the construction process of the building. During the analysis, synthesis and evaluation, the designer may need support to find an acceptable solution. At this stage she has to make decisions that can be provided with the tool (see Figure 1.1).

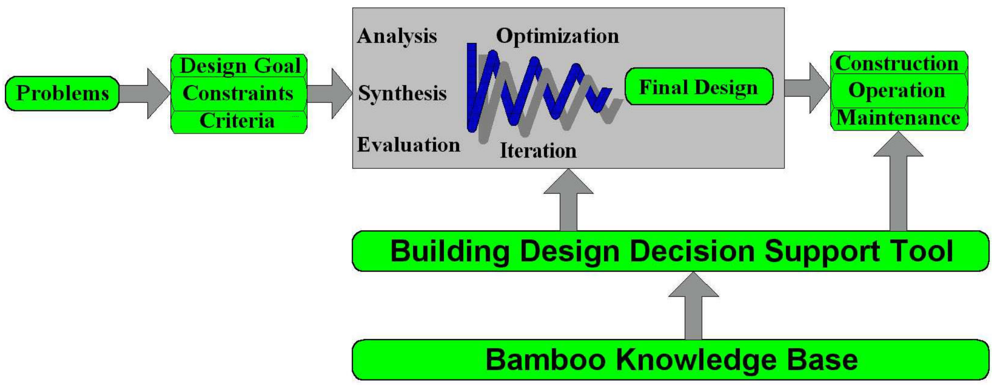

Figure 1.1: **Design of a bamboo building**

What kind of tool is needed in this process? The designer actually needs to have information about bamboo and bamboo buildings to support her own decisions. This means that the tool should contain this knowledge and information, and should also have a structure that can accommodate the designer's freedom to select the kind of knowledge or information she wants. This is why we need a Knowledge-Based System to develop the design decision-support tool. The contents and structure of the tool itself need to be verified and validated before the designer can use it safely.

1.3 **Organization of the thesis**

This thesis uses a basic idea from problem-solving for its organization: it starts by gathering information and describing problems, it then proposes the formulation of solutions and selects a solution, next it illustrates the solution, and finally it verifies and validates the solution. This dissertation is therefore made up of seven chapters, and is divided into three major parts. Part One is about gathering information on bamboo and bamboo building problems, and information on design decision-support systems. Part Two discusses the formulation of the bamboo building design decision-support tool, based on the information collected from Part One. Part Three deals with the illustration, verification, application, and validation of the tool.

Part One is divided into three chapters. Chapter 1 deals with a general description of some of the main problems related to the bamboo building design issues, followed by a formal statement of the project objective and the formulation of a solution for the problems. Chapter 2 concentrates on formulating the design problems of bamboo buildings in practice, and encompasses the general observation and exploration of available existing bamboo buildings, structuring complex design problems, and determining relevant issues in which a designer should be supported. It also presents a relational view of existing bamboo building design problems, formulated in a life cycle for the bamboo building. Chapter 3 deals with the existing knowledge of design decision-support systems, in general, and the knowledge that should support bamboo-building design. This knowledge can be used to select the type of design decision support system, based on the activities in the bamboo building design process. The scheme of design activities is constructed by adopting the IDEFØ principles.

Part Two consists of two chapters: Chapter 4 and Chapter 5. Chapter 4 deals with structuring design processes, built based on function modelling. This structure will be used as the basic structure for building the tool, and will therefore have to be verified. The structure is verified manually by comparing it with a simple design process of an imaginary building (Section 4.2 and 4.3). In Chapter 5 we introduce some available software programmes that can support the design decision-support system. The criteria for selecting software are formulated, and the most appropriate software is determined. In this chapter we are only looking at a partial prototype, as a complete tool has not been built (for time reasons). We also detail the contents of this prototype to be applied in the tool for bamboo building design decision support, including its verification. Chapter 5 also deals with the structuring of the recommended prototype to be used in the tool, and building the prototype of the tool based on the user requirements, and building the user interface.

Part Three is made up of Chapter 6 and Chapter 7. Chapter 6 deals with verification of the bamboo knowledge, validating the tool, and discussing test results for the tool. There is nothing new in this prototype, neither the design decision-support system, nor the bamboo knowledge. This thesis only focuses on the very new combination of these two existing parts. Finally, in chapter 7, we give some conclusions for this study and recommendations for future research.

Chapter 2

DESIGN PROBLEMS IN BAMBOO BUILDINGS

This chapter focuses on general observations about existing problems of bamboo buildings. These observations are needed if we want to describe the problems that will be dealt with in coming chapters. Through these observations, we learn what the real problems are and the mutual relationships between them, so we can propose how to solve these problems. We start by describing the problems of bamboo's housing/ building community, structuring the problems, and then focusing on the design problems of bamboo buildings. We will use this observation process to formulate the real design problems and to propose appropriate solutions.

2.1 General observations about the bamboo housing community

Dransfield and Widjaja (1995) states that bamboo belongs to the huge gramineae family, grows in tropical to sub-tropical regions in places varying from valleys to hilly areas, and has over 1000 species in almost 90 genera that have been described and named; more than a hundred species can be found in Indonesia alone. It grows in tight clumps, or in open groves and comes in many colours, shapes and sizes. Bamboo species can grow in a variety of ecological environments, ranging from tropical lowland to highland, from rain forest in tropical countries to deserts, and from acid to alkaline soils. Some species are only a few metres tall; others grow to a height of over 25 metres and can be harvested after 3 to 5 years (Siopongco in Dransfield and Widjaja, 1995). The planting of bamboo can repair soil devastation, even in flat or very hilly areas. Moreover, bamboo plantations can produce high quality bamboo culms that are appropriate as a wood supplement in the building industry.

Devastated rural areas have various problems, such as poverty, unemployment and environmental unawareness. These problems sometimes cause the bad environment. Participation of both the surrounding community and government are needed if bamboo is to be used as an alternative to wood to repair this environment. The surrounding community and the government should be involved, and the government should guide the community. The participation of the communities will both help the environment and enable them to obtain bamboo materials more easily. It is clear that the problems of bamboo supply cannot be detached from the bamboo plantations and the communities who use bamboo as a building material. When these problems are solved they can also provide a better environment, and help the rural communities to live in harmony with the surrounding nature.

As we know, bamboo has various physical, mechanical and chemical properties. The physical properties are the moisture content, density, fibre saturation point and shrinkage. These properties are the basis of bamboo's characteristics such as swelling, splitting and shrinking. The mechanical properties are the modulus of elasticity, the modulus of rupture, compression strength parallel and perpendicular to the grain, and the shear strength. These properties show its strength and stiffness. The chemical properties are divided into major and minor components, such as cellulose, hemicellulose and lignin, and the minor components, such as resins, tannins, waxes, and inorganic salts (Liese in Dransfield and Widjaja 1995). These properties are reflected in its characteristic durability, fire and insect resistance. There is no way of improving the durability except by keeping the moisture content low using appropriate means, protecting the bamboo from insect attacks using preservation methods, and also protecting the bamboo from fire hazards.

Bamboo's variety, such as its diameter, internodal length, skin thickness, skin colours, total culm-length and fibre sizes, is a great advantage during its use. It can be used to fulfill many of our requirements for materials, one of which is for building materials. Most Indonesians from rural communities use it for many purposes. It can be used directly as full or half culms, or as strips or slices. The splitting process to produce bamboo strips may be carried out using a knife, a specific tool, or sometimes a machine. Bamboo strips or thick slices can be woven into coarse matting for building purposes, and into thinner slices for handicrafts. The weaving process can be done by hand or using a mechanized process. Woven mats are usually produced manually in a traditional manner in rural areas; mechanized processing produces high-quality bamboo products such as ply-bamboo, woven mats and bamboo boards. These products have added value in the bamboo building industries, and are also appropriate as building materials.

Bamboo has been used for hundreds of years in many different ways and for many different purposes. As a building material, it can be found as a roof covering, and as a roof, wall, and frame structure. Bamboo is not widely appreciated, except by those who have a particular interest in or love of bamboo. Most people only appreciate bamboo as a common building material, but others appreciate it is as an exotic building material.

Traditional bamboo houses can generally be found in rural areas in bamboo growing countries. These houses are usually built using traditional methods based on the tradition of the local communities. People in these communities build their houses using their own knowledge of bamboo handed down to them by their parents and grandparents. This traditional learning process increases their acceptance of bamboo houses, and can later on enrich their culture.

The issues mentioned earlier can be classified as phenomena in the bamboo environment, bamboo communities, economic, social and cultural life, and also as developments in the use of bamboo as building materials.

2.2 **General observations on bamboo buildings**

As mentioned in the previous section, people use bamboo because it can be provided easily from their surroundings. In some regions bamboo is also the cheapest building material, and is easy to use without modern tools. People have their own traditional ways of building bamboo housing. They usually use traditional joints, such as wood or bamboo pins and natural fibres. They know that the weakness of bamboo structures lies in the strength and displacement of the joints, and they also develop connection methods based on these natural resources. This development produces various joining methods, which can later improve their bamboo building construction techniques and can be part of their tradition and culture.

The aim of observing the bamboo building is to collect facts, information, and knowledge available in the communities within a region. In a community that is familiar with bamboo, the people usually care about it, and they tend to learn about and study bamboo and bamboo buildings from both their own community and from other communities where they live. They are usually open to new information and knowledge about bamboo available in their community; they try to adopt the knowledge, practice it and apply it in their own communities. In this case, they usually use a strategy called adaptation. This process actually depends on some factors such as the level of care, their economical and educational background, and the available tools and materials. After the adaptation process they may develop the knowledge and technology based on their own surroundings; this process is time consuming. These are the typical steps in development in most bamboo-growing countries.

The characteristics of a bamboo building in Indonesia may differ with that of other countries, and even among different parts of Indonesia itself. Let us consider the weaving pattern for wall mats as an example. In some regions different sizes of bamboo slices are used for this woven mat; the construction process may also be different. As people move from one region to another, the different weaving patterns, and also slice sizes are adopted and adapted in their own community. Let us consider another example of a bamboo artisan who makes woven mats for ceilings. She receives an order from an exporter to make a different weaving pattern, using both a different bamboo species and a different preservation method. To start with it may be difficult for this artisan to fulfil the order, but once she has completed the order and the customer is satisfied with her product, she can transfer the knowledge to other neighbouring artisans, and the local community can adapt and develop the technique to enrich their own knowledge. The artisans always learn from their own experiences, and their creativeness will depend on their care and interest for the new knowledge and information. In contrast, a designer with a higher educational background can usually find information and provide knowledge from many sources, and may develop her new product based on the knowledge gained from those sources. This kind of designer needs knowledge of existing building techniques and traditions, and probably needs to see existing buildings to aid her learning process.

If we concentrate on bamboo buildings, their construction can be described as using both traditional and modern methods. The traditional method is a vernacular construction method that is available in each particular region, and people in that region always keep the method as part of their building tradition. The modern method can be defined as a method of construction based on scientific research rather than only on experience, for example, scientific research can logically determine the joint strength and the disadvantages of a particular type of joint. Both methods can enrich the building knowledge and can be used simultaneously; in the future this could be a way to both improve the traditional methods and to enhance the modern methods.

We need to develop a way to detect problems that occur in the existing bamboo building practices. We are thinking here of problems related to aspects such as bamboo plantations, the geographical condition, the social-economy and local traditions, the mechanical properties, the technology for producing bamboo products and buildings, the surrounding conditions of the buildings, the everyday life of the people who use bamboo and live in the houses, the amount of research and development put into the building, the building skills of designers and artisans, and the design, construction, and maintenance of the building. The current conditions of each of these aspects should be explored and described, and the data collated. Programmes or strategies could then be proposed to provide appropriate solutions and outcomes. Having taken these existing conditions into account, and given the conditions imposed by the designer, the problems formulation, strategy, and the predicted outcomes can be drawn up in tables. An example table for one aspect is shown in Figure 2.1.

When all these conditions have been identified, their aspects can be listed and formulated in an appropriate way by considering the complete lifecycle of a bamboo building. Those aspects were determined to be the following (Mardjono 2000b):

1. Natural environment and the bamboo building
2. Relationship between the habits, economic standard, and standard of living in the community, and bamboo
3. Bamboo plantation as a material resource
4. Bamboo harvesting and preservation
5. Research and development into bamboo as a 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.

Aspect	Designer and artisan
Conditions	a. Artisans know the traditional bamboo technology, b. Designers of bamboo building didn't know how to calculate the dimension of the bamboo exactly as they usually use other materials, c. Some of the artisans and designers don't know how to preserve bamboo or how to combine the bamboo with other materials.
Problems	a. Artisans sometimes don't know the background of the engineering properties of bamboo b. Designers have difficulties in applying the research results in their design.
Programmes/ Strategies	There should be a workshop programme and manual on bamboo building design, construction and maintenance, and/or a field trip to a bamboo factory.
Outcomes	They know the details of the bamboo design and bamboo construction.

Figure 2.1: **Example of an investigation into one aspect of bamboo lifecycles**

From these aspects we learn that the design cannot be separated from other aspects such as knowledge about bamboo, the environment, and the community who use and occupy the building. We will use this lifecycle to describe the design problems of bamboo buildings in the next section.

2.3 **Structuring the design problems of bamboo buildings**

All aspects of the bamboo building stated earlier can be considered to be a circle in which each aspect is related to the other aspects. As an example, the aspect of bamboo building design activities depends on, and is closely related to, other aspects such as bamboo building construction, bamboo building maintenance, living in a bamboo building, bamboo plantations, bamboo harvesting and preservation. A schematic diagram of these aspects is called the "lifecycle" of the bamboo building, and can be seen in Figure 2.2.

The structuring of design problems needs instrument that can give appropriate, consistent and complete guidance during the entire process. Bax and Trum (1993) identify and interpret architectural phenomena occurring in society as concepts; they arrange the concepts in a taxonomy that yields a complete and systematic description of the architectural field. This taxonomy has been discussed and proved to be suitable as a tool for design analysis and evaluation of architectural issues and design strategies. Facts and evidence provided by the bamboo itself and in the bamboo building community can also be described as architectural artefacts, thus strengthening the argument of using the taxonomy of concepts for structuring design problems and design activities for bamboo buildings. In this thesis the taxonomy is only used as an instrument to describe, structure and analyse the complex problem of bamboo building design. It is not intended to develop concepts as such.

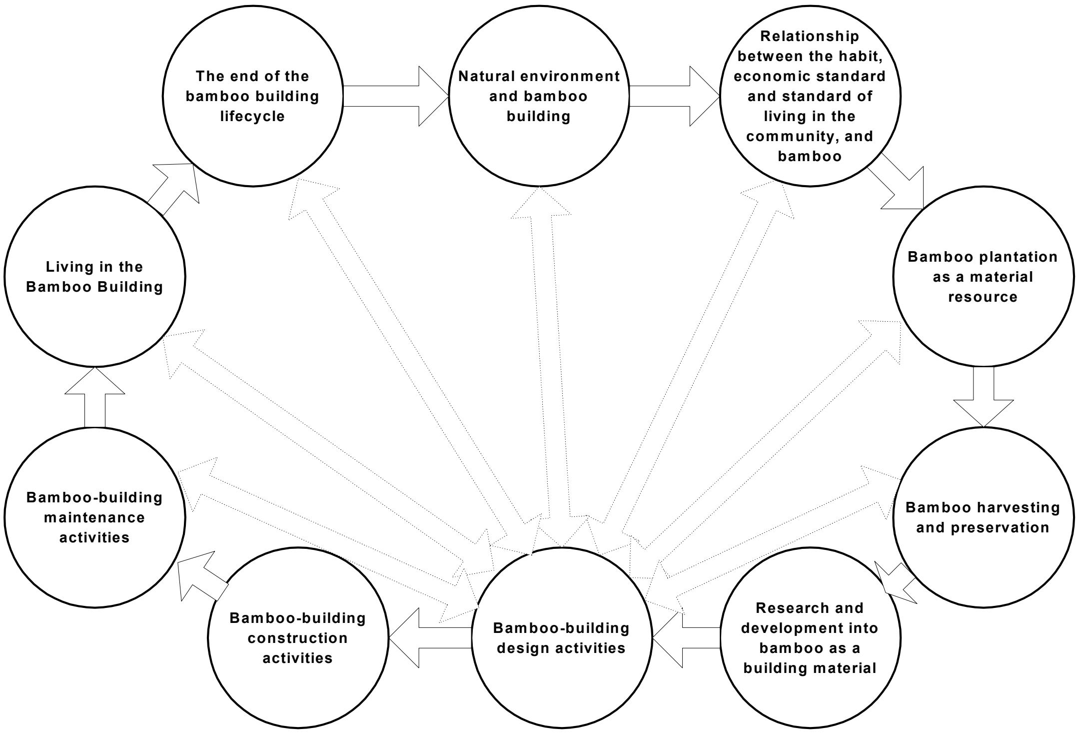

Figure 2.2: **A lifecycle diagram of the bamboo building (Mardjono, 2000b)**

Descriptions of each aspect have been made, based on the taxonomy, and are given in Appendix A. The complete set of aspects covered by the taxonomy will serve as a background of a fully developed DDSS (Design Decision Support System) for bamboo buildings; this thesis covers the requirements and the general set-up of the intended DDSS, and a worked-out partial prototype. This project only focuses on the design process; the aspect of bamboo building design activities will be taken into account, but the other aspects are also considered because they influence or interfere with design activities. There now follows a description of the different aspects in the design activities:

1. **Professional aspect**. Bamboo buildings are artefacts that can be designed in many different ways. The bamboo building design task should be performed and managed by professionals, according to recognised rules of conduct and professional management.
2. **Scientific aspect**. In many countries, bamboo buildings are made traditionally, according to local bamboo building cultures, without explicit

design activities. These traditional methods can be made explicit and developed in order to improve the quality and performance of bamboo buildings. The resulting bamboo building design knowledge can be applied in knowledge-based bamboo building design. This will be useful to innovate the design of bamboo buildings, their structure and construction methods.

3. **Aesthetic aspect**. The styling of all aspects of the bamboo building, including the combination of bamboo with other materials, should be adapted to the local culture and natural environment in order to achieve an aesthetically well-balanced design.
4. **Social aspect**. The achievable design solutions do not only depend on the designer, but also on the people who prepare the bamboo material, the construction workers, the owner, and also on the acceptance of the building by the community. Public support and acceptance are needed for these activities.
5. **Temporal aspect**. Bamboo buildings should be designed as a scenario, in which future changeability and adaptability have to be taken into account in order to maintain the building's serviceability.
6. **Economic aspect**. The cost of the bamboo building depends on the choice of building materials, the building technology, the construction method and maintenance method, which all influence the durability. The design activity therefore has an impact on the economic prosperity of the community, the employment situation, the market, etc.
7. **Usability aspect**. User requirements - above all - are the key success factors for a good building design. They should be considered as the basic guiding principles for the design of every bamboo building.
8. **Durability aspect**. The designer should consider the desired bamboo-building lifecycle to determine the required material properties. The durability of the bamboo building depends on the stability, safety, rigidity and life span of the building construction and the materials, and the possibilities of maintenance, repair, etc. The durability of the bamboo building also concerns the preservation of required or desired conditions, such as the indoor climate, lighting conditions, hygiene, etc. The design criteria for the durability of bamboo buildings should be formulated, agreed upon and applied.
9. **Makability aspect**. 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, all influence and restrict the "makability" and the eventual quality of the bamboo building. These factors should therefore 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.

Using this description, we can see that the use of bamboo as a building material depends on the previously mentioned conditions, such as selecting bamboo species, the plantation method, the harvesting and preservation method, research into engineering aspects of bamboo, the construction method, maintenance during occupation of the building, the living style in a bamboo building, and material recycling possibilities at the end of the building lifecycle. All these aspects should be considered during the design process of the building.

These descriptions have also raised some issues such as: the acceptance of a design for a bamboo building by the community, an optimal design, the stability of the bamboo building, and using a combination of bamboo material and other building materials. These issues need to be supported in the design process. The design process for a bamboo building can generally be described as having two stages: the early design stage and the detailed design stage. Both stages need to be supported with information and knowledge of bamboo and bamboo buildings. The intended complete DDSS should support both stages. This project has focused on the early design stage; the issues that should be supported in this stage are described in the next section. In this Ph.D project only a part of the complete DDSS has been worked out as a prototype, covering only the design stage of bamboo walls.

2.4 Relevant issues which a designer should be supported in during the design process

Based on the explanation in the previous sections, we can identify the design issues that should be supported as follows:

1. Identification of surrounding conditions,
2. Consideration, in the early design process, of the surrounding environment and types of occurring natural disasters,
3. Generation of satisfactory variant solutions for the bamboo building design problems,
4. Evaluation of the solutions found.

In the practical elaboration of the partial prototype, it is assumed that these issues have been met in the previous design stages. The prototype itself supports the mentioned issues. It is important that the surrounding conditions are identified so that the real conditions where the bamboo building is to be built can be described. With the knowledge of this condition and the exact location, the designer can predict and determine the environment surrounding the location, and can also anticipate natural disasters that could occur at that location. This information is also needed to be able to provide a bamboo building that fits into the surrounding environment. This information is still needed by the designer when she determines alternative solutions, but new information is also needed for the next steps in the early design stage. In the meantime, she should have access to other information to support her own decisions and to enable her to provide a fundamental and complete solution. These issues will be described in detail in the following chapters.

As described in an earlier section, this project focuses on the bamboo building design, however, other aspects of the taxonomy should also be taken into account. All aspects that support the completeness and appropriate design process should be identified, and the designer should consider these aspects. For example, when a designer designs a bamboo building in a certain location, she is obliged to use local bamboo materials. This designer will need information about the provided bamboo species, their characteristics and mechanical properties. The designer also needs information about the social and economic habits of the surrounding communities. A bamboo building located in rural area might have different characteristics than a bamboo building located in an urban area, where people tend to be more individualistic than people in rural areas. This condition may affect the building phase, the materials, and so forth.

Chapter 3

STRUCTURE OF THE DESIGN DECISION SUPPORT TOOL

This chapter deals with the decision support tool, the design process, the structure of the decision support tool for bamboo building design, and bamboo knowledge-based building design. It defines a framework for the tool that is being constructed.

3.1 **Design and Decision Support System**

The requirements, characteristics, functionality and contents of the decision support system to be developed depend on what we want to use this system for, such as design, operation or construction. When using it for design, it depends on which stage of the design process it will be used in, i.e., in the early stages or in the detailed design stage. All of these areas may need different information, but the type of decision support may be the same or similar. Before we discuss it in detail, we have to define the design process as a system of interconnected activities and decisions. In the next section we will explain the decision support system that has to support the design activities and decisions.

3.1.1 *Process of Design*

"A process is a series of actions which are carried out in order to achieve a particular result…" (Collins, 1997). The design process can be described as a series of activities that are carried out by a designer in order to achieve new artefacts based on her experiences, knowledge, talents, and creativity. An important point when designing a design decision support tool is what what kind of support it needs to achieve the result.

Dym (1993) states:

> "Design is a ubiquitous word: We see it often and in many different contexts... In fact, design has been a characteristic of human endeavour for as long as we can 'remember' or, archaeologically speaking, uncover. Design was done in very primitive societies for purposes as diverse as making basic implements (e.g. knives) to making their shelters more habitable. However, because people have been designing artefacts for so long and in so many different circumstances, is it fair to

> assume that we know what design is, and what designers do and how they do it…, …in relation with basic design, it is almost true that the 'designing' was simply linked with the 'making' of the simple implements –that there was no separate, discernible modelling process. However, we can never know for sure, because who is to say that small flint knives, for example, were not consciously used as models for larger, more elaborate cutting instruments? Certainly people must have thought about what they were making as they recognized shortcomings or failures of devices already in use and evolved more sophisticated versions of particular artefact. Even the simple enlargement of a small knife to a larger version could have been driven by the inadequacy of the smaller knife for cutting into the hides and innards of larger animals…" (pp. 13).

This is why there are many different definitions of design based on its goals and activities, since design is a goal-directed activity, performed by humans, and subject to constraints (Simon, 1996). The objective of the activity is the production of a "description of an artifice in terms of its organization and functioning –its interface between inner and outer environments" (Simon, 1996).

This condition raises several questions about the design process, such as "what did the designer think about her work", "what kinds of languages or images did she use to process her thoughts about her design", or "what mental models she may have used to assess function or judge form". In other cases, we might sometimes even use a "trial and error" method (a method called generate and test in which trial solutions are generated by some unspecified means and then tested against given evaluation criteria), but we can still apply our talents and creativeness in the design process to create unique designs. Dym describes design problems as *open*-ended and *ill*-structured and "…They are *open-ended* because they usually have many acceptable solutions; the quality of uniqueness, so important in many mathematics and analysis problems, simply does not apply. They are also *ill-structured* because their solutions cannot normally be found by routinely applying a mathematical formula in a structured way. Even when we design a simple joint connection, it becomes a complex study because there are choices to make about the form and the structure of solution, and there is no single language for ordering of many different design issues that has to be addressed…" In addition, the solving of one design problem may develop another problem, or may even change the initial design problem. For this reason design problems are also called "wicked problems" (Rittel and Webber, 1973, and NEC Research Index).

The design process generally depends on the individual designer, where each designer has her own way of designing or achieving the goal; this is why it is difficult to form and structure the process. One method of figuring out the process is to capture the designer's thoughts during the design process and then to deploy the captured ideas as a method of designing. In this approach we are only providing one type of design-process, that might be different when it is combined with another designer, but at least it enables us to construct a way of working through the design-process. Basically, the process of design may start from nothing or from a general starting point. Later, when the designer has provided specific information or knowledge, she will make decisions and determine certain parts so that the degree of freedom in the process is reduced, step-by-step, finally resulting in one solution. We can represent this process by Figure 1.1 in Chapter 1.

Archer (1969) proposed a general design-process approach, which may be useful for modelling. It can be characterized as an attempt to provide a logical and systematic model of the design process. It is principally based on finding out which properties an artefact should have in order to be able to attain one or more agreed objectives.

The objectives are determined at the start of the process; alternative solutions or results are found using appropriate properties; at the end of the process the design results are evaluated to see whether or not they fulfil the objectives. Bax and Trum (1993) propose another approach to the design process based on domain theory:

> "Domain theory is an architectural design theory in which architectural design is considered a complex activity, performed simultaneously in three interrelated design or decision fields. These fields are defined by modalities of space: morphological levels, functional domains and procedural phases. As such, architectural design space can be represented in the form of a three dimensional matrix, which is the core of a model of the design process, the so-called GOM model.
>
> According to Domain theory, every architectural artefact can be represented:
>
> - on several specification levels: the level of the (urban) environment of the building, the level of the building and on the level of the parts or details of the building, etc.,
> - in domains and orders of architectural design: fields of knowledge and design, corresponding to categories of objectives and performance of a building;
> - in different phases of development in the design process: as the outcome of a historical process in the past, as the result of decisions made already in earlier stage of the design process, as the object of actual decision-making in the present, and as the seed of a future process still to come, guided by expectations and images."

The GOM-model has three axes:

1. A Function axis, on which the building is represented as a functional phenomenon in terms of objectives and properties, related to its performance;
2. A Form axis, on which the building is represented as a formal phenomenon, expressed in morphological levels of specification;
3. A Process axis, representing the building as a temporal phenomenon, expressed in procedural terms of life cycle phases (including those belonging to the design process).

The three axes are considered to be the dimensions of a conceptual architectural space, in which the development of architectural artefacts can be described.

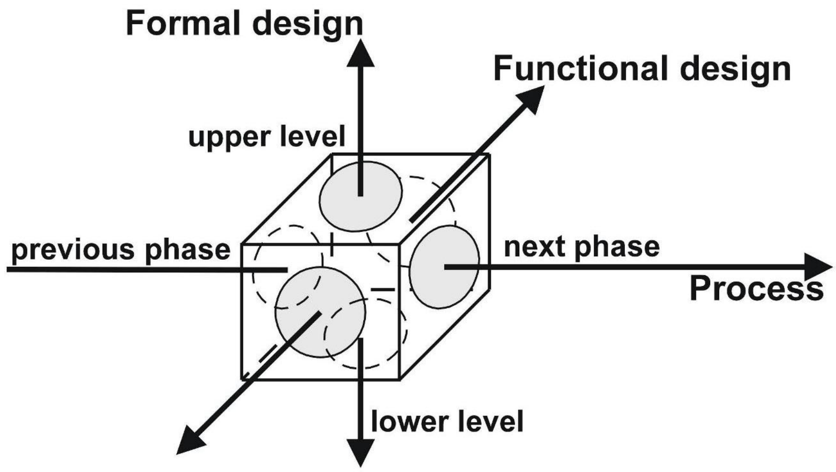

Figure 3.1: **Three dimensional model of the design process (after Bax & Trum, 1993)**

According to Bax and Trum, the designer is at the centre of the design process; she is always concerned with the three axes while looking for a solution to the problem of the six possible orientations, as shown in Figure 3.1. This three dimensional cube may be interpreted in terms of object modality and process modality. Object modality describes an artefact as it exists in its environment at any one time (even during its development in the design process), and process modality emphasises all activities of a designer during any stage in the design process. This cube can therefore be applied to analyse both an existing artefact in the environment and for designing a new artefact.

In this thesis we will apply the two approaches proposed by Archer, and Bax & Trum to build the tool. Archer's approach is used to relate artefact properties to design objectives, and the Bax & Trum model is used to integrate partial designs into an overall architectural design; both models are used to propose decision support in each task.

3.1.2 *Decision Support System*

There are many definitions and descriptions of decision support systems (DSS). Rhodes (1993) defines a DSS as "…A methodology, embodied in an organised group of people and machines, which is designed to assist, but only in a secondary role, one or more members of the organisation to express a preference for one action amongst the many which could be taken where at least one of those actions involves embarking on a sequence of events whose outcome cannot be precisely determined. The preferred action is deemed to be related to the person's job within the organisation and is deemed to influence and be influenced by the actions of others within the organisation…" Bidgoli (1997) gives another definition; he defines a decision support system (DSS) as "…A computer-based information system consisting of hardware, software, and the human element designed to assist any decision maker at any organizational level. However, the emphasis is on semi-structured and unstructured tasks…" He describes the application of a DSS as computer-software to:

- Assist the manager in his/her decision-making process for semi-structured tasks.
- Support, rather than replace, managerial judgment.
- Improve the effectiveness of decision making rather than its efficiency.

This definition or description gives several requirements for a DSS: it requires hardware and software; it needs human elements (designers, programmers, and users); it is designed to support decision-making; it helps decision-makers at all organizational levels; and it emphasizes semi-structured and unstructured tasks. The bamboo building design decision support tool will be set up as a computer-programme that is developed based on DSS software and knowledge about building design, bamboo and bamboo buildings. It will be used to support the designer in the design process for bamboo buildings. The reasons for choosing a computer-based programme are given in Chapter 5.

Alter in Bidgoli (1997), detected 56 systems with DSS characteristics; they can be divided into the following 7 categories:

1. File drawer systems
2. Data analysis systems
3. Analysis information systems
4. Accounting models
5. Representational models
6. Optimisation models
7. Suggestion models

The first three categories can be defined as data-oriented systems, and the last four can as model-oriented systems. DSS software developers offer these two systems. DSS software usually accommodates both systems, so it is not possible to distinguish between the systems. In our problem, in the design process of bamboo buildings, it is also difficult to define the exact type of system, as we use both of these systems in almost every step of the process. We use the "file draw model" to show a specific figure required in the process, but we also use the "analysis information systems", "suggestion models", and "optimisation models" to maximize the strength or minimize the dimensions in the detailed design process. The *model-oriented* approach might be appropriate in the early stages of the design process, while the *data-oriented* approach might be applied in the detailed stage.

A specific DSS is said to have achieved its goals if users of the system find it useful for their design problem solving. It can usually be developed from resources that are already available. So, this specific DSS will be constructed based on the assumption that this system will provide some benefits. Bidgoli (1997) explains "…the function of the DSS differs and depends on which analysis will be applied, such as 'what-if', goal-seeking, sensitivity, or exception analysis". These are only some of the capabilities of a typical DSS.

In the context of the tool development, the DSS is applied to systematically support the knowledge of bamboo and bamboo buildings during the design process.

3.1.3 *Construction of a decision support system*

According to van Zutphen (1999), a decision support system (DSS) has the following components: Databases, database management, knowledge management, a rule base, a reasoning engine and a user interface. (See Figure 3.2). Databases are a collection of data stored in a systematic way, where a specific character identifies each property of the data. The data can be called, added, and deleted through the operation of the database management. A DSS also has a rule-based component, that is, a collection of rules to be used in the decision-making process. The database management carries out operation and data transactions; it is used to organize the data transaction and is itself organized through the knowledge management. A reasoning or inference engine may be needed in this construction. As the DSS is built as a computer programme, an interface is also needed to connect the databases and the main programme: the database management. Two interfaces can be distinguished, as shown in Figure 3.2. The database management functions as the interface between the database and the main programme, and a user interface acts as the interface between the programme and user of the programme.

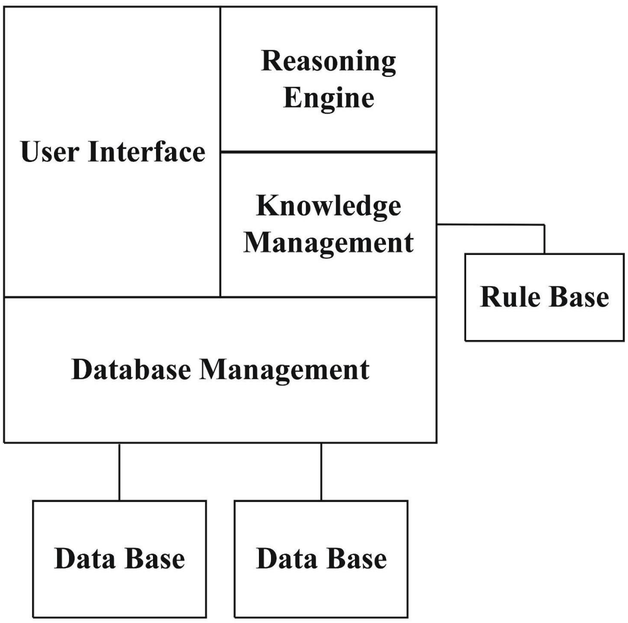

Figure 3.2: **Typical structure of a DSS (after van Zutphen, 1999)**

3.1.4 *Design decision support system (DDSS)*

Based on the explanations in the previous sections, we can define a design decision support system as a system to support decisions made by the designer the designer during design process. When a designer makes a decision, it always has two conditional (pre-decision and post-decision) implications, i.e. considerations and consequences. The designer has to pay attention to certain factors before she makes a decision, and she has to know the effects after she makes a decision. During this decision-making process she will create uncertainty and risk by choosing a set of possible choices. This is the difference between decision and choice. When we make a decision there is always some related uncertainty and risk (uncertain consequences), but if we make a choice the uncertainty and risk are already known (there are no uncertain consequences) (Rhodes, 1993). One or more people usually make the decision, but the choice is probably best made by machine. Hence when we use a DSS, the user of the DSS should start the decision-making process, which means that the user should be informed about the consequences of making a decision by selecting an available alternative or choice, and the computer/machine will continue the selection by making a choice. To achieve the goals of the DSS, there should be coordination and synchronisation between the user and the machine, or an interrelationship between the user and the programmes running on the machine.

3.1.5 *Structure of a DDSS*

The structure of a DDSS can be based on the approach offered by Archer (1969), which attempts to provide a logical and systematic model of the design process. This model allows designers to choose which type of decision should be used: a strategical, tactical, or optimisational decision. Moreover, Awad (1992) gives the following scheme (Figure 3.3) for database design.

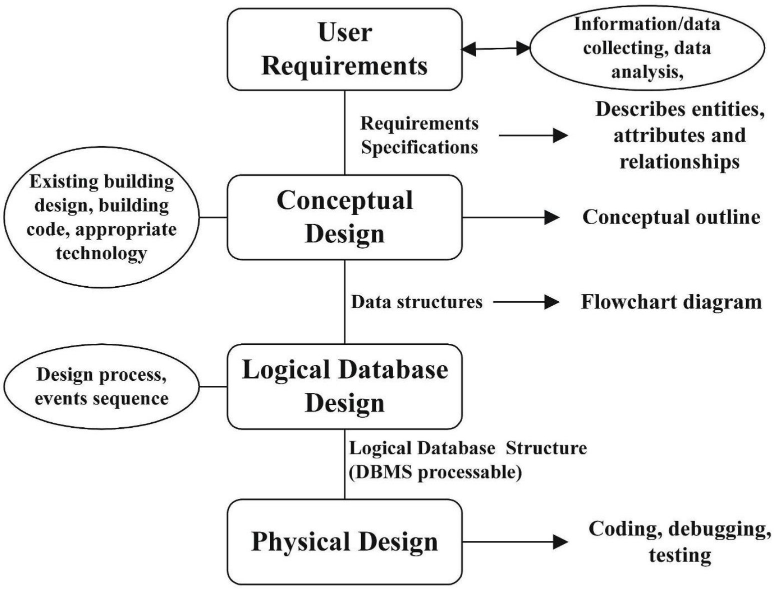

Figure 3.3: **Steps in a database design (adapted from Awad, 1992)**

One decision-point that should be noted is that decisions have to be formulated and structured before they can be made. Rhodes (1993) states "…A Decision Support System will not be effective unless the decision is expressed in some sort of formal system. Often the most difficult part of using mathematics to solve a problem is expressing it in mathematical terms. However, it is often a most important step, not simply because it facilitates the use of mathematics, but also because it increases the user's understanding of the problem. With decisions too, expressing them in formal terms will be one of the major tasks…" Hence the usability and effectiveness of a DSS will greatly depend on whether we can express the decision in an appropriate way. An alternative to the decision-making process in design will be explained in the coming chapters.

3.2 **Bamboo knowledge for building design**

The owner of the building, or the environment where the building will be built, can provide preliminary information in preparation for the building design. The environment of the building terrain can be described from two different viewpoints: that of the local and regional environment. The local environment may provide the designer with situational information such as land slopes, characteristics of the soil, local vegetation or conditions, land boundaries and their dimensions, land conditions under all circumstances (such as caused by floods, land-slides, and high groundwater conditions) and the situation in neighbouring areas. Information from the regional environment may consist of a master plan of the city or town where the bamboo building will be built, building regulations in that region, the price of building materials, the availability of labourers or artisans and their costs and skills, and also the local bamboo species available in that region, the types of natural disasters occurring in the region, and the regional culture and traditions. All this information is needed for many different purposes during the design and construction processes. The designer should therefore be supported with appropriate, accurate information.

To meet this condition we have to determine the types of information, a description of each information type, where the information is needed, etc. The information must be selected and structured, so that it can be shown to the designer when it is needed. We also need to determine the criteria for the selection process. It will be difficult to determine the criteria until we know what the designer's needs are.

As stated earlier, the design process for a bamboo building can be divided into two categories: the early design stage and the detailed design stage. These two steps cannot actually be described or distinguished exactly. In practice, the designer can detect and separate these two different steps. The main goal of the early design stage will be to determine the building orientation and layout, the building façade and general dimensions, and to determine all parts of the building in general. The detailed design stage turns the results from the early design stage into design reality; a structural designer will play a major role here. In this stage, all building parts will be determined and calculated accurately and their details will then be drawn. The building construction costs can be estimated at the end of the design process. The end product of the detailed design stage will be the design output for the client, usually consisting of a collection of building drawings and specifications of the building design, and construction and maintenance documents that are ready to be used during construction. These documents will be used as supplements to fulfil requirements according to the building regulations in the city. This is a traditional method of design.

Information supported in the early design stage can be described as follows:

1. *Identification of surrounding environmental factors*
   Designing a bamboo building that uses natural resources greatly depends on the surrounding environment. Identification of these environmental factors enables the designer to design a building that blends in with nature. The environmental factors include: location, topography, vegetation and climate. The location influences the orientation of the building, which is usually determined by the position of the sun during the year. In a tropical country like Indonesia, located on or near the equator, the sun is south of the equator for almost six months of the year and north of the equator for the remaining time. For example, a macro season in Java is almost entirely related to the position of the sun. The season when the sun is in the south, between March and September, is called the dry season; the period between October and February is called the rainy season. The dry season is characterised by low rain intensity, low humidity, and southeasterly winds (from the Australian continent); the rainy season is characterised by high rain intensity, high humidity, and northwesterly winds (from south-eastern Asia and the Pacific ocean). In a micro condition the season sometimes depends on the altitude and surrounding environment such as mountains, valleys, and the terrain in general. In higher place like Bogor or Malang, the rain intensity is higher than in other places in Java. The topography of the surrounding environment, such as lowland or highland areas, steep slopes or flats, dry or flooded areas, may influence the building form, the drainage system surrounding the building, and sometimes even the building direction. A steeply sloping area is good for the drainage system, but it may cause problems for the building platform. The surrounding environment plays an important role in the early design process of a bamboo building. This role can be described as follows:
   a. It may determine the direction, orientation, layout, configuration of rooms, and the main access to reach the building
   b. It may determine the building façade, and building material.

   Vegetation may sometimes reduce the wind impact on the building, and allow fresh air to circulate around it. The surrounding climate, such as the daily temperature, air pressure, absolute humidity, and the seasons that are usually identified by rain intensity, will determine the suitable air circulation system for the building, that is, the space needed to produce a natural air circulation system.

The soil condition and the number of soil layers will determine the type of foundation, the elevation of the foundation, and the material to be used. Soil investigation is usually needed before the type, elevation, and material of the foundation can be determined. The designer needs geological information for the building's surrounding area. This information can be provided from geological maps of the location, usually available at the city hall or public library.

2. *Identification of natural disasters*

   In addition to information on the surrounding environment, the designer should also be supported by information about natural disasters. Information about the different types of natural disasters occurring in the area can be gathered from the local community. These natural disasters can be: landslides, floods, volcanic eruptions, hot air caused by eruptions, hurricanes, earthquakes, etc. The characteristics of each disaster are also needed to identify an appropriate solution. For example, landslides usually occur in highland areas, on steep slopes, and unstable soils. If such a location is situated near a volcano, it may also be at risk from hot air during an eruption. On the other hand, a seaside location may have other typical disasters such as floods, hurricanes, or earthquakes. The characteristics of a hurricane or earthquake can differ per location.

3. *Knowledge of bamboo buildings*

   Knowledge of existing bamboo buildings can be used as evidence and information for bamboo and bamboo buildings, and can be used to support the design process of a bamboo building. According to Collins Cobuild Dictionary (1997), a building can be defined as "…a structure that has a roof and walls, for example house, clinic, school and factory. Roofs, floors, frames, walls and foundations are main parts of a building that protect occupants who live or use it from weather/climate changes; they also have an important function in the building. The function of the building itself may differ, such as for general living or working purposes and for many other human activities and purposes. A building may need different spaces and therefore different separators/dividers for the different functions; the spaces for these different purposes are called rooms. Rooms usually have their own walls, ceiling, floor, windows and door, and are used for a particular kind of activity. The different activities in a building may require rooms with different characteristics, such as sound absorption, heat or lighting control, room colour, and sometimes structure..." Bamboo as a building material should fulfil all of these characteristics, and should therefore be usable in different forms and for different purposes; the building must still be able to use material other than bamboo, or even composite materials. These parts may not be stand-alone parts of the building and may therefore need other structures to support them or to attach to. The frames are used to carry and transfer loads and weight from other building parts such as walls, floors and roofs, to the foundations. Material for these parts can be concrete, steel, wood, or bamboo. A bamboo building is therefore a building that uses bamboo as the major material for the main structure and almost all of the building parts. Knowledge of bamboo buildings can be described as knowledge about the bamboo building itself and knowledge about bamboo as a building material.

Facts and the existing condition of bamboo and bamboo buildings, discussed in the previous section, all contribute in developing a structure for the bamboo building design. Before using these facts and evidence in the design process, we have to determine a hierarchy or structure for the knowledge that should systematically support each process.

3.3 **Structuring the bamboo knowledge base**

The explanation of the design process, the theory of DSS, and knowledge about bamboo given in the previous sections raises a question, i.e. what will be the next step in order to build a decision support tool? When 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 at the factors that design decisions have in common. In general terms, the decision making process consists of findings and a series of actions which will tend to an outcome, preferably to the best or optimal outcome. The decision-making process will find a set of possible outcomes, allocate a degree of desirability to each possible outcome, and choose one which is more desirable than the rest. A scientific approach to problem solving uses problem observation, problem definition and analysis, structuring of the decision-making process, identification of possible decisions, identification, evaluation and verification of possible outcomes, and finally decision-making to achieve and accept the best solution from the set of possible solutions.

When we want 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 that needs to be made, we cannot expect to find a suitable possible outcome. Equally, if we have wrongly identified the decision, we are likely to choose the wrong possible outcome. The structure of the bamboo knowledge can be developed as a bamboo building resource system based on this real but ill-defined problem and the decision-making explained in the previous sections.

Buildings are formed by combining a great deal of complex knowledge and components along with today's technological possibilities. Many disciplines will take part in the system with their own components and tools. To achieve a successful building, an architect should coordinate, organize and supervise these components. These components are the elements of sub-systems that form the building system of an architectural product. This definition characterises the sub-system components in concrete terminology, preventing the building system from being expressed as important complexities and contradictions, even if different integration principles and different architectural approaches are followed.

According to Celebi, 1998, the sub-systems are considered as a "whole", they actually are integrated to form a "greater whole". That is to say, they all form the "wholeness of the building system". In the same way, bamboo buildings, which are being constructed with new building systems and construction techniques, are being improved by opportunities provided by the improvement of the traditional technology and development of bamboo industrialisation. The analysis principles of the bamboo building system, made up of the man-made environment as well as the relationships between analysed systems, components, and their integration possibilities, need to be determined.

The general performance criteria for the building can be defined as follows:

- To maintain the wholeness of the building, taking into account the decrease in the mechanical and physical qualities over time,
- To increase the level of comfort for the occupants,
- Life span,
- Natural environment,
- Materials and their characteristics,
- Comfort,
- Safety issues,
- Physical performance,
- Health care,
- Price.

According to these criteria, the wholeness of the building should always be reliable both in the short term and in the long term. The aim of integration is therefore to integrate the functioning of the building sub-systems in a harmonious and appropriate way, so that they achieve the maximum building performance criteria (Rush 1986 in Celebi 1998), contributing to the efficiency of energy, lifetime and material.

In attaining of the wholeness of the building, the designer can be guided by the "Taxonomy of concepts in architecture", which is a systematic elaboration of architectural phenomena occurring and observable in society, according to Domain Theory. Here we only use the taxonomy as a systematic list of observable architectural phenomena (on which it was originally based as a derivation of the contents of Art. 3 of the EC Architects' Directive of 1985) (Bax & Trum 1993). Figure 3.4 shows the bamboo building system based on the building functions.

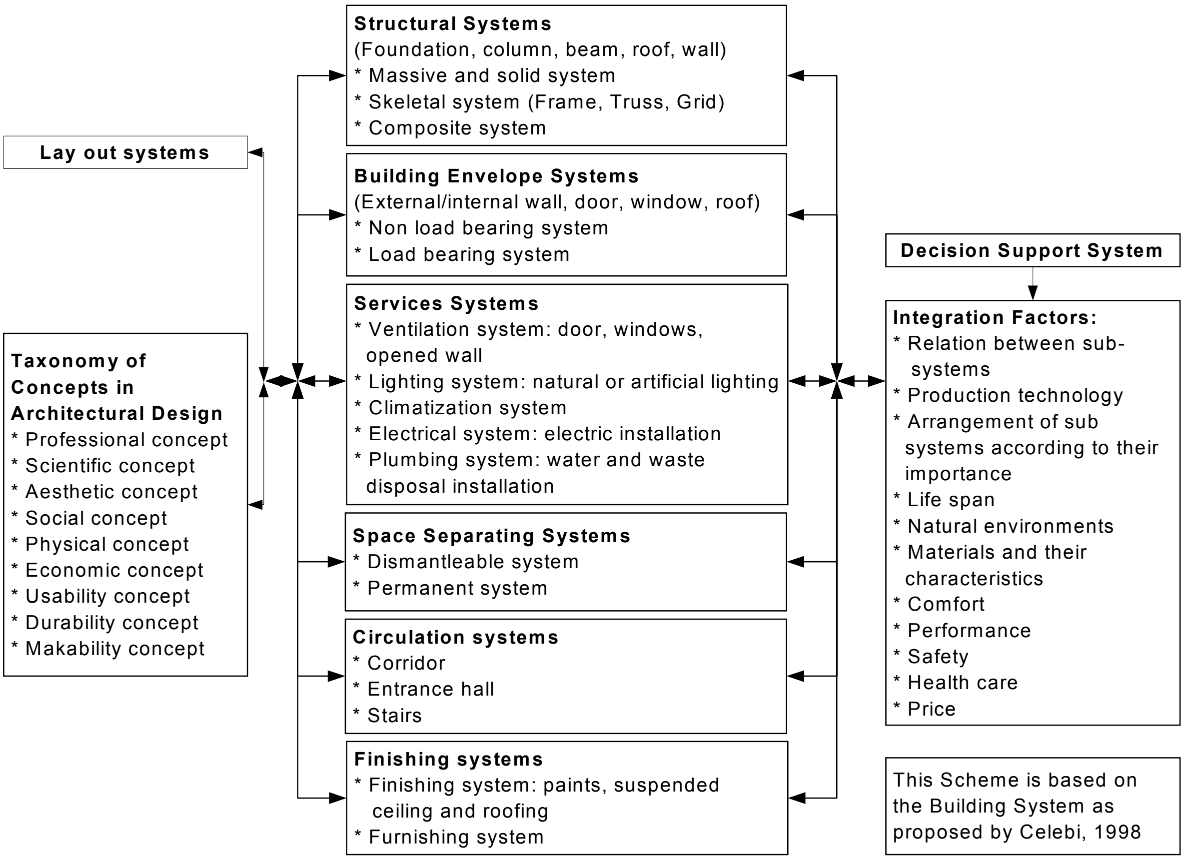

Figure 3.4: **A Bamboo Building System**

3.4 Relationships between the bamboo building system and DSS

At this stage, we might ask: What is the relationship between the bamboo building system and a DSS in the design process? This relationship can be explained as follows:

a. Each sub-system in the bamboo building system should be integrated. Integration of every two or more subsystems is the result of decision-making. Some aspects of integration need decision support during the design process, especially when the consequences of decisions are difficult to predict,
b. Decision-making in the design process should be carried out at each design stage.
c. During the integration process of the whole system, the boundary conditions of each subsystem and of the integrated system should be considered.

These kinds of decisions in the design process can be supported by the DSS. The system gives decision support to provide appropriate alternative solutions during the design process.

As mentioned in 3.1.1, we use Archer's approach and Bax & Trum's model of the design process in the development of our tool. Archer gives concepts of the design process step by step based on the design tasks. He proposes a design process through the determining of properties and objectives, the rating of objectives, completing the performance, and evaluating the performance of each alternative solution. Archer's approach deals with "how to proceed with a design": determined properties of a task give a description of the design requirements; determined objectives and the rank of the objectives of a task propose solutions; completing the performance to fulfil the objectives and evaluation of the performance deals with alternative and acceptable solutions. Bax & Trum offer a model of a decision process in a stage of the design according to formal and functional design. A combination of these two approaches can guide us in the development of our tool. For example, suppose we are in the process of designing a door. According to formal design, on a certain level of abstraction the door can be seen as an opening in a wall and is also part of the wall, and at that level the door has the function of giving an opening in the wall and also allowing persons or things to enter a room, in other words, the door belongs to the opening and is also part of the wall. On a lower level, the door may also be considered as a whole, a system containing its own components such as the panelling, frame, key, handle, and joints, in which all elements have different functions. In this case, the level of formal design of the door is lower than that of the room, but is higher than the level of formal design of the key or handle. During the design process of the door, we should always consider its relationship with the design of the room at the upper level, and also with the key or handle at the lower level. If we make safety more important in terms of the functional design, the decision-making may result in a different acceptable solution, and it may have immediate consequences for the formal design of the key and handle. If this situation occurs during a design process, the designer may jump to the design of the key or handle of the door, and this means she jumps to a lower level of formal design of the door. If we picture each design task as a cube like in Figure 3.1, we will provide an "unlimited" number of cubes during the design process, and when a task has been completed, the uncertain decision task will be reduced.

The types of decision-support in the design process of a bamboo building may include: information, evaluation, explanation, computation of technical features, cost calculation of each part or sub-system in each proposed alternative solution, and the selection of an example of a previous solution that meets the present criteria.

The required type of DSS depends on the specific parts of the bamboo building system. The complete DSS may be needed to yield a satisfactory bamboo building system. A bamboo building design decision support system should be thought of as an information system for the users. As such, it might be implemented as guidelines, an audio-visual display or a computer programme. Note that in developing countries the implementation form of the DSS may not depend on the appropriate type of bamboo building system, but on the ability of those users to access the information system.

An appropriate DSS can be tested according to the requirements that an information system should meet (Mardjono, 2000a, after Zamanian, 1999), as follows:

1. Comprehensiveness. The type and level of complexity of the system depends on what kind of information is needed and how detailed and adequate it is in describing some particular aspects of an artefact at a specific phase.
2. Non-redundancy. This should be the rule. However, in some cases, it will be desirable to have some consistent redundancies that are designed and managed to provide information efficiently.
3. Extensibility. Information systems must be extensible so that necessary modifications and enhancements can be readily implemented.
4. Classification. Semantics play a key role in information classification, and therefore it is extremely important to capture the correct semantics. It is often challenging because the multi-disciplinary and even multi-national nature of the information domain might lead to overlapping of its schemata.
5. Inheritance or reuse of data and behaviour is provided via the hierarchical class structure of an information system.
6. Assembly modelling. Physical objects and processes are not monolithic but are assemblies of various components that can be successively decomposed into more detailed components until no further decomposition is needed or possible.
7. Multiple referencing. An assembly-modelling scheme suggests a more structured hierarchical approach. But it is often desirable to aggregate information components in such a way that those components are shared among several assemblies. For example: the connection between a beam and column consists of many components, which must be considered as part of both the beam and column.
8. Multiple-functional views. It is common for a component of a constructed facility to perform several functions. For instance: the interior walls of a building are viewed as spatial partitioning elements by architects, but structural designers may assume them to be load resisting members, and sometimes as containers for outlets of the air conditioning, water, plumbing or electrical utilities.
9. Extensibility to new functional views. The information model must be extended to accommodate the additional functional views of components and processes required by these disciplines. For example: an environmental view may be developed for monitoring indoor pollution of constructed facilities.

10. Data accumulation and evolution. As an information system, various types and forms of data should be developed over time through various phases of its lifecycle - i.e., design, analysis, fabrication, maintenance, and demolition.
11. Adaptability to codes and standards. The design and construction of an information system must comply with the applicable local codes and standards. The information model must be adaptable to the codes and standards that guide the creation and use of its content targeted for use in a particular region of the world.
12. User-defined extensions. The information model might be unable to address the specific needs of all of its intended users. The protocols for adding user-defined extensions to a model and the mechanism for accessing such information are therefore needed.

These requirements will fulfil the completeness and acceptable service levels of a DSS and, as result, the DSS should satisfy the users.

These explanations show us that it is essential to build the tool in the form of a DDSS to provide a systematic approach to supporting the design process of a bamboo building. At this point we might ask "Why do we use the DDSS?" and "In which form do we have to realise the DDSS?" We can also make the following remarks based on this chapter:

1. We need to apply an appropriate model of the design process that can be used at each stage of the process,
2. We need to utilise a DSS to build the tool,
3. We need to utilise some criteria to create an appropriate DSS.

These questions and remarks will be answered and utilised in the next chapter.

Chapter 4

SETUP OF THE DESIGN DECISION SUPPORT TOOL

This chapter deals with the description and model of the design decision process for bamboo buildings. (A process is a series of actions or thoughts by which one comes to a decision or finds a solution). The description and model will be used as a framework for the design decision support tool. The framework describes opinions, views and observations of the design process, which will be applied in the tool. This framework therefore consists of the most important activities in the design process as a representation of the designer's thinking. Using this approach, the designer's personally preferred processes of design can be matched with those activities. The designer has the freedom to select which activities have to be carried out in the design process, and the freedom to determine the sequence of the activities.

As we discussed in Chapter 3, this tool is only concerned with the early stages of design for bamboo buildings, and the tool is intended to help the designer. We decided that we wanted to build this tool as a computer programme. In this situation there are four factors that should be taken into account when setting up the tool: (1) the structure or model of the tool, (2) the related design knowledge that will be processed in it, (3) the programme or software developer that will be used to construct the tool, and (4) the verification and validation of the tool. This chapter deals with the first and second factors as components of the basic construction of the tool. The third and last factors are discussed in Chapters 5 and 6. Section 4.1 describes how the design process is modelled using the IDEFØ (pronounced IDEF zero) method. The model is then presented in section 4.1.1 and the model is discussed in section 4.1.2. The systematisation of the design process model is discussed in section 4.2. Section 4.3 gives an example of the design process, carried out spontaneously by the designer. We give comments on the design process model at the end of this chapter.

4.1 Introduction to the Design Process

The modelling of a design process is not easy, since it has to connect a representation of a design process that is already in the designer’s mind with a systematic structure. This structure is important for the tool that is to be built. The design decision support tool focuses on supplying knowledge to the designer in the early stages of the design process. The supplied knowledge is specific to the design in question. The tool will contain knowledge databases, database management, user interfaces, rule bases, and inference engines, which are all explained in Chapter 3. Users will receive knowledge and information from the tool by answering a series of questions given through the user interface. Processes in this transfer of knowledge should be done in the correct way to give the users the right knowledge and information based on their answers. Since this tool is related to the design process, it should be able to cope with any design process. This can be done if the tool has a proper mechanism, a well-implemented design process, and is able to manage the data transfer. The model of the design process therefore needs to perform all data transfers and support knowledge that is given to the users. This model can be built using a function modelling method, since such a method can figure out design processes made by the designer that usually have no specific design patterns. The function modelling method can be adopted to model the design process, and will be explained in the next section.

4.1.1 *Integration Definition for Function Modeling (IDEFØ)*

IDEFØ is a standard for modelling techniques, found in the Federal Information Processing Standards Publication (FIPS-PUBS) 183, issued by the National Institute of Standards and Technology (KBSI, 2000). IDEFØ is part of a series of modelling techniques, i.e. IDEFØ, IDEF1, ... IDEF9. KBSI (2000) explains

> "…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…"

The basic syntax for an IDEFØ model is shown in Figure 4.1.

KBSI (2000) also mentions a misunderstanding in the interpretation of the IDEFØ as follows:

> "…One problem with IDEFØ is the tendency of IDEFØ models to be interpreted as representing a sequence of activities. While IDEFØ is not intended to be used for modelling activity sequences, it is easy to do so. The activities may be placed in a left to right sequence within a decomposition and connected with the flows. It is natural to order the activities left to right because, if one activity outputs a concept that is

used as input by another activity, drawing the activity boxes and concept connections is clearer. Thus, without intent, activity sequencing can be imbedded in the IDEFØ model. In cases where activity sequences are not included in the model, readers of the model may be tempted to add such an interpretation. This anomalous situation could be considered a weakness of IDEFØ. However, to correct it would result in the corruption of the basic principles on which IDEFØ is based and hence would lose the proven benefits of the method. The abstraction away from timing, sequencing, and decision logic allows concision in an IDEFØ model. However, such abstraction also contributes to comprehension difficulties among readers outside the domain. This particular problem has been addressed by the IDEF3 method..."

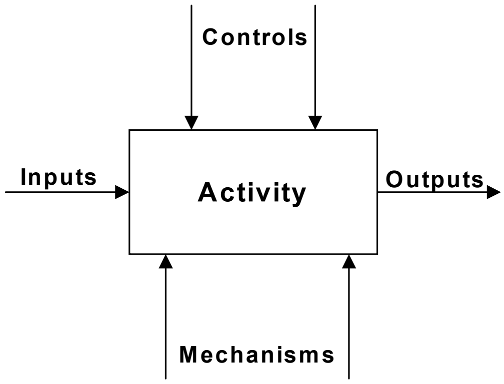

Figure 4.1: **IDEFØ Function Box and Interface Arrows (KBSI 2000)**

Activities can be decomposed into sub-activities until they can no longer be decomposed. IDEFØ allows these activities and the decomposed activities to have a similar input, control, mechanism and main output.

4.1.2 *IDEFØ Analysis of a Bamboo Building Design*

Let us consider the main function of the tool as seen in Figure 4.2. It is intended to support the conceptual design of a bamboo building that can later on be applied in a design decision support tool. The activity produces an output that is called the conceptual design of a bamboo building. An activity is an element of a process that manages all information such as inputs, controls, and mechanisms. To achieve the correct output, all information should be considered in the process. Inputs may consist of project information and the user's background. Project information is specific information such as location, climate, surrounding conditions, etc. The user's background is information provided by the user that is important to model queries, to determine functions and transform them into building parts that fulfil the requirements. The controls for this activity consist of a design database, an example case base, and a general intention. The design database contains several databases with data and bamboo knowledge. The example case base is a case study as a decision-support example of the bamboo building design.

Finally, the general intention is the user's plan of how to design the bamboo building, as she wants and so that it fits in with the building's surroundings. The main purpose of the control for this activity is to maintain the process of the activity to run on the right track, so that it can produce a relevant output. Another component in this activity is a mechanism that provides output as a result of the activity. These mechanisms also help to process the activity to cope with a difficult situation during the process. Before we construct a whole system or tool, we must build a partial prototype of the tool, which should then be tested by prospective users. These users may give corrections, suggestions and criticisms to the developer of this prototype. Their input helps the developer to build a better prototype and later on to construct the whole tool or system. So, the mechanisms consist of input from prospective users and the prototype of the bamboo building design decision support tool. The output of this process is called a conceptual design of the bamboo building that can be considered as a proposal for a bamboo building that fulfils the user's requirements. Each activity in the scheme has its own identification or numbering system, which is derived from the composed activity followed by dot and the number. This identification number is used for easier identification and for checking purposes. The main activity has identification number A0, and the decomposed activities have identification numbers A1, A2, and A3, as seen in Figure 4.3. Later on A1 can be decomposed into a series of activities that have identification numbers A1.1, A1.2, A1.3, etc., respectively.

This activity can be decomposed into three activities: determine the bamboo building design requirements, establish a total bamboo building design, and evaluate (alternative) bamboo building design(s). Each of these can be further decomposed into specific activities until, in the end, the specific activity cannot be decomposed any further. Each of these activities still has to maintain the main activity to achieve the whole output. Inputs and/or outputs, controls, or mechanisms of an activity may become inputs, controls, or mechanisms for another activity, respectively. The complete IDEFØ analysis for this design decision support system can be seen in Appendix B.

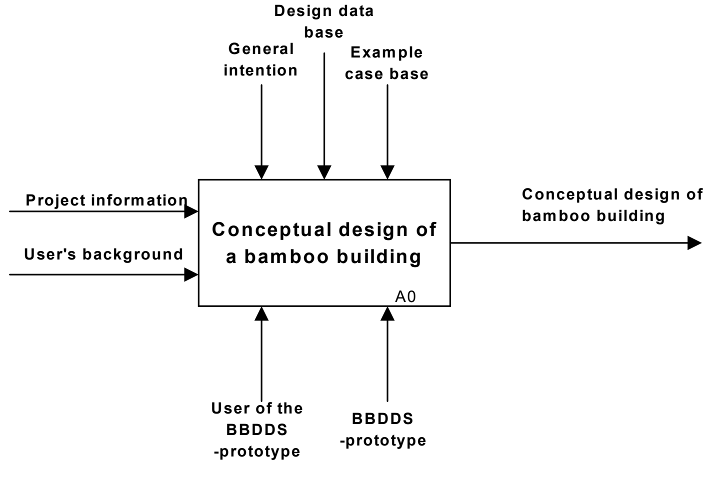

Figure 4.2: **Main activity of the conceptual design of a bamboo building**

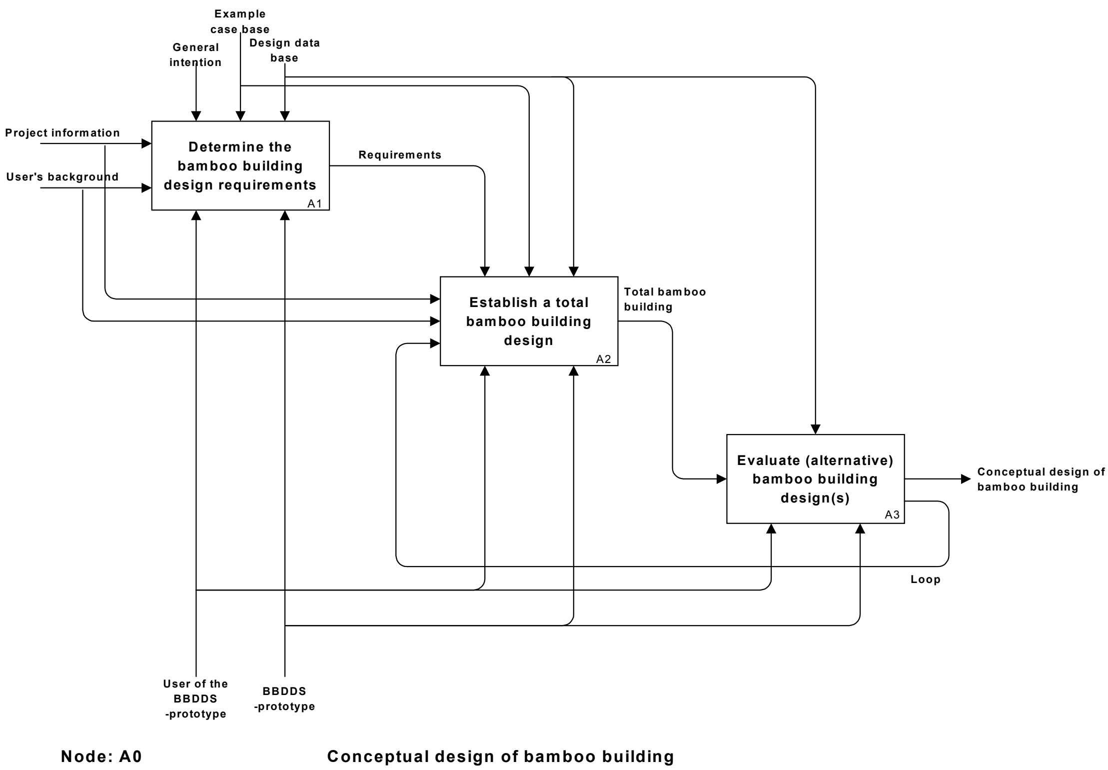

Figure 4.3: **Decomposition of the main activity**

The principle of decomposition of the activities can be described as follows: (The complete result is given in Appendix B)

1. Determine the bamboo building design requirements (A1)
    - Transform intentions into requirements for a systematic bamboo building design (A1.1)
        - Show aspects of intensions relevant for the project (A1.1.1)
        - Show project requirements for a systematic bamboo building design (A1.1.2)
    - Determine the design requirements of bamboo building (A1.2)
        - Show list of the bamboo building design aspects (A1.2.1)
        - Show additional information at user request (A1.2.2)
        - Select the bamboo building design requirements (A1.2.3)
        - Check user's satisfaction of the bamboo building design requirements (A1.2.4)
2. Establish a total bamboo building design (A2)
    - Select the space plan for the bamboo building (A2.1)
        - Select total or aspects of the space plan (A.2.1.1)
        - Determine complete aspects of the space plan (A2.1.2) or
        - Determine some aspects of the space plan (A2.1.3)
        - Check user's satisfaction of the space plan (A2.1.3)
    - Select the structural system of the bamboo building (A2.2)

  - Select total or aspects of the structure (A2.2.1)
  - Determine complete aspects of the structure (A2.2.2) or
  - Determine some aspects of the structure (A2.2.3)
  - Check user's satisfaction of the structure (A2.2.3)
- Select the skin system of the bamboo building (A2.3)
  - Select total or aspects of the skin system (A2.3.1)
  - Determine complete aspects of the skin system (A2.3.2) or
  - Determine some aspects of the skin system (A2.3.3)
  - Check user's satisfaction of the skin system (A2.3.3)
- Select the services system of the bamboo building (A2.4)
  - Select complete or aspects of the services (A2.4.1)
  - Determine complete aspects of the services (A2.4.2) or
  - Determine some aspects of the services (A2.4.3)
  - Check user's satisfaction of the services (A2.4.4)
- Establish the integrated bamboo building (A2.5)
  - Combine the structure, skin, services and space plan systems (A2.5.1)
  - Specify control, construction, maintenance, dimensions, and materials (A2.5.2)
  - Check user's satisfaction of the bamboo building system (A2.5.3)

3. Evaluate (alternative) bamboo building design(s) (A3)
   - Retrieve the specifications of the complete bamboo building system (A3.1)
   - Show the specifications of the complete bamboo building design (A3.2)
   - If the designer is not satisfied, establish an alternative bamboo building design (A3.3)
   - Select the most appropriate bamboo building design (A3.4)

The above IDEFØ schemes are representations of the design-processes of the bamboo building. Arrows connecting activity-boxes in those schemes give the designer the freedom to start designing, or to proceed with a design activity, or jump to another activity of the design process. The specific identification of each activity facilititates a comparison between a spontaneous design-process by the designer and the activities in the systematic model of the design process in the IDEFØ scheme.

4.2 **Systematise the design process model**

The model of all design activities built in the previous section will then be filled with knowledge related to each activity. This knowledge can be provided based on the tool builder’s experiences, handbooks, experiments, and other related sources. All collected information will be used and discussed to determine the decision. We also have to model the decision-making process. Wiegeraad (1999) gives an example of a systematised model of a decision-making process, as seen in Figure 4.4. This approach can also be applied in our decision-making process for the design. This systematized model is useful to provide clues for appropriate modelling of decision-making during the design. In our case, a decision at a stage of the design process can be made after analysing information and input data provided from the previous stage. When a decision has been taken, it may raise a new problem, or new considerations or consequences that should be considered in the coming stages. At this stage the user may continue to another stage within the whole process at the same level, or to a different level of function or activity, or she may go back to the previous design stage, if required.

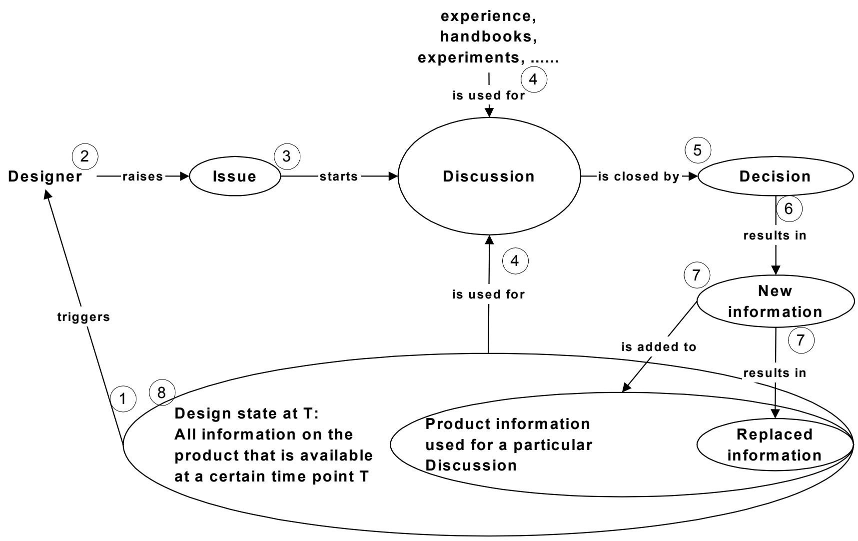

Figure 4.4: **Basic cycle of decision-making in a design process (Wiegeraad 1999)**

Now we can develop support for decision making at every noted activity in the IDEFØ scheme. Every single decision in the known activity can be described as 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-decisions 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 this purpose, each decision needs attributes and attributes values.

4.3 An illustration of the design-process of a house/building

The design-process of a bamboo house or building can be started at any point in the design process model, and it is not necessary to start at the beginning point. As an illustration, let us suppose the designer starts by designing the building layout.

1. The design processes of a building can be initialised by determining the design scope of the building. Factors such as sites, building codes, legal requirements and the environment, affect design processes. The macroclimate as part of the environment can be used as a basic consideration for decision-making in the design process. Included in this macroclimate consideration are (1) the topographic condition of the site in determining surface contours, (2) the direction of the sun related to the building in all seasons, (3) the wind direction in various seasons on the site, (4) the temperature, soil humidity, vegetation, and (5) the type of natural disasters that occur on the site such as hurricanes, rainstorms and earthquakes. If the designer concentrates on the location of the building, surrounding conditions should also be considered, such as the effect of surrounding buildings, neighbours and regulations, and site features such as road access to the building. The designer has to make a decision about the building orientation to the access road, and also takes the building regulations into consideration. The designer is now at node A1, A1.1, A1.2, and A2.4.
2. The design process may then be continued by developing building forms, structures of the building parts, or connections between these parts. Let us assume that the designer chooses structures of the building as the next design stage. Decisions have to be made by analysing all inputs, synthesising appropriate data and information, and evaluating probable outcomes of possible decisions that need to be made, and finally making a decision. When the designer makes a decision on the building structure, she has to consider any other stages that will involve the building structure. Let us assume the designer chooses a frame system as the building structure. At this stage she has to consider the building material and any earthquake or wind risks that influence the design of the building structure. The designer is now at nodes A2.1, A2.1.1, and A2.1.3. At this stage she may go back to the building layout since she has to arrange the layout according to the frame structure limitation (for example).
3. Suppose she continues to design the layout. She has to decide whether to change the layout or not when she receives the structural needs provided from the previous stage. She may now have to analyse all this new information, analyse the information and provided data, make a synthesis of this data and information, and evaluate each possible decision on the building layout. (The designer is at node A2.4).
4. When the decisions have been made, the designer is satisfied with her design for the time being; we assume that the result of the design process is presented in the form of an image, or a drawing, and the coming decisions have to correspond with this image. At this stage she may continue to design the outside wall, which functions both as a water-resistant wall and a load-bearing wall. The designer is now at node A2.2. She now needs related data such as types of water resist-

wall and types of load to be applied to the wall. She may then jump to node A2.1.3 (structural system). After deciding to use a combination of full culm bamboo and bamboo reinforced cement mortar as the wall material (at node A2.2), she may continue to make a decision on the load characteristics. Soon after she learns that the building is located in an earthquake-prone area, she will have to decide whether to use bamboo reinforced cement mortar or bamboo mats. She may now change her mind to use bamboo mats, as they are very light and elastic to match with the earthquake-resistant building requirements. When she is thinking about a water-resistant wall, she will probably change her mind to use the bamboo reinforced cement mortar material, since a wall made of this material can also function as a water-resistant wall.

From this example it is clear that the designer may start at any stage of the design process, and then go or jump freely from one activity to another, at will. These design processes will obviously be difficult to model if we use a flowchart scheme that is usually used when we design a single track design process. But if we use the IDEFØ scheme, as explained in this example, all those design decision processes can be traced. The interrelated design activities in the scheme automatically bring related issues to the designer's attention.

4.4 **Remarks on this chapter**

We have seen that the IDEFØ scheme is not yet complete, as the scheme can be enlarged by making decomposition processes of every last decomposed activity, as required. This means that the scheme will be more complicated, but can be based on those schemes. As an example, if we want to build an IDEFØ scheme of the wall design process, we can use the decomposition of node A2.3 as a starting point. We can therefore adopt this idea and use the design process of a wall as a small prototype of the tool. This prototype will be explained in Chapter 5.

Chapter 5

DESIGN OF PARTIAL PROTOTYPE OF THE TOOL

This chapter concentrates on the design of a partial prototype of the tool and the implementation of the design decision support system in a computer programme. It starts with the selection of a computer programme to build the prototype, the designing of the main components of the prototype, and the building of the prototype. We talk about here a "partial prototype" of the tool since this prototype only focuses on the design decision support for a wall. We assume that the design decision support for other building parts can be built in a similar way, but due to time constraints we have not built prototypes for those other parts. The complete tool will contain all parts of the bamboo building design decision processes, and will also contain a programme for the integration of those parts. In the following sections we will discuss: the selection of a computer programme; the structure, scope and components of the prototype; the building of the prototype and the integration of the wall components. We assume that this part of the programme will be similar to the overall integration programme at the building level. This chapter ends with some design remarks about the prototype.

5.1 Selecting a computer programme

The selection of a computer programme or a developer programme to be used to develop the tool was a crucial activity in this study. There are many computer programmes currently available, and we had to select just one of them. Our first step in the selection process was to find as many knowledge-based computer programmes as possible, available on the Internet and from other sources. We also determined criteria for choosing a computer programme based on the characteristics of the tool and the prototype that we wished to develop.

5.1.1 *Criteria for the selection process*

We can list the criteria for this selection process as follows: the platform, performance, functionality, ease of use for the developer of the tool, integrity or connectivity with other programmes/languages, whether it is widely used, and its future development. In relation to the bamboo DDSS, we first had to decide which of those appropriate rule-based languages to select. Before we started the selection process we had to make suitable selection criteria for the bamboo building problems. The Programme Developer may consist of a single programme or of several programmes, such as *Delphi* for Object Oriented Programming Language, *Microsoft Access* for database programming and rule-base languages. Those criteria can be met as follows:

1. The programme should have a Windows operating system platform.
2. The programme should be able to handle and manage large data especially images, knowledge and multimedia elements.
3. The programme should be able to build an interactive and friendly user interface.
4. The programme should be able to handle the development of the tool in the future.
5. The programme should operate on most computers.
6. The programme should be easy to use, and should not need any other programmes.
7. In future the programme should be usable for developers to manage the tool.

We assumed that we needed to select a knowledge-based system and a rule-based language as the main programme of the decision support tool. We therefore compared several currently available computer programmes. Those computer programmes can be described as Knowledge-Based System programmes (KBS), and Rule-Based programmes. In the first programme, all components of the programme are integrated into a single programme, but the second category only contains a partial programme, so that other programmes need to be used and several programmes have to be managed in a single programme. Appropriate knowledge-based programmes are *KPWin* (2000), and *XpertRule Knowledge Builder* (Attar Software Limited, 2001). Rule-based programmes that integrate with Object Oriented Programming (OOP) are *Active Agent X, Agent OCX, Eclipse, Rete++, and CIA Server* from The Haley Enterprise (2002). Suitable data-based programmes are *Microsoft Access, Paradox, etc.*

Using a single developer programme makes it easier to develop the tool and the user interface, rules, and databases can be maintained in one programme; otherwise the user interface would have to be maintained in one programme, rules in another programme, and the databases in a different programme. Multi-developer programmes would allow us to build an attractive tool, since each developer programme can work in its own capacity. We came to the conclusion that developing a tool with multi-developer programmes would be appropriate for a programme developer team, as it can reduce the time spent in the developing process. But a single developer programme is more suitable for a single programme developer. Using a single developer programme we would be able to develop a tool easily using the facilities available in the programme. This is why we decided to use a single developer programme to build the tool, and after we had tested these two programmes and had looked back at the scope of the design decision support tool, we selected the *XpertRule Knowledge Builder* programme.

5.1.2 *Specification of the selected developer programme*

The *XpertRule Knowledge Builder* programme has backward chaining, forward chaining, decision tree, cases table, dialog, and report facilities. The main facilities in the programme each time we build a new project or open an existing knowledge module are *Attributes, Procedures, Dialogs and Reports, Variables,* and *Decision Map*. Refer to the manual of *XpertRule Knowledge Builder* for a more detailed description. These facilities are shown in Figure 5.1.

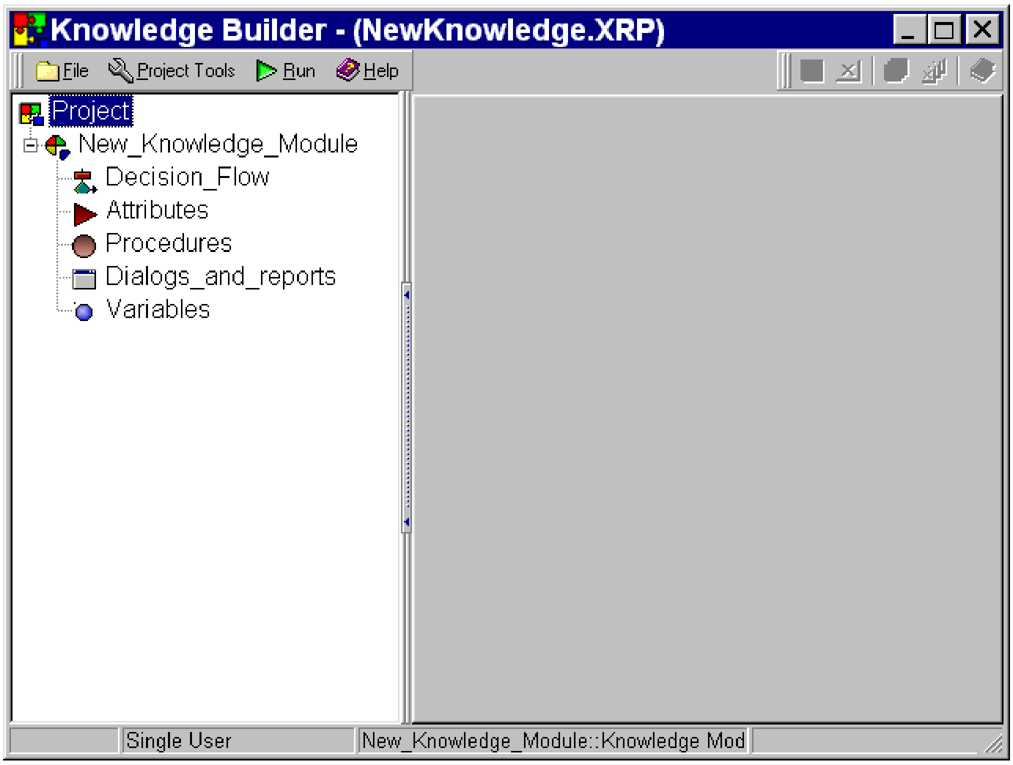

Figure 5.1: **Main screen of the developer programme**

One of problems in knowledge-based systems is the lack of a model for decomposing a large knowledge application into a hierarchy of rule sets. So by structuring the rule sets, developing a rule base for the application can be managed easily. *Knowledge Builder* gives the user the flexibility of multiple knowledge representations, allowing knowledge to be expressed in the most natural way; the knowledge builder also utilises rule induction as a catalyst for knowledge acquisition. Rule induction can convert a table of cases into a decision tree. Before we start to develop a partial prototype of the tool, in the sections that follow we will explain the structures, scopes, requirements and a rule-base set up for the prototype.

5.2 **Decision-making in the programme developer**

There are two utilities of decision-making in the programme developer that can be used. These decision-makings utilities can be described as follows:

5.2.1 Decision Tree

The *Decision Tree* is the most important utility in this programme developer, since it is used to build a decision-making process. Decision-making in the decision tree is done by an induction process. In this decision tree we can add a *procedure* as a rule to trace the decision-making process. An example of a decision tree is shown in Figure 5.2.

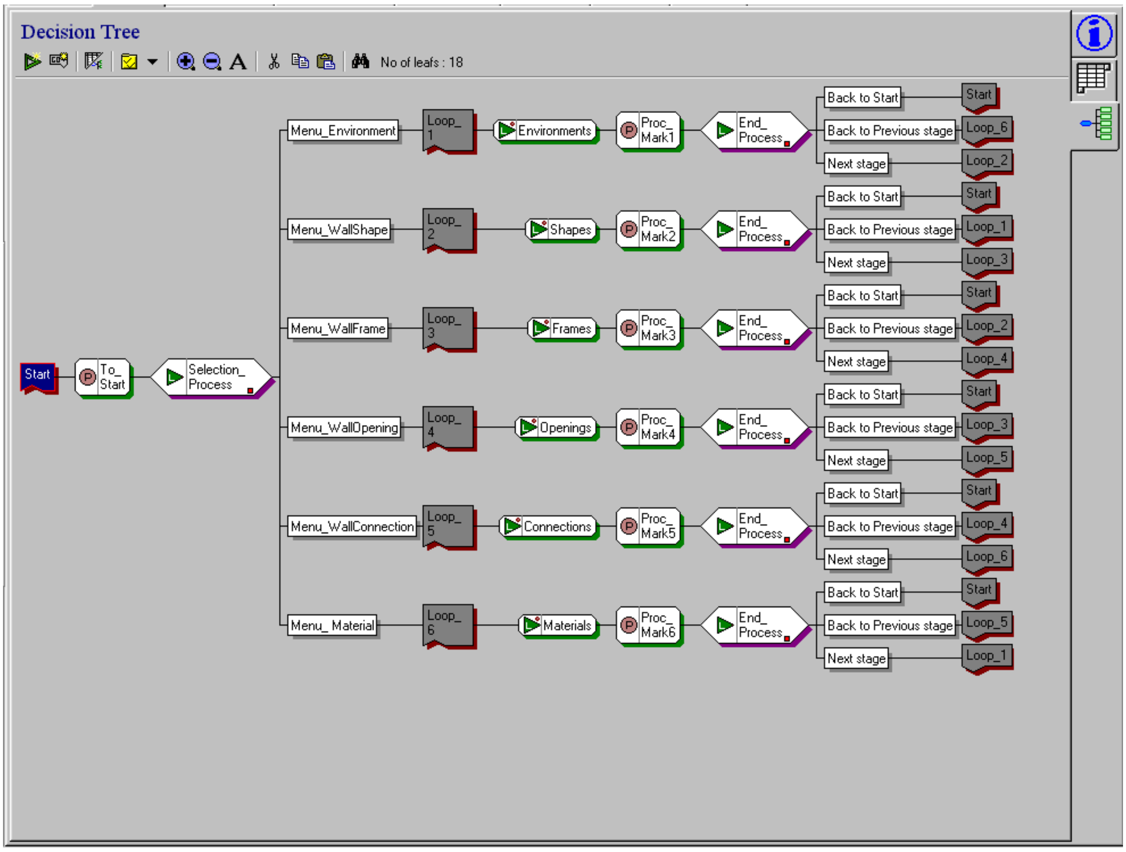

Figure 5.2: **A result of the decision made by the programme developer in order to support the architectural designer in her Bamboo Building Decision making.**

5.2.2 Cases Table

The *Cases Table* is a representation of cases from previous experience, based on several attributes or properties that influence it. We can build a decision tree based on the cases table.

5.3 Structure of the prototype

Based on the process model explained in Chapter 4, we developed support for decision-making at every design stage of a wall. As we saw in that chapter, every single decision in the structure can be expanded into 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-decisions can be combined together in some way to allow the overall decision to be made. The outcomes should be formulated simultaneously and then ranked according to their degree of desirability. A sub-decision may need attributes and attribute values to do this. Figures 5.3 and 5.4 show the decision support for a wall and wall-opening design process, as an example.

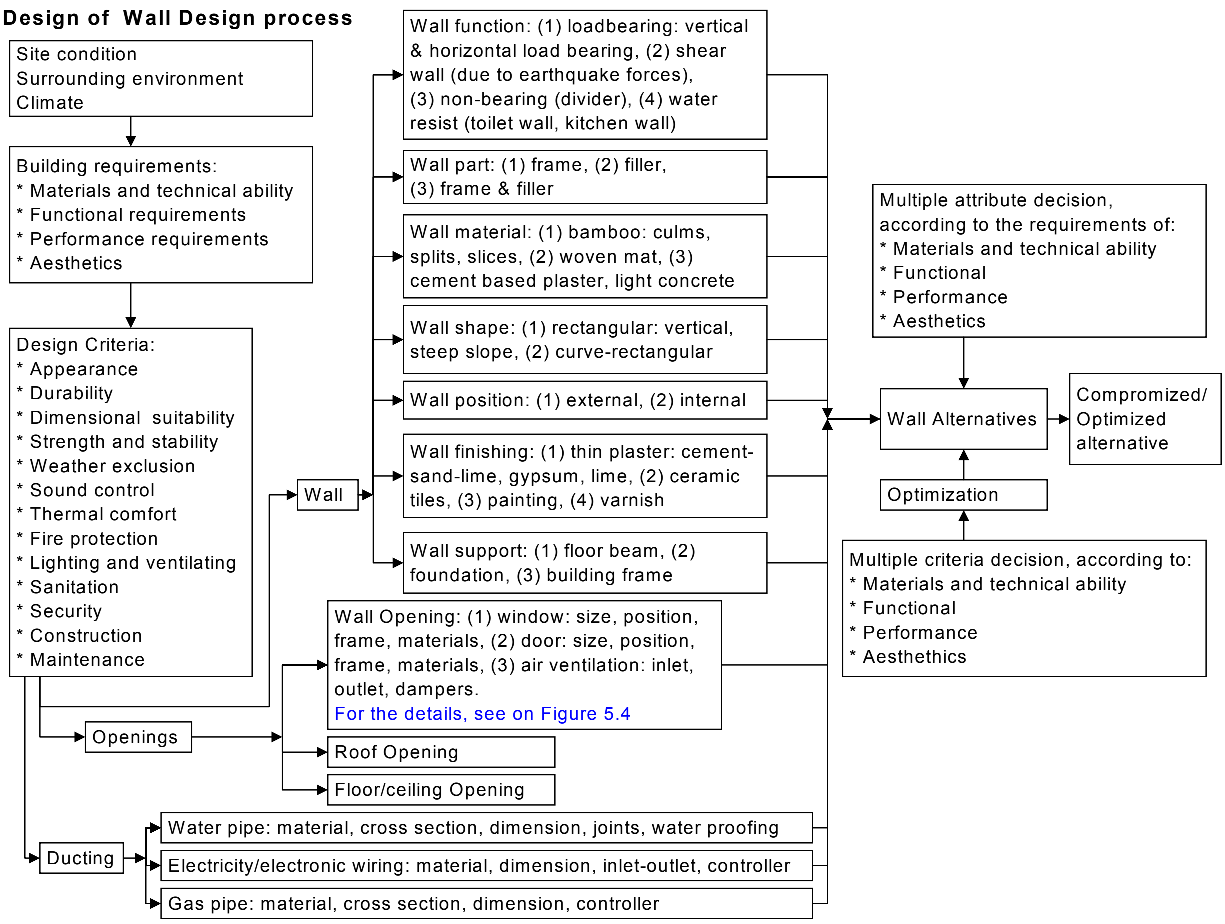

Figure 5.3: **Aspects of a wall design (based on Mardjono, et al., 2001, 2002)**

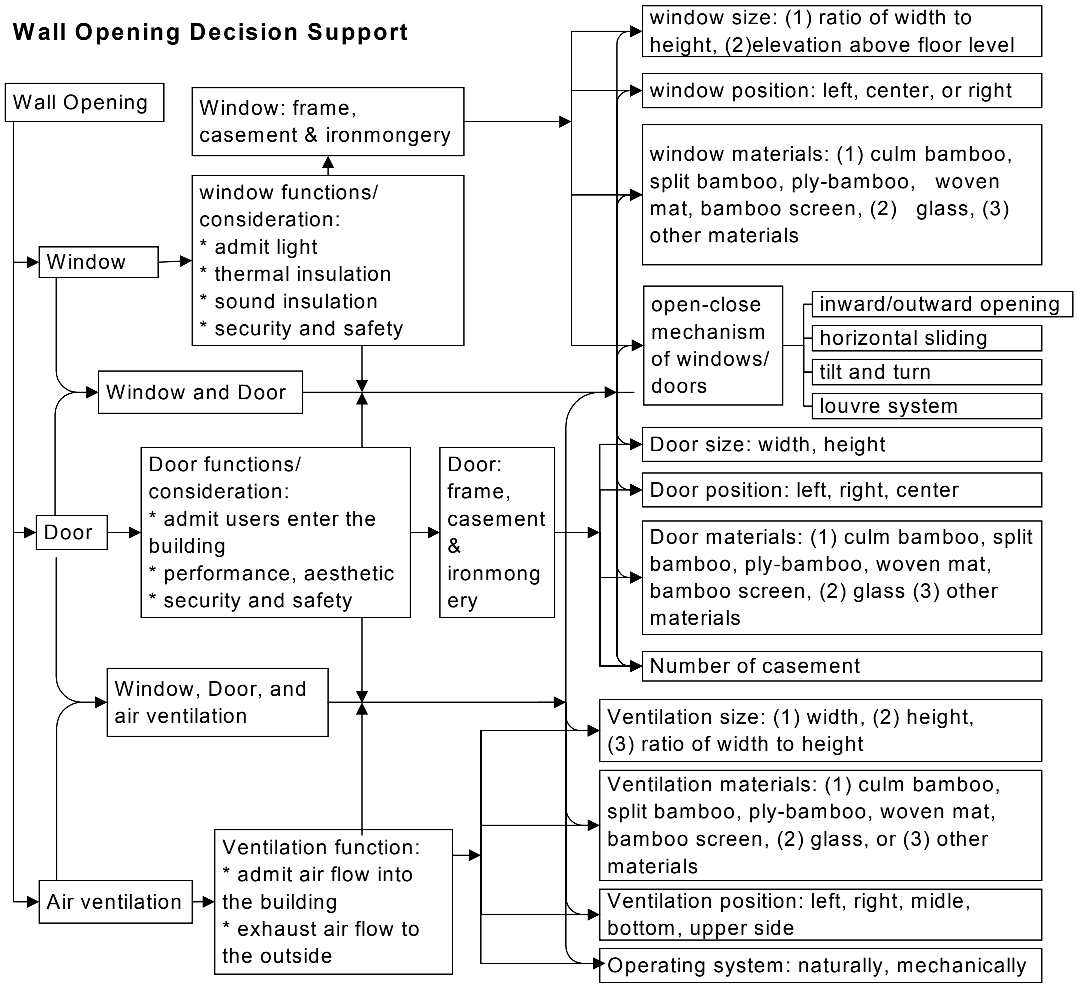

Figure 5.4: **Aspects of the design of wall openings (based on Mardjono, et al., 2001, 2002)**

5.4 **Scope of the prototype**

This partial prototype is meant as an example implementation of the design-decision support tool. The prototype covers the design decision process of a wall, based on the bamboo species available locally in the surrounding location, and the surrounding environment. The main parts of this prototype are the surrounding environment, the wall frame and structure, the wall shape or form, wall openings, wall connections, and wall materials.

5.4.1 *Surrounding environment*

The surrounding environment concerns the climate, such as the temperature and air humidity, the elevation of the building site, the rain intensity, and any natural disasters occurring in that area. The databases of the surrounding environment contain:

1. City name as a string attribute.
   This attribute has other attributes, such as elevation, type of natural disaster, average temperature that can be characterised by a monthly mean and a daily variation, and wind speed. The natural wind is turbulent and its mean speed varies with the height from the ground. The vertical profiles of wind speed and the turbulence characteristics vary with the stability of the atmosphere and the roughness of the terrain over which the wind is passing. Local topographical features such as hills and valleys can also affect wind profiles. All that we will consider here is the variation of mean wind speed with height (see Figure 5.5)
2. Bamboo species and their specification.
   These attributes are the local bamboo name (vernacular name), the botanical name, the average bamboo diameter, internodal length, and the thickness of the bamboo skin (see Figure 5.6).
   The surrounding environment and bamboo databases are needed in the design process to provide a design that fits with the surroundings and that utilises the local sources of bamboo as building materials.

Botanical_Name3 | Botanical_Name | Bracing_Structure | Botanical_Name4 | City

Instance Properties

	Value	Altitude_1	Earthquake_Zone	Teks	Nat_Disaster
1	Banda Aceh	100	I	Mass Acceleration should be taken at least 0.15	B
2	Padang	150	I	Mass Acceleration should be taken at least 0.15	B
3	Medan	50	I	Mass Acceleration should be taken at least 0.15	B
4	Pekan Baru	50	I	Mass Acceleration should be taken at least 0.15	B
5	Bengkulu	200	I	Mass Acceleration should be taken at least 0.15	B
6	Jambi	100	I	Mass Acceleration should be taken at least 0.15	B
7	Palembang	150	II	Mass Acceleration should be taken at least 0.10	B
8	Bandar Lampung	150	I	Mass Acceleration should be taken at least 0.15	B
9	Jakarta	50	II	Mass Acceleration should be taken at least 0.10	D
10	Bandung	550	I	Mass Acceleration should be taken at least 0.15	A
11	Semarang	50	II	Mass Acceleration should be taken at least 0.10	A
12	Yogyakarta	100	I	Mass Acceleration should be taken at least 0.15	A
13	Surabaya	50	II	Mass Acceleration should be taken at least 0.10	D
14	Pontianak	100	III	Mass Acceleration should be taken at least 0.08	C
15	Palangkaraya	200	III	Mass Acceleration should be taken at least 0.08	C
16	Banjarmasin	100	III	Mass Acceleration should be taken at least 0.08	C
17	Samarinda	150	III	Mass Acceleration should be taken at least 0.08	C
18	Denpasar	50	I	Mass Acceleration should be taken at least 0.15	A
19	Mataram	50	I	Mass Acceleration should be taken at least 0.15	B
20	Kupang	150	II	Mass Acceleration should be taken at least 0.10	B
21	Manado	50	I	Mass Acceleration should be taken at least 0.15	D
22	Palu	100	I	Mass Acceleration should be taken at least 0.15	D
23	Makasar	75	I	Mass Acceleration should be taken at least 0.15	D
24	Kendari	150	I	Mass Acceleration should be taken at least 0.15	B
25	Ambon	50	I	Mass Acceleration should be taken at least 0.15	B
26	Jayapura	150	I	Mass Acceleration should be taken at least 0.15	D

Figure 5.5: **Some characteristics of some cities**

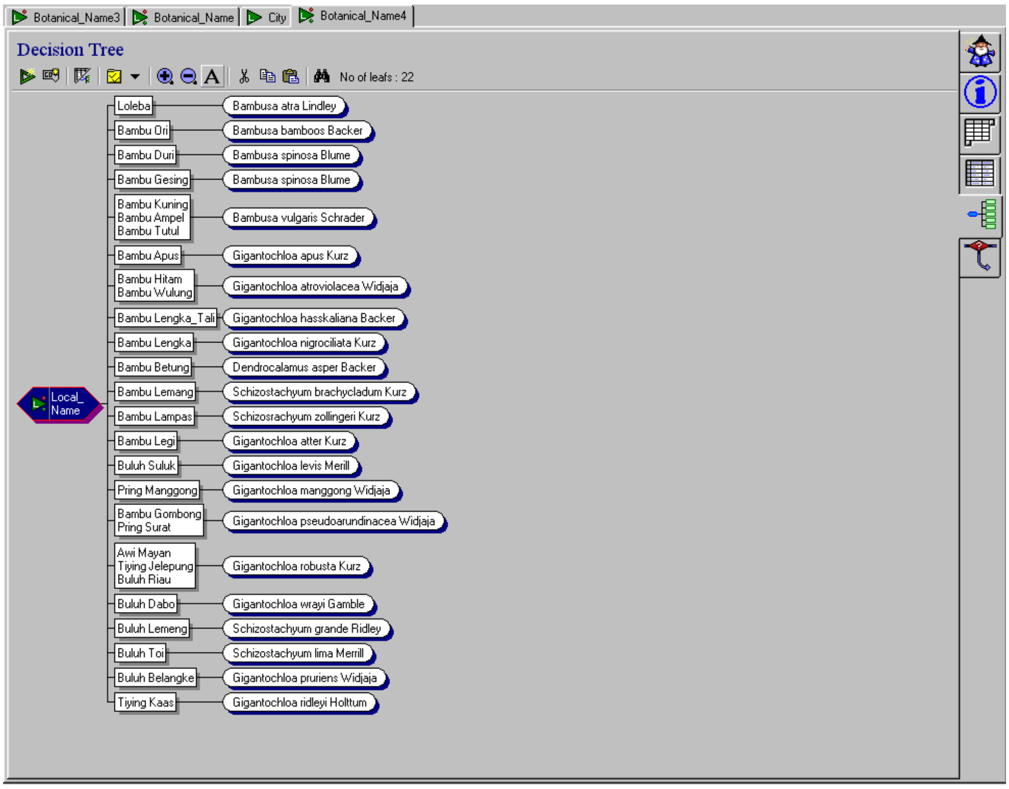

Figure 5.6: **Local and Botanical names of bamboo species**

5.4.2 Wall frame and structure

The choice of wall frame involves a decision process or selection of the type of wall load and the wall frame. Depending on the wall load, it can be described as a load bearing wall or non-load bearing wall. A load bearing wall is one where the wall has to carry its own weight and other wall loads, such as wind loads, earthquake loads, and other loads and forces that are placed on the wall. A non-load bearing wall is one where the wall only carries its own weight, and small loads that are too insignificant to be calculated. In addition to these two definitions, a wall can also be identified as a frame structure and a monolith structure. A frame structure is used to specify a non-rigid wall system, while the monolith structure specifies a rigid wall. These labels can of course be based on assumptions such as using single materials and connection types. If we use a pin connection, we may say that the connection is a simple joint and it will be assumed to be a wall frame. If we use a steel plate and bolts with cement mortar as the wall filler, however, we could define the wall as both a rigid and monolith wall.

5.4.3 Wall shape or form

The wall form can be based on its surface condition, i.e. flat plate wall, arch 2D wall, or arch 3D wall. Selecting an arch 2D or 3D wall may result in a different wall frame.

5.4.4 Wall opening

Wall opening will depend on the wall material, building layout, types of openings, and position of the openings. For a door, it depends on its site, door side, and the opening-closing mechanism.

5.4.5 Wall connection

A wall connection is the connection between two parts of wall, or the connection between a wall filler and a wall frame, the connection between a wall part and other building parts, such as a beam-column, floor, foundation, or wall frame. The characteristics of a connection material can be described as follows:

1. Ropes (natural fibres, steel wire, synthetic fibres) are use to bind and to minimise the distance between two elements.
2. Pins/dowels/pegs are used to carry shear and compression forces.
3. Bolts can carry shear, compression and tension forces.
4. Glue can be used to bond two surfaces and as a forces mediator.
5. Plate is used to distribute a member’s force in a joint, and also has a function as a forces mediator and to strengthen the joint.
6. Steel rings are used to reduce the splitting of culm bamboo.
7. Wood, bamboo, ply bamboo, steel plate, and plywood can be used as force mediators and as sealers or fillers.
8. "Horn" and notch can be used to carry the shear force and perpendicular movement of a member.

5.4.6 Wall material

Materials that can be used for a wall have an important function in the design process of the wall. There are many possible ways of using bamboo as a wall material, such as:

1. Full culm,
2. Half culm,
3. Flat, woven flat,
4. Split, woven split, laminated split,
5. Slices, woven sliced mat, ply-mat,
6. Bamboo reinforced cement mortar,
7. Bamboo reinforced clay soil.

These materials can be applied in wall parts as: wall-covers, wall-filler, wall-frame, opening-covers, opening-frame and opening-cover frames. But selecting the material will influence the wall shape/form, so this will be used as a consideration in the material decision process.

5.5 **Components of the partial prototype**

The prototype has four components, i.e. the user interface, the databases and database management, the rule bases and knowledge management, and an inference engine.

5.5.1 User interface
The user interface is a window that is displayed on the monitor; it captures the user input, shows the results and guides the user through the programme. The most important function of this interface is to make a link between the database programme and the user.

5.5.2 Databases and database management
The database and database management are used to support data transactions between the user of the programme and the databases. The programme developer will manage the databases built in the programme. This data is placed in the tool, its location being based on each attribute.

5.5.3 Rule bases and knowledgebase management
Rule-bases and knowledge management should contain the user's needs and requirements, and allow data transaction between the user and the designer. These rules can be translated into the decision tree or into a cases tables.

5.5.4 Inference engine

5.6 Build the prototype of the wall design decision support tool

The prototype of the wall design decision can be constructed based on the design requirements, design scopes, and formats of the prototype.

5.6.1 General requirements for bamboo buildings
Problems of the bamboo building may arise from the building material, the environment surrounding the building, the building layout, and building parts. To solve these problems we may need information from the user, building standards, and also from scientific knowledge related to the problems. This information can then be discussed to make judgements during the design. We may justify certain things during the judgement process, and this may be followed by an evaluation and selection process. When decisions have been made, the discussion should be stopped and the information related to these decisions should be used as new input in the next step of the design process.

In the earlier stages of the design process we may start with general issues of the building layout. We assume that we are given information about the building layout and cross section in the earlier stages. We may then start to describe new issues or problems related to the design of building parts, such as the foundations, frame structure, walls, beams, floors, roofs, and also other non-structural building parts such as openings, doors, windows, stairs, ceilings, plumbing, and finishing. During the process we may need information about the non-structural building parts.

5.6.2 Requirements for wall design in general

We should consider the design requirements and select which information can be used as a specification, criterion, or argument. Discussions about wall alternatives should be based on this information. We may also formulate the consequences of choosing or selecting each alternative. In the previous step we may not make a decision about which alternative will be chosen, but we may use an option if we choose an alternative. When we make a decision with an alternative solution, the information related to the consequences of choosing or selecting the alternative should be used in the next stage of design process, i.e. the design process of the wall structure. If during the design process of the wall structure there is no match between the openings and the wall requirements, we can provide new information or arguments related to the openings, and may go back to the openings process to find an alternative which does match the requirements for walls and openings.

This information that can be used to identify problems or to make solutions for the problems, can be described as follows:

1. From the building standard we are given the requirement for openings for a room in relation to the thermal or humidity comfort criteria in a tropical country, e.g. the size of openings should be more than 1/20 area of the room. We may use this criterion to determine the size of the openings.
2. From the building standard we are given the requirement for the light condition inside the room, and for a natural day-light system we are given the criteria of the minimal size of wall opening for the sunlight to pass through the room. These criteria can be fulfilled using the existing openings, or we may use glass as a window material.
3. The need for natural airflow inside the room may be fulfilled using the mechanism of openings in the wall, and also the position of openings that can create the natural airflow inside the room.
4. The need for openings can be fulfilled windows and also by opening mechanisms for windows during the day.
5. If the need for a natural airflow system cannot be fulfilled by the openings, we may decide to use a mechanical airflow system that may have different criteria.
6. The structure of openings may use the same material as the wall structure.
7. Openings in the wall may consist of windows and doors, so the frame of the openings is the same as the frame of the windows and doors.
8. The wall itself has requirements that may not match with the information about the openings. If this happens we may use a judgement during the design process.
9. Since the openings may let in rainwater, we need to determine where the openings should be, or we may anticipate this with the openings mechanism.

This information should be discussed in the design process. It can be categorised as a specification, solution, criterion, or argument. The information may just be used as information for the openings themselves, but may also be used for the design process of other building parts. So, in the process of design we should select which information belongs to the openings design process and which information belongs to both the openings design process and other design processes.

This design process is interrelated with the design process of the wall structure, so the process cycles may concern both the openings and wall structure simultaneously.

5.6.3 Rule bases for the wall design

Rules for the wall design decision-making can be collected from several sources such as books and bamboo building traditions. The rules provided can include rules for the surrounding environment, local bamboo species, wall types, wall covers, wall frames, wall connections, and wall materials.

As an example, rule bases for the surrounding environment can be described as follows:

a. If the bamboo building is located in a tropical country then the temperature depends on the elevation of the building. For every additional elevation of 100 m, the average temperature decreases by 1° C.
b. If the bamboo building is located in an earthquake area then
    - Primary suggestion is to select lightweight material.
    - Wall frame should be reinforced using diagonal members.
    - Suggest using uniform material.
c. If the bamboo building is located in an area with strong winds then
    - Primary suggestion is to select heavyweight material.
    - Wall frame should be reinforced using diagonal members.
    - A strong anchor/joint is needed for each building part.
d. If the bamboo building is located in a high intensity rainfall area then
    - Use a steeply sloping roof to drain rainwater quickly, but if there are also strong winds then use less sloped roof.
    - Use enough distance between floor elevation and the ground surface.
    - Use water-resistant material for the exterior wall, but if there is an overhanging roof, this water-resistant wall may be lower than if there is no overhanging roof.
    - Use water-resist material for the roof covering.
e. If building is located at seaside then
    - Assume there is strong wind.
    - If there is a flood then use a platform floor type, and assume that the soil is weak so you may use full culm bamboo as piles for the building foundation.
    - Do not use corrosive materials.
f. If there is local bamboo species then
    - Use the local bamboo species appropriate for the building parts.

- Use the local method of bamboo preservation if it exists.
- Consider making the bamboo building with local tools and local techniques.
- You get the cheapest bamboo building if you use local materials and local technology.

g. If there is no local bamboo species then
- Try to find a bamboo species that exists near to that location, if it doesn't exist nearby try to find a bamboo species in this country, and if this country doesn't have a bamboo species then you should find out which bamboo species its neighbouring country has.
- Use bamboo products such as ply-bamboo or ply-mat board.

We would like to draw the reader’s attention to the *if-then-else* structure. Similar rules should be developed for bamboo species, wall types, wall frames, wall covers, etc.

Table 5.1: **Utilisation of bamboo for walls**

	Wall		Wall Opening			
	Covers	Frame	Filler	Covers	Frame	Covers frame
Full culm	ok	ok	-	-	ok	ok
Half culm	ok	ok	-	ok	ok	ok
Flat	ok	-	-	ok, but less common	-	-
Woven flat	ok	-	-	ok, but less common	-	-
Split	ok	-	-	ok	-	-
Woven split	ok, might need filler	-	-	ok	-	-
Laminated split	ok	ok, with special section	-	ok	ok, with special section	ok, with special section
Woven sliced mat	ok	-	-	ok	-	-
Ply-sliced mat	ok	ok, with special section	-	ok	ok, with special section	ok, with special section
Bamboo reinforced cement mortar	ok	bamboo as temporary frame	cement mortar	-	-	-
Bamboo reinforced clay soil	ok	bamboo as temporary frame	clay soil	-	-	-

Table 5.1 is an example of a table which helps to select wall materials. After we have selected the material, we should decide about the formation of the material in the wall as follows:

a. One frame and one layer of covering layer,
b. One frame and two layers of covering layer,
c. Two frames and one layer of covering layer.

Table 5.2 shows performance of wall materials due to condition, such as weather, water, sound, and fire resistance.

Table 5.2: **Performance of wall materials**

	Weather resistance	Water resistance	Sound resistance	Fire resistance
Full culm	Fair	fair	fair	fair
Half culm	Fair	fair	fair	fair
Flat	Fair	bad	bad	bad
Woven flat	fair	bad	bad	bad
Split	fair	bad	bad	bad
Woven split	fair	fair	fair	bad
Laminated split	good	good	good	fair
Woven sliced mat	fair	fair	fair	Bad
ply-sliced mat	good	good	good	fair
Bamboo reinforced cement mortar	good	good	good	good
Bamboo reinforced clay soil	fair	bad	good	good

5.6.4 Implementation of the wall design decision in the prototype

The main purpose of the prototype is to support the designers by providing information. To do this the prototype contains a specific format for each decision, i.e. background, making a decision, considerations before making a decision, and consequences of the decision. When the consequences of several decisions are known, the tool shows these results to the user. The tool has a user interface to give explanations about these specific formats to the user. Several examples of these design decision processes can be explained as follows:

1. Frame Decision process

   Background information

   In the design process of a wall frame, you may first select the type of frame structure. You should know the wall characteristics beforehand.

Decision

In this decision process you should basically determine the loads that will be applied to the wall. There are usually two types of wall, i.e. non-load bearing walls and load bearing walls. Non-load bearing walls can be defined as walls that only carry their own load. Bearing walls can be defined as walls that carry all kinds of loads that are placed on them. Actually you do not need these two categories to determine the wall frame, since even if you select a non-load bearing wall, you must consider the stability and stiffness of the wall. The differences between these two types of wall are the direction of the loads and their magnitudes. For non-load bearing walls, the loads come from their own weight and other things attached to them, and there are no external forces. You should therefore determine the characteristics of the loads. Since the wall usually has a vertical flat surface, and since its depth is smaller than its surface size, the stability of a wall will depend on the loads that are perpendicular to the wall surface. What you should decide is whether:

a. The axial load is dominant
b. The perpendicular load is dominant
c. The axial load and perpendicular load are dominant

Considerations and Consequences

If the axial load is dominant, you can easily manage the wall stability. If the perpendicular load is dominant, however, you will need to determine the depth of the wall, or you will need a wall support in the load direction to reduce deformation and to maintain the stability. It is easier to manage the stability and deformation if both the axial load and perpendicular load are dominant.

1.a. The axial load is dominant

Background information

If the axial load is dominant, the wall frame will be simple. In this case the frame pattern will usually depend on the wall-shape and also the wall-filler material, rather than on its weight.

Decision

In this case you should determine the frame pattern. The wall-frame pattern will basically contain members in the horizontal and vertical direction; if you think the frame will be unstable, you can add diagonal members. This frame is considered to provide stiffer and more stable walls. (See Figure 5.7)

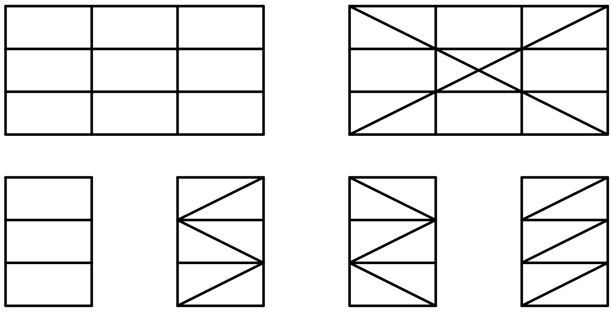

Figure 5.7: **Typical frames for a wall structure**

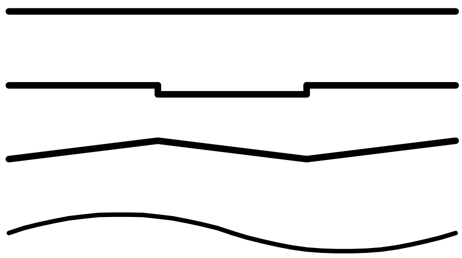

Figure 5.8: **Typical forms of a bamboo wall**

If you use curved wall, your frame should follow this shape. Using a curved wall will usually provide a more stable wall (see Figure 5.8). The distance between two horizontal members or between two vertical members will depend on the wall-filler material. If you use bamboo matting, its weight will not be dominant, but the deformation will be, so you need to use smaller distances. If you use half culm bamboo, its weight will be more dominant than the deformation.

Considerations and Consequences

If you select a curved shape this will influence the frame material: you could not use full culm or half culm bamboo with a large diameter since it would be very difficult to bend it. In such a case we suggest the use of split bamboo or laminated split bamboo, or steel.

For cases 1b and 1c we can give similar considerations and similar text.

2. Design process for a wall connection

   We can continue to design a connection after we have determined the wall structure, wall material, wall form/shape, or wall openings. Generally, there are four types of connection, i.e. (a) a connection between wall-filler members, (b) a connection between wall filler and wall frame, (c) a connection between wall-frame members, and (d) a connection between a wall frame and other building part as shown in Figure 5.9.

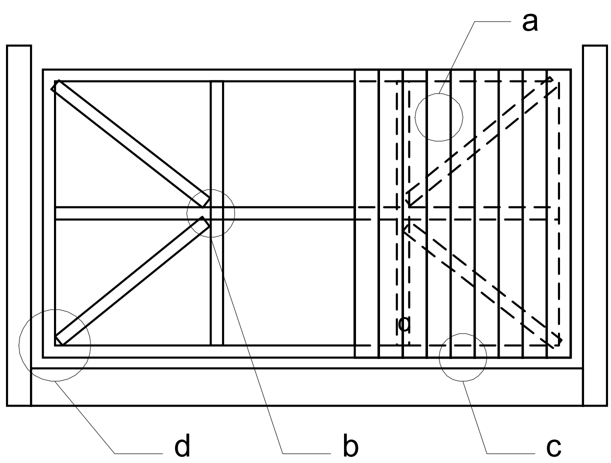

Figure 5.9: **Types of connections on the wall**

The designer is free to select from those 4 types, but we suggest starting with a connection between wall-filler members. We only need a connection between wall-filler members if we use bamboo split, half culm bamboo, woven mat, or bamboo board. This connection can be categorised as a two-dimensional connection. The need for a connection depends on the wall shape/form. The connection type *b*, *c*, or *d* can be categorised as a structural connection.

Connections between wall-filler members (as shown in Figure 5.10) can be determined to provide a smooth wall-shape/form. We need this connection if we want to avoid the gap between members of wall-filler. No connection is needed if we use bamboo-reinforced cement mortar as a wall-filler.

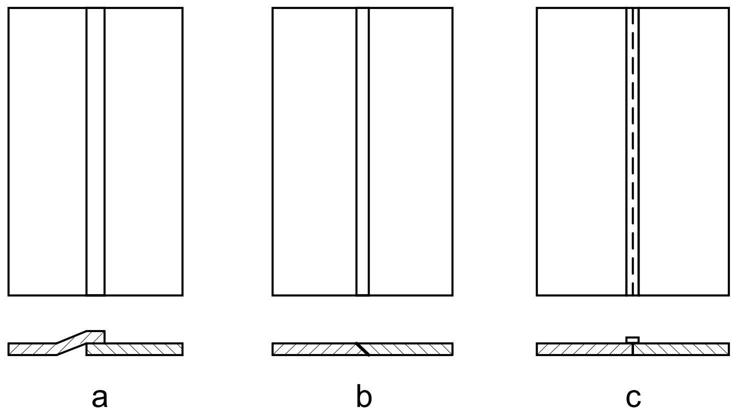

Figure 5.10: **Connection between wall-fillers**

Connection types between wall fillers are (a) an overlapping connection, (b) a tongue and groove connection, and (c) a connection using filler. For an overlapping connection with woven matting as the wall filler, rope can be used as the connection material; nails can be used if we use ply-bamboo or laminated-bamboo board. We can also use a tongue and groove connection if we want to provide a smooth wall surface. We can make a connection without filler if both wall-filler members are of the same thickness, otherwise we need another filler.

A connection between wall-frame members is needed in order to provide frame stability and frame stiffness. This connection can be categorised as a two-dimensional connection. It can be one of three types, i.e. a corner connection, a side connection, or a general connection.

This is demonstrated in a separate partial prototype with graphical user-interface, and is illustrated with images, scheme diagrams, photographs and drawings (provided from literature).

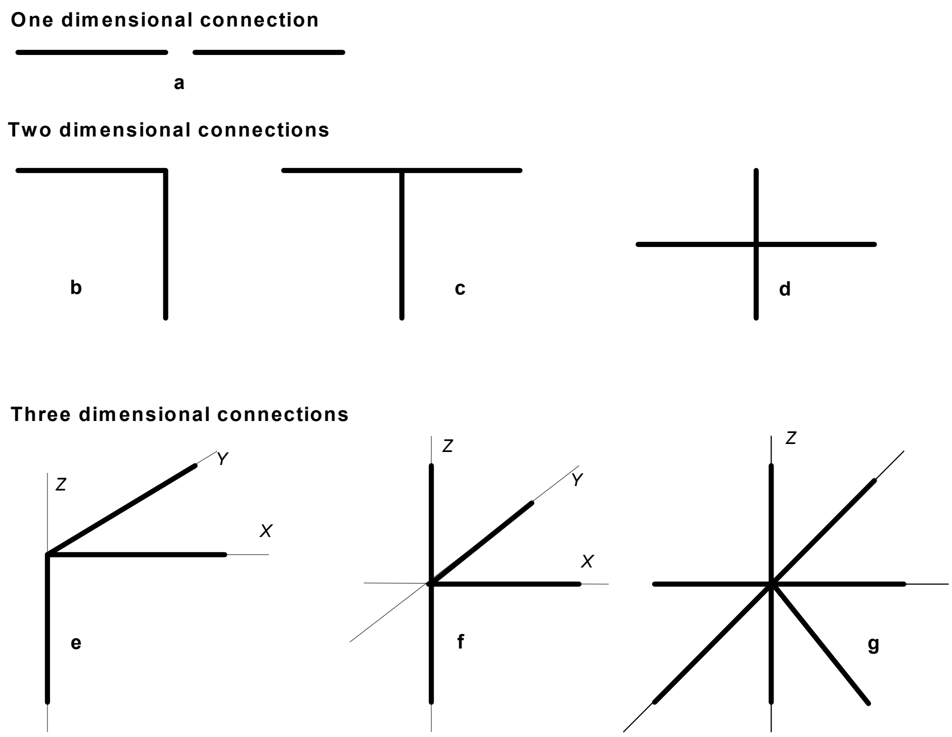

Figure 5.11: **Connection types for a wall**

An extension connection is used to provide a longer member. In this case the two members may have the same dimensions or different dimensions. A corner connection can have more than two members. The type and connection material depend on the dimension and material of the members. You may need an interface to connect all members at a joint. A general connection may also have more than two members in different directions.

A connection between a wall-frame and another building part is needed to transfer the wall loads and forces to the other building part, and finally to transfer these loads to the foundations. The connection may be categorised as a two or three-dimensional connection as shown in Figure 5.11. For a three-dimensional connection, the connection may be a side or joint connection.

5.7 **Integration of wall components**

At the end of the wall-design process, the prototype will analyse whether all decision stages that have been made in the previous stages are matched together. If not, the prototype will give comments on those decisions. The prototype also detects interdependencies of the wall parts. For example, a connection is dependent on the materials and structure, and it is not dependent on openings. If we start with the materials decision process, this may have an impact on the limitation of the shape/form, structure and connections. In this case, structure and connection decision-making processes depend on the decision process of the shape and material. So, if we want to start with the structure or connector decision process, it will depend on the decision process of the shape and material, that will be proceed in the coming decision process. But if the shape and material decision processes are done after the structure decision process, we would have to use these considerations during each decision process for the structure. The user therefore still has the freedom to start the design at any stage.

5.8 **Remarks on Chapter 5**

We have discussed the selection process of choosing a developer programme and the implementation of the design decision support tool in the form of a partial prototype of a wall. This prototype will be verified and validated to find an appropriate prototype, so that the complete prototype for a bamboo building can be built later on in a similar way. In chapter 6 we will discuss this verification and validation.

Chapter 6

VERIFICATION, VALIDATION AND TESTING OF THE TOOL

This chapter deals with the verification and validation of the partial prototype of the tool presented in Chapter 5. It starts with description of the verification and validation, and the results from the try-out at the International Bamboo Housing Workshop in Mizoram, India, in November 2001.

Let us now discuss the main structure of the computer programme containing the partial prototype of the tool, shown in Figure 6.1. This structure is only visible to the tool-developer. The user of the tool is free to select any starting point in the design process. When the programme is running, the main menu as seen in Figure 6.2 is displayed. The user can determine her own path through the design-process with the help of this menu. While the programme is running, the user can check whether she is satisfied with the results of decisions made during the programme, and can go to the next decision in the process if she is happy with her design result, or return to the previous steps if she is not. In order to verify and validate the prototype, we first have to define the terms verification and validation, and then propose a method suitable for our prototype.

6.1 Definition of the terms verification and validation

According to Bahill (1991), the terms verification and validation are usually used differently by different people. It is therefore important to define the terms explicitly. In expert systems, verification means "building the system right", that is, ensuring that it implements the specifications correctly. Verification is therefore meant to ensure the completeness, consistency, and correctness of the syntax, rules and data in the tool; this is done by correcting the knowledge contents in the tool. Validation means "building the right system", that is, writing specifications and checking performance to make sure that the system does what it is supposed to do. Validation is the process of assuring the compliance performance of the tool based on it requirements and needs. In other words, validation checks the rules and knowledge management of the tool.

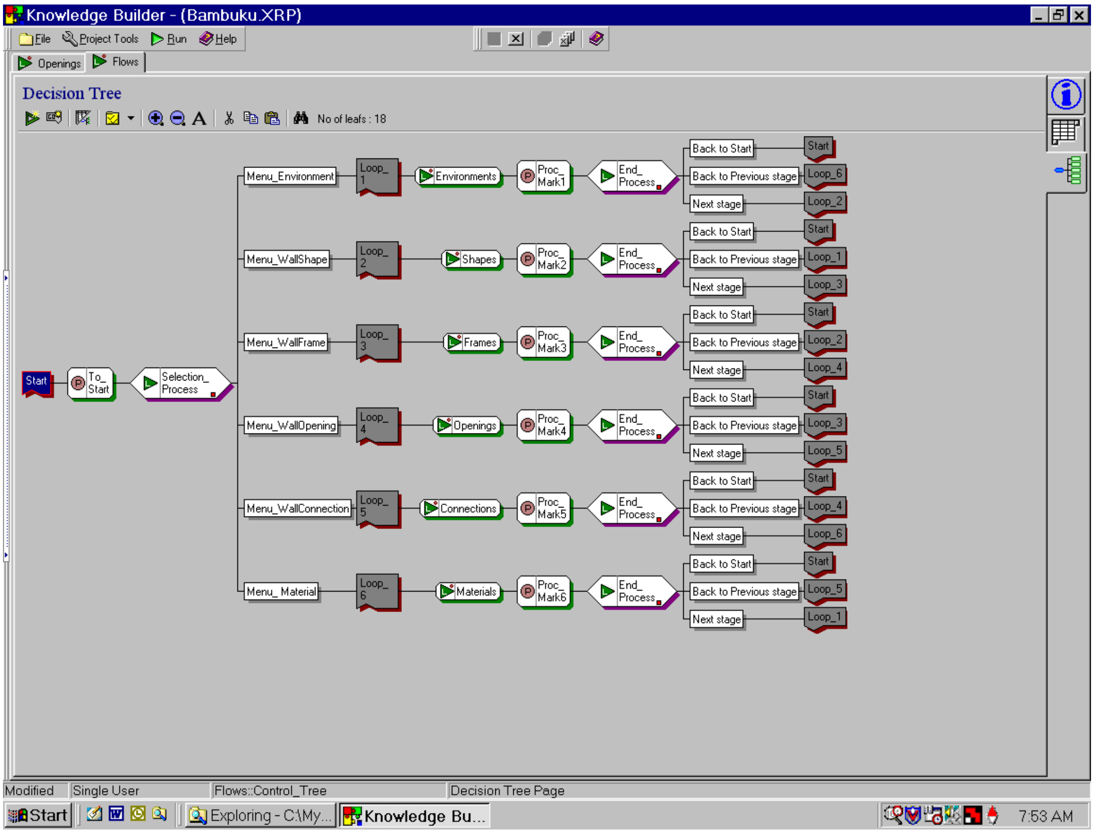

Figure 6.1: **Main structure of the decision support tool**

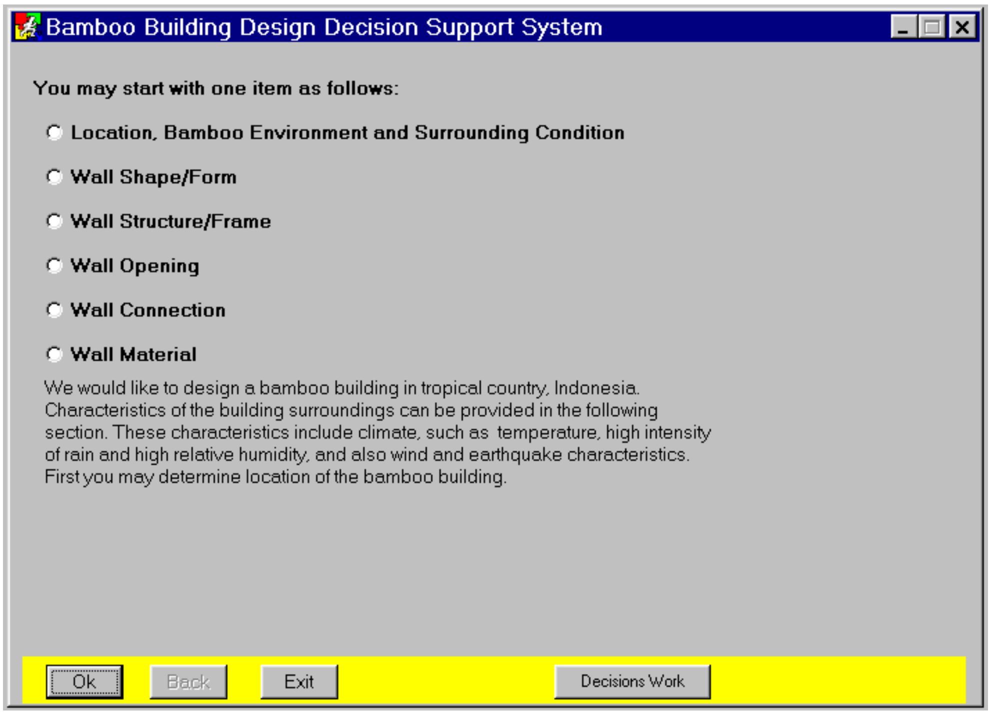

Figure 6.2: **The user interface of the tool**

Testing means running test cases on the system to see if it emulates input-output actions. Verification is usually done first, then validation, and finally testing. After verification is complete, validation can begin. Even after we have completed verification and validation, the tool may still suffer from unsatisfactory performance due to a lack of user-interfaces or incomplete and unclear requirement specifications. So, after the prototype has been verified and validated, it should be tested by a group of prospective users. The main goal of these processes is to improve the tool and to increase the user's confidence in using the prototype and eventually in using the final tool.

Before we verify, validate, and test the tool, we have to clarify some questions, such as (1) How do we determine parameters to be used in those processes (knowledge contents, knowledge hierarchical patterns, and applied strategy for building the tool), and (2) How to continue with the processes in a systematic way. The answers to these questions may depend on the process and models that are used during the construction process of the tool. As we discussed in Chapters 4 and 5, we built the tool based on the conceptual modelling IDEFØ for bamboo building, applying decision-making processes provided from the programme developer (*"XpertRule Knowledge Builder"*), and using facilities available in the programme developer. So the verification of the tool consists of proving the knowledge contents that are used in the tool, and proof-reading results provided when we run the tool (in terms of completeness, consistency and correctness); the validation is meant to make it plausible that users find the tool useful and supporting. The verification of the tool should be done by analysing the knowledge contents and their hierarchy in the tool that are represented in a diagram, as seen in Figures 5.3 and 5.4 in Chapter 5. The validation is done by checking probable syntax errors when we run the tool. This means checking the rules, knowledge management and the decision-making process of the tool. The last task is allowing the prospective users to test the tool and analyse their comments and suggestions. The test was done at the International Bamboo Housing Workshop in Mizoram, India, in November 2001.

6.2 **Verification of the tool**

The process of verification starts by checking the knowledge contents and the hierarchy patterns applied in the tool, then analysing the design-decision making of the tool. To carry out these tasks, we use Wets' approach to verification. Wets uses the idea of verifying knowledge contents in decision tables. Wets (1998), who also refers to Lucardie (1994) gives the following explanation about verification:

> "… verification of the DTs (Decision Tables) 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 differs, 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…". (based on Lucardie 1994)

It would be difficult for us to use Wets' approach in our verification process, since we did not build the tool based on the decision tables. In fact, we did the verification of the tool afterwards, that is, by building the decision tables based on the knowledge contents and checking whether these decision tables perform indications of some factors such as consistency, completeness, and correctness.

A theory about DT can be found in Lucardie (1994), Wets (1998) and Witlox (1998), and is described as follows:

> "…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).

A representation of a DT can be seen in Figure 6.3.

Abstract	
Conditions	Values of the conditions
Actions	Values of the actions

Figure 6.3: **Representation of a DT (based on Lucardie 1994)**

According to Wets (1998), a decision table is consistent if no columns in the DT exist for which the condition part intersects while the action part differs; a decision table in the DT is exclusive if at least one element of the condition part in a column does not intersect with the corresponding element in the condition part of another column; and a decision table is complete if every *condition entry (CE)* is included in the DT and for each combination of condition values at least one action is specified.

Due to time limitations, we only performed the verification-process of the tool for "showing images of detail connections". We assume the verification of other parts in the tool can be done in a similar way. The "showing images" is a sub-programme, and represents a small part of the decision-making in the tool. The results of the decision-making in this part consist of images and explanations about them; these results will be shown if the connection criteria given by the user match with decision-making properties stated in the tool. If the result exists, this means it is possible to make the connection based on required criteria called *"conditions"*, such as connection type, connection form, member material, connection forces, connection filler and connection material. Each *"condition"* in this decision process has certain values, and the combination of each value from each *"condition"* will determine whether the connection exists or whether it is possible to make it. In this decision process there will be two actions, i.e. proving the existence of the connection, and showing the image (the connection will be shown if it exists). Since we found that there are certain number of values in each *"condition"*, the number of columns grows rapidly, and will cause difficulties in making a table. We therefore propose using sub-tables as representations of relations or combinations between two or more existing *"conditions"*. In each sub-table there will be sub-actions to be carried out. We have to determine values for the sub-actions and a meaning for each value. The values of each sub-action are "X", "-", or ".", meaning "the action has to be executed", "the action should not be executed", and "the action is unknown", respectively. Since the final actions contain two related actions, the sub-action will only contain one action, i.e. "Proceed existence of the relationship between *conditions*" in the sub-table. The action in a sub-table will become a *"condition"* in the next sub-table, and the value of this action will be a value of its condition. If the sub-action value is "-" or ".", this value will not appear in the next sub-table, since a combination of condition with this value is not possible and it will therefore be deleted.

It is true that the decision-making in the *"XpertRule Knowledge Builder"* is not based on this type of DT's, but is based on decision trees, or cases tables. A cases table is usually used as a representation of decision cases. For example, there are two attributes of knowledge, and each attribute has three and four values, respectively. If we construct possible combinations of these two attributes in a table, we will get 12 probable possibilities, in which each possible result can be "determinate", "indeterminate", or "unknown". If it is "determinate", it means that it has a proper result; if it is "indeterminate", it means that there is no proper result; if it is "unknown", it means that there is an impossible result. These terms of possible results are analogues to "the action has to be executed", "the action should not be executed", and "the action is unknown" as in the DT's. The knowledge contents in the result of a decision-making will only be consistent, exhaustive etc. if the result is "determinate". A cases table in *"XpertRule Knowledge Builder"* is usually used to construct a decision tree when we start to build a knowledge module programme. If we do not know all values of the attributes, this built decision tree may be useful in the following decision-making process in the knowledge module programme. We can revise this decision tree based on the new or latest attribute values. In this situation, a cases table is just an instant way of building a decision tree.

If we already have complete attribute values, then it may be better to build a decision tree directly. Decision trees give us an advantage, that is, we can add procedures before or after we trigger an attribute value. This procedure may contain rules and/or a calculation sub-programme. These rules will affect the results of the decision-making process.

Let us now look at the attributes of the connection and their values as seen in Table 6.1. The attribute name is shown in the first column, and the following columns represent its values. The decision-making process can be represented as a relationship between the attributes values, and it can be deployed into DTs. We also have to determine a sequence in the attributes. This determination of rank does not produce different numbers of possible-relationships, however, in practice, it will reduce the time needed to develop the tool. The easiest way to deploy the relationships between the attributes is to follow the decision-making activities on the lowest levels of the tool. The verification of this sub-programme should therefore be done by analysing the relationships between those attribute values that are represented in the DTs.

Table 6.1: **Attributes of connections and their values**

Connection Type	One Dimension	Two Dimensions	Three Dimensions				
Connection Form	I	II	III				
Members 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	Cement Mortar		
Connection Material	Wood pin OR bamboo pin	Steel bolt	Natural ropes	Glue	Nail	Combina-tion	
Structure type	Truss structure	Frame structure					

For example, Table 6.2 (sub-table 1) only represents the relationship between *"connection type"* and *"connection form"*. In this table the values of the actions are identified as results using identification numbers 1.1, 1.2, ..., 1.7, respectively. When we want to work out a relationship between *"connection type and connection form"* and *"connection material"*, we will provide sub-tables as shown in Table 6.3. The remaining relationships with *"connection forces"*, *"connection filler"*, *"connection material"*, and *"type of structure"* can be done in a similar way, as shown in Appendix C.

Table 6.2: **Decision Table for the relationship between "connection type" and "connection form"**

Sub-table 1:

Connection Type	One Dimension			Two Dimensions			Three Dimensions		
Connection Form	I	II	III	I	II	III	I	II	III
Show 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

Table 6.3: **Decision Table for the relationship between "connection type and connection form" and "connection material"**

Sub-table 1.1:

Determined Value:

Connection Type: One Dimension

Connection Form: I

From result	1.1			
Condition of the connection existence from previous sub-table	X			
Member material	Full Culm	Half Culm	Laminated Bamboo	Ply-Bamboo
Show existence of the connection	X	X	X	X
Result	2.1	2.2	2.3	2.4

Sub-table 1.2:

Determined Value:

Connection Type: Two Dimensions

Connection Form: I

From result	1.2			
Condition of the connection existence from previous sub-table	X			
Member material	Full Culm	Half Culm	Laminated Bamboo	Ply-Bamboo
Show existence of the connection	X	X	X	X
Result	2.5	2.6	2.7	2.8

Sub-table 1.3:
Determined Value:
Connection Type: Two Dimensions
Connection Form: II

From result	1.3			
Condition of the connection existence from previous sub-table	X			
Member material	Full Culm	Half Culm	Laminated Bamboo	Ply-Bamboo
Show existence of the connection	X	X	X	X
Result	2.9	2.10	2.11	2.12

Sub-table 1.4:
Determined Value:
Connection Type: Two Dimensions
Connection Form: III

From result	1.4			
Condition of the connection existence from previous sub-table	X			
Member material	Full Culm	Half Culm	Laminated Bamboo	Ply-Bamboo
Show existence of the connection	X	X	X	X
Result	2.13	2.14	2.15	2.16

Sub-table 1.5:
Determined Value:
Connection Type: Three Dimensions
Connection Form: I

From result	1.5			
Condition of the connection existence from previous sub-table	X			
Member material	Full Culm	Half Culm	Laminated Bamboo	Ply-Bamboo
Show existence of the connection	X	-	X	X
Result	2.17		2.18	2.19

Sub-table 1.6:
Determined Value:
Connection Type: Three Dimensions
Connection Form: II

From result	1.6			
Condition of the connection existence from previous sub-table	X			
Member material	Full Culm	Half Culm	Laminated Bamboo	Ply-Bamboo
Show existence of the connection	X	-	X	X
Result	2.20		2.21	2.22

Sub-table 1.7:
Determined Value:
Connection Type: Three Dimensions
Connection Form: III

From result	1.7			
Condition of the connection existence from previous sub-table	X			
Member material	Full Culm	Half Culm	Laminated Bamboo	Ply-Bamboo
Show existence of the connection	X	-	X	X
Result	2.23		2.24	2.25

Looking at those tables and referring to the verification criteria, it seems that the DTs in Table 6.2 and 6.3, and the tables in Appendix C are consistent, exclusive, and complete, because there is no action value "." in those tables. The correctness of the information and knowledge in the sub-programme is checked by comparing the results with resources such as handbooks, building practice, etc.

6.3 **Validation of the tool**

Validation is more complex, since during validation we have to prove that the system that has been built meets the requirements of the user. Actually a system will never completely satisfy the user, nor will it completely dissatisfy the user. We can only detect whether the system contains incompleteness or inconsistencies.

That is why we have to validate the system after the verification process has been completed. Using the theory of IDEFØ to construct the structure of decision support in this process has some advantages, since the relationship between activities (in any chosen sequence of activities) in the design process can be properly determined. Using this scheme we can exactly construct the structure and relations of the design activities in the prototype of the tool through the *"ExpertRule Knowledge Builder"*. When we have built a decision support system with this software that is based on the scheme of design processes of a bamboo building, we can focus the validation of this system on this scheme. We have to prove that the system meets the requirements of the user of this system. Each activity in this system contains design decision tasks that are defined in the prototype. So the validation is to check whether all those decision tasks match with the activities defined in the scheme. This scheme shows the design aspects that are constructed correctly according to the user's requirements. We therefore have to prove that all the decisions can be found in the system, and that the results of the decisions in the system will be as described in the scheme. The DTs were already constructed when we verified the prototype, so we can see all the proofs of the decisions in the DTs. In addition to this proving method, we also tested the prototype to detect whether the results of the decisions satisfy the users. To eliminate any subjectivity of the validation, we used test cases and delivered a questionnaire to the prospective users.

Validation has also to do with the "adequacy of the knowledge". In the case of bamboo wall design, the knowledge is adopted from the existing bamboo building practices, bamboo handbooks and other sources, so we assume that there is no problem with the adequacy of the knowledge. The validation of the knowledge can only be done by experts in the field. So, even if it is difficult to formulate the validation of the knowledge, it can be detected by letting the "prospective users" (in the workshop) test the tool, and asking them about their degree of satisfaction with the knowledge in the tool.

6.4 **Results from try-out at the International Bamboo Housing Workshop**

The partial prototype of the tool was presented at the workshop mentioned above, and participants of the workshop practised using the prototype to help in solving their problems in the design process of bamboo houses. The main purpose of this presentation was to introduce the design tool to the participants, and we assumed that they represented the prospective users of the tool. We gave them the opportunity to test and play with the tool during the workshop. After the participants had tested the prototype, they were given a questionnaire to fill in. The questionnaire (see Appendix D1) contained some background information from the participants and their responses according to the usability, "makability", and friendliness of the prototype. Thirty-six participants tested the prototype. Of those participants, eight persons had an educational background as a building designer or architect, eleven persons had an educational background as a construction worker or bamboo artisan, ten persons were social workers (Non-Governmental Organization or NGO) or motivators in rural areas, and the others came from public offices of various departments of the Mizoram government.

The responses collected from the participants at the workshop were analysed to view their comments and criticisms after testing the prototype. If we look at the questionnaires, they can be grouped into two parts, i.e. user's background (working background, experience in design and construction of bamboo buildings), and their satisfaction with using the prototype. Although this type of questionnaire uses an "ordinal" scale, we treat it as a "metric" scale to allow simple analysis. For example, in question 2 the possible answers for indicating their familiarity with computers are *poor, less than fair, fair, greater than fair,* and *good*. The given values for the possible answers are one, two, three, four and five, respectively.

The complete set of values given for all questions in the questionnaire can be found in Appendix D2. The complete collected data from the answers to the questionnaire can be found in Appendix D3. Those data were then analysed using statistical analysis to find any correlation between the users backgrounds and their level of satisfaction. The last row in Table D3.2 shows the average values for each question. The working background of the user can be grouped into 4 categories, based on the assumption about their understanding of bamboo building design and construction, as follows:

- Group 1 consists of participants who are social workers, NGOs, or public officers. We assume that persons in this category are less familiar with and understand less about bamboo building design
- Group 2 consists of participants working in the bamboo board industry, as a forester, or a product designer. We assume that they are familiar with bamboo but less familiar with bamboo building design.
- Group 3 consists of participants working on the construction of buildings and bamboo artisans. We assume that they are familiar with bamboo and bamboo building construction, but less familiar with bamboo building design.
- Group 4 consists of participants working in building design. We assume that they are familiar with bamboo building design.

The collected results from these groups can be seen in Tables D3.3, D3.4, D3.5, and D3.6. The average value for each question for those four groups can be seen in Table D3.7. If we look at this table, we see that Group 3 has the highest average value for experience in understanding the design and construction of bamboo buildings of all the groups. This means that Group 3 seems to be familiar with bamboo building design and construction. Group 4 scores as highly as Group 3 in the experience of designing a bamboo building, but lower than Group 3 in the experience of constructing a bamboo building. Group 4 also has the highest average value for their familiarity with computers, for the satisfaction with the layout of the user interface of the prototype, and for agreeing that the prototype can improve the quality of design.

If we assume that there is a linear correlation between the participants' backgrounds and their level of satisfaction, we can test the assumption using linear correlation. To prove this assumption we can derive a correlation between the answers to questions from Table D3.2, for all participants. A *"t-test"* on a 5% level gives evidence of a correlation between the following answers:

* their familiarity with computers (a2), and:
  - satisfaction in design process of wall parts (b1)
  - satisfaction in support of design process (b4)
  - experience in architectural design of bamboo building (a3)
* experience in architectural design of bamboo building (a3) and:
  - satisfaction in design process of wall parts (b1)
  - satisfaction in interrelationship elements of wall (b2)
  - improvement of your design due to using prototype (b5)
  - suitability of knowledge for design or construction (b6)
  - experience in bamboo building construction project (a4)
* experience in bamboo building construction project (a4) and:
  - satisfaction in design process of wall parts (b1)
  - satisfaction in interrelationship elements of wall (b2)
  - improvement of your design due to using prototype (b5)
  - suitability of knowledge for design or construction (b6).

Participants feel that the prototype really helps their design processes for bamboo buildings, they are satisfied with the layout of the prototype, and they "agree more than disagree" that the prototype improves the result of the design process. They also gave opinions and suggestions after using the tool. These opinions and suggestions have been used to improve the prototype. As a consequence, a new user interface was made and the textual form of design results was changed into graphical output. 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 it.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

7.1 Conclusions

This thesis presents the development of a bamboo building design decision support tool. Looking back to the aim of this PhD-Project in Chapter 1, the project was concerned with the development of a tool to help the designers of bamboo buildings, especially in the early stages of the design process. Based on the explanation in the earlier chapters, we identified the design issues that can be supported by the tool as follows:

1. Identification of the surrounding conditions, to attain a bamboo building design that matches with its surrounding environment,
2. Considerations and consequences of choices available in the tool, in order to find a harmony between the bamboo building and its surrounding environment,
3. Freedom in starting the design activities, selecting the possibilities, and helping the designer throughout the design process.

Descriptions of the design problems in bamboo buildings, explained in Chapter 2, gave us an overview of the huge problems of the design related to other aspects of bamboo and bamboo buildings; these are covered by the taxonomy of concepts. Those problems served as a background for the partial prototype of the tool. The aspects of bamboo building design activities were taken into account, but the other aspects were also considered, because they influence or interfere with the design activities.

The basic development of the design decision support tool for bamboo buildings is based on knowledge of bamboo, the surrounding conditions of the building site, bamboo species available in the location, user requirements and so on. Its general objectives are to develop an appropriate design decision-support tool, and to implement and apply the appropriate requirements for the tool.

In the practical implementation of the partial prototype, we mainly considered issues of wall design. In this prototype the identified surrounding conditions can help the designer to make a decision during the design process. With the information about the surrounding conditions, the designer can determine the environment of the bamboo building in order to fit in with the surrounding conditions, and can also anticipate any natural disasters that could occur at the building site. The designer still needs this information when she determines alternative solutions in the coming design process.

Although this project focuses on bamboo building design, other aspects of the bamboo material and bamboo building problems have been taken into account. All aspects that support the completeness and appropriate design process have been identified, such as using local available bamboo materials, information about the provided bamboo species, their characteristics and mechanical properties; the designer also needs information about the social and economic habits of the surrounding communities. A bamboo building located in a rural area might have different characteristics from a bamboo building located in an urban area, where people tend to live more individualistically. This condition may affect the construction process, the materials, the architectural form and layout of the building, and so forth.

Our criteria showed that it was essential to build the tool in the form of a DDSS, to provide a systematic approach to supporting the design process of a bamboo building. To build the tool in this form we needed an appropriate model for the design process that could be used in each stage of the process. The realisation of the tool fits best into a computer programme. The results may be published as a book later on, for those people who do not have access to a computer.

We have seen that the IDEFØ schemes (Appendix B) are not yet complete, as each scheme can be enlarged by further decomposing every last decomposed activity, as required. This means that the schemes are flexible, and the idea of structuring the design process model can be based on those schemes.

In Chapter 5 we discussed the selection process of a programme developer, and we chose the *"XpertRule Knowledge Builder"*. To build a decision support tool using the *"XpertRule Knowledge Builder"* we needed several tactics to determine the components for the partial prototype of the tool and their attributes and values. From practical experience using the programme developer, we learnt how to build the decision process through the cases table. This experience gave us an idea of how the programme developer can handle the cases table and construct the decisions based on the cases table, and how the programme developer suggests which attributes of each decision aspect should be constructed in an appropriate way.

Chapter 5 also showed the main programme of the partial prototype, consisting of sub-programmes such as the surrounding environment, wall shapes, wall frames, wall openings, wall connections and wall materials. It does not matter which sub-programme is run first and which sub-programme follows, the user of the prototype has the freedom to start the design at any stage. There is no need to follow a specific design path or method.

The partial prototype was verified, validated and tested to provide an appropriate prototype; the complete prototype for a bamboo building can be built in a similar way at some later date.

The partial prototype was verified by putting the knowledge contents of the decision processes provided in the prototype into decision tables (DTs). Looking at those tables and referring to verification criteria, it seems that the knowledge contents in the DTs are consistent, exclusive, and complete. The correctness of the information and knowledge in the sub-programme was verified by checking the syntax, rules and data in the prototype, and by comparing the results with resources such as handbooks and examples from building practice.

The partial prototype was validated in several steps, such as checking all possible outputs to see whether they were the same as the expected outcomes in the design of the prototype, and testing the prototype to detect whether the results of the decisions could satisfy the users. To eliminate subjectivity of the validation, we used test cases and we gave the "prospective users" a questionnaire at the International Bamboo Housing Workshop in Mizoram, India. As a result of that workshop, we now know that participants feel that the prototype really helps in their design activities for bamboo buildings, they are satisfied with the layout of the prototype, and they "agree more than disagree" that the prototype improves the result of their design process. Their opinions and suggestions after using the tool have been implemented in the latest version of the prototype. Their responses after using the tool indicate that they are satisfied with the knowledge contents in the tool and the decision making support.

The original idea of developing the tool has been applied and elaborated on in the partial prototype, and it has been verified, validated and tested. We now assume that the complete tool can be developed in a similar way.

7.2 Recommendations for future work

Several recommendations for future work can be given:

1. Although we did not use the DTs to build the tool, the verification of the knowledge available in the partial prototype using the DTs gave systematic tables, and the result of this verification also supports the completeness, consistency and exclusivity of the knowledge and the decision-making procedures. We recommend using the DTs from the beginning; this will enable the immediate verification of the knowledge contents in the prototype.
2. The partial prototype is only a small part of the whole bamboo building design decision support tool. More programmers would therefore be needed to develop the complete tool, and it will be considerably more time consuming, since the complete tool contains a wider knowledge content and more interrelated decisions.
3. Anticipating future developments in the design process of bamboo buildings, the decision support tool can be completed using audio-visual data sources to provide better understanding and recognition of the design

of bamboo buildings in practice. This would be particularly useful for designers who are unfamiliar with bamboo and bamboo building design. The *"XpertRule Knowledge Builder"* can accommodate the multimedia databases for such an implementation.

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APPENDICES

Appendix A:

Background study of phenomena and issues related to bamboo buildings and bamboo building design, based on the "Taxonomy of concepts in architecture" (Bax & Trum, 1993).

I. Natural environment and bamboo buildings

1. Professional aspect
   The natural environment of the bamboo building comprises the climate, local terrain ruggedness and soil quality. It is the professional designer's task to take into account the conditions of the natural environment in order to provide an ecologically balanced design solution, a desired overall performance of bamboo buildings, and to develop appropriate design, construction, and maintenance methods for the future.
2. Scientific aspect
   Adaptation and adjustment of the bamboo building to the natural environment is an important part of the bamboo building culture. Expertise obtained through experience with traditional building throughout history should be considered, gathered and applied. Knowledge about the natural environment and its relationship with bamboo buildings should be considered, in order to be able to apply the appropriate structural bamboo building system, combination of bamboo materials with other structural materials, and construction method.
3. Aesthetic aspect
   People can use the adjustment to the bamboo building to fit in with the surrounding natural environment as a basis for an artistic expression in order to achieve an architectural result.
4. Social aspect
   The specific conditions of the natural environment will have an impact on the social and human behaviour of users of the bamboo building. The natural environment should be taken into account in order to provide a better relationship between people and the bamboo building.
5. Temporal aspect
   The actual behaviour of the bamboo building during its lifecycle in a given natural environment depends on its specific properties, assigned during the design and construction process of the bamboo building. For instance, variation in the slope of the roof to resist wind and rainfall. The relationship between the natural environment and the bamboo building should be evaluated periodically in order to provide a better adaptation in the future.
6. Economic aspect
   The natural environment will influence the initial costs of a bamboo building and thus, indirectly, the economic value. For instance, if using a

platform system in a rugged area, the floor structure will be more expensive than when using a normal floor structure in a flat area.

7. Usability aspect
   The applicability of different structural bamboo building systems and construction methods depends on the actual dynamic behaviour of bamboo buildings under the influence of the environmental conditions. In seismic areas it would be appropriate to choose lightweight and elastic materials, for instance.
8. Durability aspect
   Bamboo buildings should be adapted to the natural environmental conditions. The quality of this adaptation will have a major impact on the life span of the bamboo building.
9. Makability aspect
   Bamboo building methods and techniques should be chosen in accordance with the local natural environmental conditions. For instance, using a platform system for building in a marshy or forest area.

II. Relationship between the habits, economic standard, and standard of living in the community, and bamboo

1. Professional aspect
   Professional management and professional codes related to the economic level and habit of the community and bamboo should be maintained as part of their life. For instance: related to the value of traditional craft, the traditional tools, and building tradition.
2. Scientific aspect
   The history of bamboo buildings, which is related to the variations in income, profession, and educational background of the community, is always part of the economic life standard and habit of the community. The community has a "milieu" for bamboo building. The interaction of bamboo and the social life of the community will have an impact on the variety of uses of bamboo in the community, for instance: using bamboo as a ship material, building material, kitchen utensils, ropes for their cattle, or cutting the umbilical cord of a new born child with a bamboo knife. These activities will be part of the appreciation and the community economy base for using bamboo.
3. Aesthetic aspect
   Increasing the interaction between the application of bamboo and social life should improve the economic level of the community. Traditionally, bamboo is considered to be a characteristic of poverty within these communities.
4. Social aspect
   The social value of the relationship of the community’s economy and bamboo can be improved in the future, for instance in the role of non-formal leaders to sustain traditional bamboo building culture, and the sustainable production of bamboo. If bamboo is part of the social habit of

the community, the appreciation of the bamboo will grow, and the community can extend their ideas about bamboo and can feel comfortable using bamboo in their life.

5. Temporal aspect
   There are social means that could improve the appreciation of bamboo by the community.
6. Economic aspect
   Improving the image of bamboo in social life will change the economic condition of the community.
7. Usability aspect
   Appreciation of bamboo by the community will have an impact on the usability of bamboo.
8. Durability aspect
   The community, with its relationship between social, habit, economic level, and bamboo, will undergo an improvement of their social life. For instance, even though they can use kitchen utensils made of plastic, they still use utensils made of bamboo.
9. Makability aspect
   The community can use bamboo as part of their life, and they can improve the quality of their life using bamboo. For instance, they can produce good quality and durable bamboo handicrafts.

III. Bamboo plantation as a material resource

1. Professional Aspect
   Government policy on bamboo plantations should be intensified in bamboo growing countries. With professional management, this activity will increase bamboo production and ensure the continuation of bamboo resources in the future. Government and people should promote this activity because bamboo is recognised as the fastest-growing large plant in the world, and is able to give an annually renewable harvest of great diversity of bamboo species. Systematic and regular exploitation increases the production of the bamboo stock. In the management of bamboo forests, maintenance cannot be overlooked: all efforts are aimed at encouraging the formation of healthy and vigorous clumps for high production of new culms.
2. Scientific aspect
   Preparing bamboo-plantations for human use, as part of their life, is becoming an important activity in some parts of the world. Bamboos should be giant, rainforest-type plants, and are huge, beautiful, powerful grasses. The increasing demand for bamboo culms, to be used by the people, is promoting the intensification of bamboo cultivation. Using modern technology on bamboo plantations will develop the plantation techniques, and the diversity of the bamboo species. Technology can improve the propagation, intensify bamboo land use for bamboo in the area, fertilise the soils, clear grasses around bamboo plants, and maintain

the plantation until the bamboo is ready to be harvested. There should be a database on bamboo plantation activities, and this database can be improved in the future. The optimum spacing is very important for the productivity of bamboo plantations, but very little research has been done on this subject. The thinning design for shoot production also differs from that for culm production, because light is essential for shoot development.

3. Aesthetic aspect
   Bamboo plantations in a terrain will yield a good scene. Bamboo plants will grow quite happily in almost all terrains and climates, both tropical and subtropical. Some bamboo species originate from the high mountain areas, and they can survive temperatures of minus 20 degrees C.
4. Social aspect
   Bamboo plants should improve the structure of the community and the self-reliance of the people. On the other hand bamboo plants are grown and can be maintained if there are people in the community who have adequate knowledge, experience and skills.
5. Temporal aspect
   There are approximately 1500 species of bamboo in the world, with variety in colour, the diameter of culm, wall thickness, engineering properties, and application possibilities. If a variety of bamboo species can be planted in one area, these species will interact. A bamboo plantation will have some patterns in the plantation activities, and diversification in planting related to the required and where necessary or useful. Bamboo plants should be replaced periodically in order to maintain the quality of the bamboo culm. There are many ways of propagation, for instance by seeds, rhizome cuttings, culm cuttings, branch cuttings, layering, and tissue culture.
6. Economic aspect
   Bamboo plantations have an economic value which varies depending on whether the products are shoots, culms, etc. This can result in bamboo-based factories, and in profit for the community. Bamboo plantations can improve the economic standard of life in the participating community. All activities in the bamboo plantation can develop the economic activities in the region.
7. Usability aspect
   Bamboo plantations have many advantages, such as protecting the soil from landslides, fertilisation, erosion protection, and stabilising/increasing the area of rainforest as the world’s "lungs". Bamboo plantations can be used as material resources for many activities of the people in the communities. Bamboo plantations have the potential to fulfil our needs for food, shelter, furniture, transport, and entertainment.
8. Durability aspect
   With intense bamboo plantation, there should be a balance between supply and demand. This condition will change the social life of the community, from passive to active. The community can create other activities based on bamboo materials.

9. Makability aspect
   There are many bamboo plantation patterns to which the community can apply their abilities in order to improve the plantation technology. They can apply their knowledge of the variation of species according to the climate, geographical conditions and other options like terrain, soil condition, average annual rainfall, altitude and so on.

IV. Bamboo harvesting and preservation

1. Professional aspect
   Most people in bamboo growing countries are acquainted with the traditional ways of bamboo harvesting and bamboo preservation. This knowledge is based on their experience with bamboo buildings. Professional management of harvesting and preservation activities may improve the quality and durability of bamboo.
2. Scientific aspect
   The bamboo can be harvested when the plants have reached a sufficient size and strength. In rural areas people know when it is bamboo-harvesting time, and this varies in different climates. There are two methods of harvesting culms: clear-cutting and selective cutting. With clear-cutting the entire clump is cut down, which causes the clump to produce smaller culms the following year. It is not advisable to use this method if you are aiming at a sustainable production of culms. Selective cutting is generally used for exploiting and maintaining bamboo clumps. Various techniques for selective cutting are applied to promote clump productivity. Similar considerations apply to the preservation methods, which will increase the durability of bamboo. These insights and experiences should be used as a knowledge base on harvesting science and the preservation technology of bamboo.
3. Aesthetic aspect
   Harvesting and preservation activities can affect the aesthetic aspect of the bamboo building material. Bamboo should be harvested in accordance with its suitability for the intended use, the age and the season. For instance, for culm production, harvesting should be started at the beginning of the dry season and carried out during the dry season in order to prevent culms being attacked by borers. Preservation techniques prevent bamboo being attacked by termites, borers and other insects, but they can also change the colour of the bamboo surface. The only chemical preservation liquids that should be used are those that do not endanger human health.
4. Social aspect
   Bamboo preservation and harvesting activities have social implications for the people who work on these activities. They will interact with each other and contribute to the improved social appreciation of harvesting and

preservation activities as a job. These activities should be managed as a feature of everyday community life.

5. Temporal aspect
   Bamboo should be harvested in accordance with the intended use. For instance, the one to two-year-old culms are suitable for handicraft purposes and for pulp production. The three-year-old culms are mostly suitable as a building material, for furniture and other cottage industries. This involves selective-cutting, which also promotes a higher productivity of clumps. Bamboo culms become degraded during transport and storage due to attacks by staining and rotting fungi and insects (beetles, borers, and termites). The durability of bamboo mainly depends on climatic conditions. Untreated bamboo may last one to three years when directly exposed to the atmosphere and soil, but up to seven years when protected. Because of its low durability, treatment with preservatives is necessary. The preservation method should be chosen in accordance with the skills, tools, intended applications and the required quality and durability of bamboo. Routine evaluation of these methods should be performed in order to attain a sustainable production of culms and to ensure that the objectives of these methods are achieved. For example, painting with lime is a widely used technique for walls, and is said to be effective against fungi; the other non-chemical method commonly used in South-East Asia is to submerge culms in either stagnant or running water, or mud for several weeks, (this method is said to give resistance to borers, but not to termites and fungi). The chemical methods of preservation are more effective but not always applicable or economical.
6. Economic aspect
   These activities will provide economic advantages for the people. They can find jobs and receive money for their work. There is also an opportunity to start producing tools and preservation materials, which will increase the economic activities of the community.
7. Usability aspect
   New scientific knowledge and appropriate technology is needed for most harvesting and preservation techniques. Preserved bamboo material has the same engineering properties as untreated bamboo, so the people can use it in the same way.
8. Durability aspect
   The safety, sustainability, and durability of harvesting techniques, and the safety and durability of preservation techniques should be described.
9. Makability aspect
   Experiments with different preservation and harvesting techniques should be performed in order to develop an appropriate bamboo harvesting and preservation technology.

V. Research and development into bamboo as a building material

1. Professional aspect
   The researchers, the developers and the community can realise the products by using their imagination with bamboo as a building material. Researchers and developers should work professionally, based on their experience and on the tradition of building with bamboo.
2. Scientific aspect
   People have grown up in a "milieu" of building with bamboo, which depends on their appreciation of bamboo as a building material and of bamboo technology. Researchers and developers should carry out research and development of the culture, to strengthen it. There should be an explicit knowledge base of bamboo as a building material, including innovation of design. (e.g. methods and techniques for design and construction).
3. Aesthetic aspect
   Research and development on bamboo could improve the aesthetic value of bamboo as a building material.
4. Social aspect
   Research on and development of bamboo will have an impact on the social activities of the community, like the supply of materials to and the creation of jobs in a research centre or factory.
5. Temporal aspect
   Knowledge about bamboo should be extended to promote activities in the design, construction and maintenance of bamboo buildings. Research and development on bamboo, including the engineering properties, the life cycle of bamboo as a building material, and bamboo structures, will have an impact on the life cycle of bamboo buildings. This research and development should be developed for an improved performance and longer durability of bamboo buildings.
6. Economic aspect
   Activities in research and development of bamboo will support the economy; it will have an impact on the market of bamboo-based products, and the use of bamboo as a building material.
7. Usability aspect
   Research and development on bamboo will provide criteria for the use of bamboo as a building material, like the use of bamboo culms as columns or beams or in a truss, and the use of bamboo mats in walls, ceilings or floors.
8. Durability aspect
   Continuous research and development on bamboo as a building material is needed. Research and development should be directed towards the improvement of a balance between the supply and demand of bamboo with required mechanical and physical properties. This will have an impact on the life span of bamboo buildings.
9. Makability aspect
   There should be a system of research and development on bamboo as a building material, and on building construction, production processes, and

management. This system depends on the technical and engineering properties of bamboo, and it will have an impact on the steady state of bamboo as a material for buildings and products.

VI. Bamboo building design activities

1. Professional aspect
   Bamboo buildings are artefacts that can be designed in many different ways. The bamboo building design task should be performed and managed by professionals.
2. Scientific aspect
   In many countries, bamboo buildings are made traditionally, according to local bamboo building cultures, without explicit design activities. These traditional methods can be made explicit and developed in order to improve the quality and performance of bamboo buildings. The resulting bamboo building design knowledge can be applied in knowledge-based bamboo building design. This will be useful to innovate the design of bamboo buildings, their structure and construction methods.
3. Aesthetic aspect
   The styling of the bamboo building in all its aspects, including the combination of bamboo with other materials, should be adapted to the local culture and natural environment in order to achieve an aesthetically well-balanced design.
4. Social aspect
   The achievable design solutions do not only depend on the designer, but also on the people who prepare the bamboo material, the construction workers, the owner, and also on the acceptance of the building by the community. Public support and acceptance are needed for these activities.
5. Temporal aspect
   In order to achieve an optimal design, the designer should take into account the future use of the bamboo building when choosing building methods and materials. For example, it is possible to combine a wooden frame structure and bamboo walls, a wood floor structure and a bamboo frame structure, etc.
6. Economic aspect
   The designer should consider the desired bamboo-building life cycle (durability) in order to determine the required material properties and material life cycle. The cost of the bamboo building depends on the choice of building materials, building technology, construction method and maintenance method. Thus, the design activity has an impact on the economic level of the community.
7. Usability aspect
   User requirements - above all - are the key success factors for a good building design. They should be considered as the basic guiding principles for the design of every bamboo building. People’s appreciation

of and belief in the bamboo building design activity should encourage them to use the appropriate design techniques.

8. Durability aspect
   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.
9. Makability aspect
   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, all influence and restrict the makability and the eventual quality of the bamboo building. These factors should therefore 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.

VII. Bamboo building construction activities

1. Professional aspect
   The construction method should be chosen in order to achieve the bamboo building quality required by the inhabitants or the company. The inhabitants and the company should build the building in a professional way. Their activities will have an impact on the codes for the management and profession of building in bamboo.
2. Scientific aspect
   The construction method should be studied in order to get the quality of building that the people want, including examples from traditions and bamboo construction history. This study includes the selection of the material, the tools, the number of workers, the time needed, the costs and the supervision, all to fulfil the specifications. This study will also have an impact on the innovation of traditional bamboo building structure and construction, and on the bamboo knowledge based building construction.
3. Aesthetic aspect
   The development of the construction method will have an impact on the performance of the building, and on the aesthetic value of the building during and after the construction period.
4. Social aspect
   The construction process will provide an opportunity for the community to work on the construction site. This activity should be managed to increase the skills of the community, as well as its social structure.
5. Temporal aspect
   There are many aspects in the specification of materials, tools, construction method, and skill of the workers, which will influence the building time and the quality of the bamboo building. A periodic evaluation of the construction process will improve the efficiency of the construction

method, resulting in a shorter building time and better quality. The construction process will also influence the maintenance.

6. Economic aspect
   The construction activities have an economic impact, and they should therefore consider the building time, and the number and the skill of the labourers, in order to result in a minimum of constructions costs. The construction activities will also have an impact on the economy of the community, the construction company and the material supplier.
7. Usability aspect
   The construction activity uses the local materials, and should therefore meet the needs of the local population, the community and the company.
8. Durability aspect
   The construction activity should consider the quality, safety, stability, and durability of the bamboo building.
9. Makability aspect
   By using sufficient materials, tools, skills, time and a suitable construction method, the construction process will be safe, smooth and ordered.

VIII. Bamboo building maintenance activities

1. Professional aspect
   Maintenance of the building is an activity driven by the desire to preserve and - if necessary - restore the desired condition of the bamboo building. Maintenance should already be taken into account during the design of the bamboo building. All persons involved in building maintenance should know this activity. The process of building maintenance should be performed professionally, for instance: routine inspections of the building condition, condition analysis and decision making on the necessary repair activities.
2. Scientific aspect
   Given that future building maintenance is thoroughly considered during design and construction of the building, it will be possible to issue guidelines for building maintenance activities. Knowledge of preservation or repair data, methods and techniques of the bamboo building, should continuously be completed and developed in order to obtain better conditions in the future. This constitutes the foundation of knowledge-based bamboo building maintenance.
3. Aesthetic aspect
   The aesthetic building aspect should be considered during inspection and repair. This includes the choice and preparation of original or substitute materials, as well as the choice and the execution of the repair method. The aesthetic quality of the result is an important aspect of the appraisal of the whole maintenance process.
4. Social aspect
   The type of maintenance activities resulting from the decisions made during the design of the building will have consequences for the user of

the bamboo building and an influence on the social life of the people (can they be carried out by the users with or without help of neighbours, etc.; are they dependent on specialised enterprises).

5. Temporal aspect
   The maintenance activities consist of data collecting, problem identification, data analysis, solution determination and execution. Alternatives of repair techniques should be considered, for instance: materials to be used, worker skills, time needed, costs, and the quality to be provided. The development of maintenance activities will improve repair methods. All aspects of the maintenance activities should therefore be evaluated in order to find new solutions for the maintenance of the bamboo building.
6. Economic aspect
   The maintenance activities will have an impact on the economy of the community. This includes production of and trade in materials, training and employment of workers, and a market for maintenance companies. These activities may contribute to a higher economic level in the community.
7. Usability aspect
   The quality of building maintenance depends on the usability of the chosen repair methods and materials, and the resulting repair time and costs.
8. Durability aspect
   Maintenance activities are carried out in order to keep up the safety and stability of the building and to improve the durability of the building. The life span of the repairs themselves is an important measure for the maintenance quality.
9. Makability aspect
   Preparation and production of all things that will be needed for maintenance, as well as education and training of workers, will influence the makability and workability of the maintenance process during the life time of the building.

IX. Living in a Bamboo Building

1. Professional aspect
   Rules on how to live in a bamboo building should be determined by the inhabitants, the community or the government. Inhabitants may have experience of living in a previous building of a different type. They might be exposed to a style or culture which is different compared with living in another building. This experience will have an impact on their style of living itself. They can plan how to live in the building, and they should develop rules, for example how to keep it clean and safe, and how to live safely and comfortably. They can also make rules on how to reduce risks.

2. Scientific aspect
   The inhabitants can describe their knowledge of living in the building based on their experiences; for example inhabitants may feel unsafe if anybody outside can see what is happening inside at night, or they may be afraid that a thief can enter the house by breaking through the bamboo wall, or by digging a hole under the wall, or by making an opening in the roof. There is also the risk of a fire destroying the house.
3. Aesthetic aspect
   The bamboo house inhabitants should find a lifestyle that is adapted to living comfortably in a bamboo house and that is synchronized with the characteristics of a bamboo building.
4. Social aspect
   The users can develop their own social interaction with the bamboo building. They can manage their life style. It may be an existential experience for them, because they know the character of the bamboo building is environmentally friendly. They can develop a culture of living in the bamboo building. For example, they know the risk of fire, and therefore they adapt their life to avoid this risk. They can also adapt their life to the conditions of a bamboo house.
5. Temporal aspect
   The inhabitants should know about advantages and disadvantages of living in bamboo housing. The most distinctive advantage of bamboo housing is its low earthquake risk. And if the bamboo materials are protected from changes of either weather, temperature, or humidity, they may be used longer than the nominal lifetime for untreated bamboo. On the other hand, the inhabitants should know the disadvantages of bamboo materials, such as that they catch fire easily, so that people can anticipate these characteristics.
6. Economic aspect
   The users can develop their house step by step. They can complete and develop their house within the limits of their budget.
7. Usability aspect
   The inhabitants may feel comfortable in the hot climate because in a bamboo house air circulation is better than in other houses. At night a bamboo house is cooler, so that inhabitants are more comfortable and do not need air conditioning. In the daytime sunlight may enter the house, resulting in fluctuations in the humidity in the building. During rainy weather, water may enter the house, resulting in too high a humidity or even a wet interior, which might harm the health of the inhabitants. This problem can be prevented by adapting the opening in the walls which can be opened or closed, by a greater height of the room, and by a greater overhang of the roof. They can develop a fire warning system. They can also save money in the bamboo culm as a symbol to prepare for the future. They can make a musical instrument, a "kentongan", to be used in case of fire, the death of a member of the family, theft, natural disaster, or at any time when they need to gather.

8. Durability aspect
   The users should reflect upon the maintenance of the building to keep it in good and durable condition. They know when to paint or to inspect the building. The users can maintain their bamboo building easily as part of their daily life. They can complete their building as they like.
9. Makability aspect
   The inhabitants can develop their house in many phases, making new dividing walls with bamboo, enlarging the building, or decorating the house in a natural way. They can live in their house in a dynamic way.

X. The end of the bamboo building lifecycle

1. Professional aspect
   Users or government should determine a standard condition or criteria for repair, replacement and demolition of bamboo buildings. The criteria should take into account the safety, comfort, and health of the users of the building in relation to the bamboo building durability.
2. Scientific aspect
   There should be a standard to determine (with certainty) the end of the life span of the bamboo building, i.e. the condition of the building in which neither maintenance nor repair are worthwhile. Demolition methods should be developed, that take into account all aspects of environmental protection. In order to develop the necessary building knowledge, it is necessary to collect data on the bamboo building condition during its lifecycle and on the environmental pollution aspects of demolition.
3. Aesthetic aspect
   Users should know the environmental cycle of the bamboo building which is originally obtained from nature, used for human objectives and in the end returned to nature, so the demolition activities should be only carried out following a final decision after a series of inspections and analyses.
4. Social aspect
   Users need a demolition method for their houses that they can preferably apply themselves (with or without the help of other community members).
5. Temporal aspect
   Demolition activities should be carried out after thorough inspections, and the demolition decision should be based on the results of an analysis and evaluation of the bamboo building condition. The demolition decision should take into account the different levels of consideration of the building: the end of the life span of the building as a whole does not automatically mean that all the building parts are also in that same condition. They may still be reusable in other buildings or for other purposes.
6. Economic aspect
   Demolition activities have an economic impact, because there may be parts of the building that have to be reused or recycled, or have to be dumped. The waste materials may be used as firewood or – depending

on the preservation method applied - as a fertiliser for soil-improvement (e.g. for bamboo plantations).

7. Usability aspect
   Appropriate methods of demolition should be chosen, and should be adjusted to the skill level of the workers, the tools that will be used, time needed, costs, etc.
8. Durability aspect
   Users desire an everlasting bamboo building. All waste material from the bamboo building should be harmless to the environment; natural materials can be returned to nature.
9. Makability aspect
   Demolition activities should be executed easily, safely, quickly, and at minimal cost.

Appendix B:

IDEFØ for a Bamboo Building Design

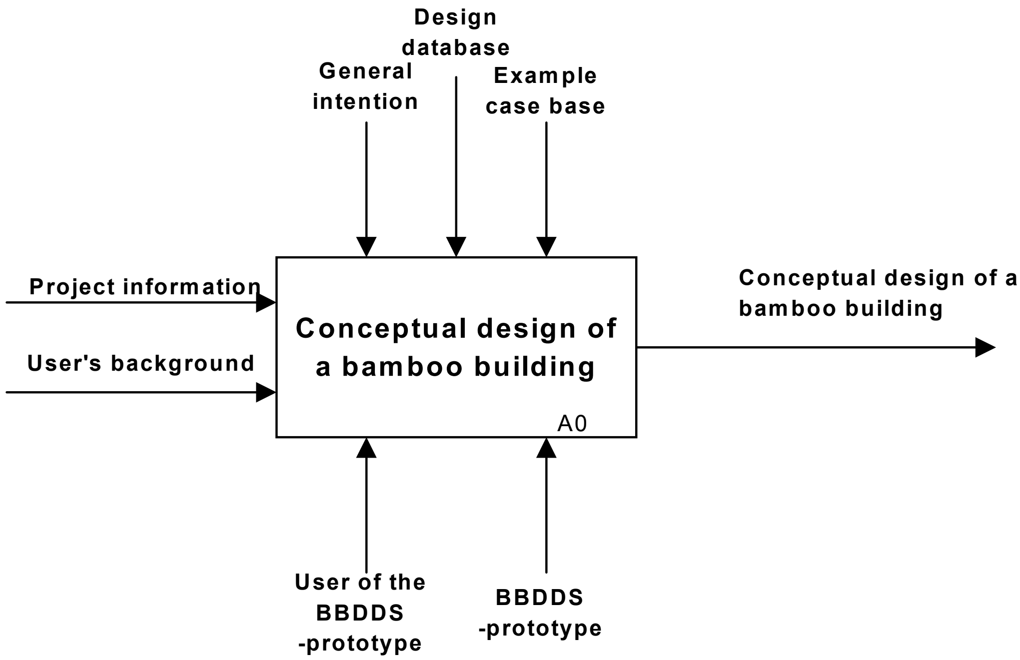

Figure B.1: **Main activity of the conceptual design of a bamboo building**

Activity or arrow name	Definition
A-0: Conceptual design of a bamboo building	Subdivided further, Figure B.2

BBDDS (Bamboo Building Design Decision Support) –prototype	The demo programme of the BBDDS.
Conceptual design of a bamboo building	An integrated bamboo building system which fulfils the user's requirements.
Design database	Several databases contain data and bamboo knowledge
Example case base	A case study as an example of the BBDDS
General intention	General plan provided from the user or owner of the design product
Project information	Specific information on the stage of the project
User of the BBDDS –prototype	The user of the software has to make decisions
User's background	Information on the user that is important for the structure of the query and the help-function programme

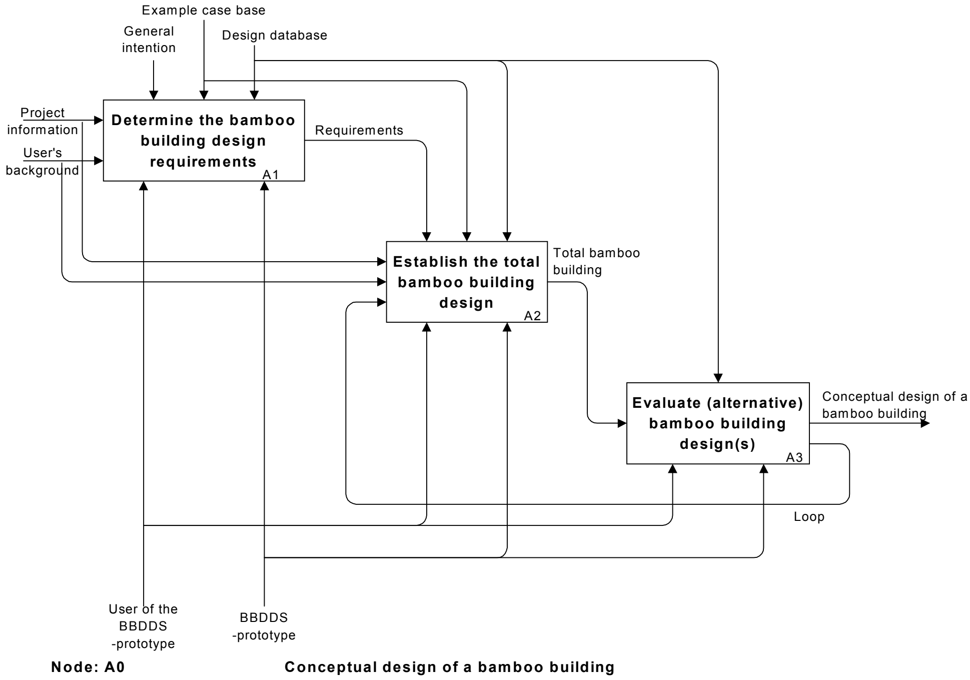

Figure B.2: **Decomposition of the conceptual design of a bamboo building**

Activity or arrow name	**Definition**
A1: Determine the bamboo building design requirements	Subdivided further, Figure B.3
A2: Establish the total bamboo building design	Subdivided further, Figure B.6
A3: Evaluate (alternative) bamboo building design(s)	Subdivided further, Figure B.12

BBDDS (Bamboo Building Design Decision Support) –prototype	The demo programme of the BBDDS.
Conceptual design of a bamboo building	An integrated bamboo building system which fulfils the user's requirements.
Complete bamboo building design	A combination of all possible systems in the bamboo building system to meet the requirements
Design database	Several databases contain data and bamboo knowledge
Example case base	A case study as an example of the BBDDS
General intention	General plan provided from the user or owner of the design product
Loop	A redirection in the programme
Project information	Specific information on the stage of the project
Requirements	All requirements needed for the bamboo building system
User of the BBDDS –prototype	The user of the software has to make decisions
User's background	Information on the user that is important for the structure of the query and the help-function programme

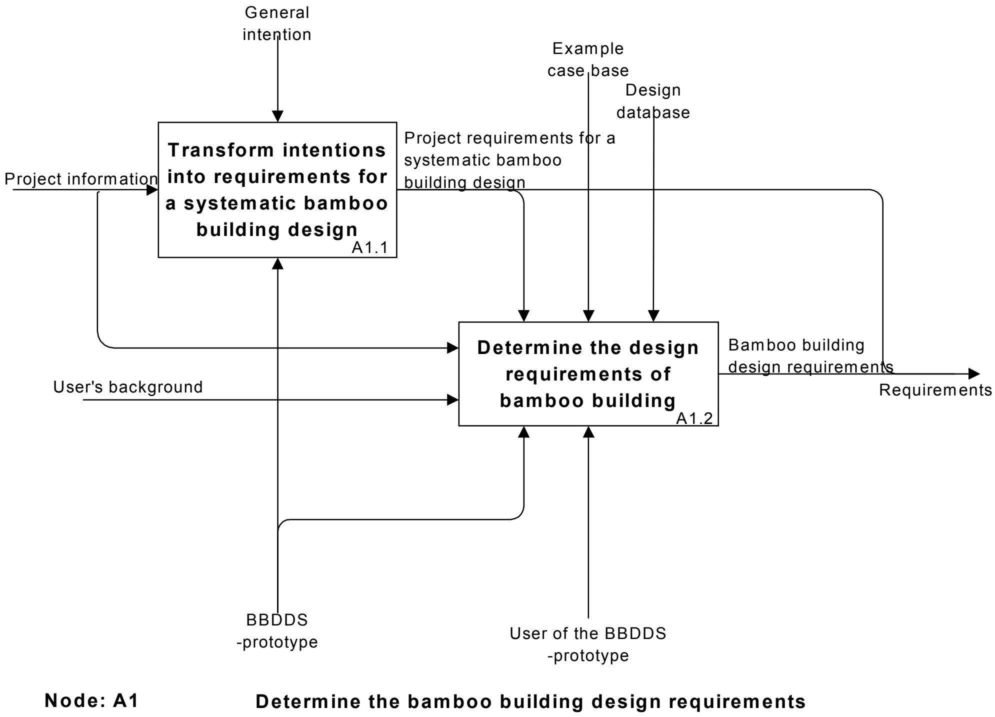

Figure B.3: **Determine the bamboo building design requirements**

Activity or arrow name	Definition
A1.1: Transform intentions into requirements for a systematic bamboo building design	Subdivided further, Figure B.4
A1.2: Determine the bamboo building design requirements	Subdivided further, Figure B.5

Bamboo building design requirements	Requirements that concern the bamboo-building design
BBDDS –prototype	The demo programme of the BBDDS
Design database	Several databases contain data and bamboo knowledge
Example case base	A case study as an example of the BBDDS
General intention	General plan provided from the user or owner of the design product
Project information	Specific information on the stage of the project
Project requirements for a systematic bamboo building design	Some requirements that have boundaries to the design system
Requirements	All requirements needed for the bamboo building system
User of the BBDDS –prototype	The user of the software has to make decisions
User's background	Information on the user that is important for the structure of the query and the help-function programme

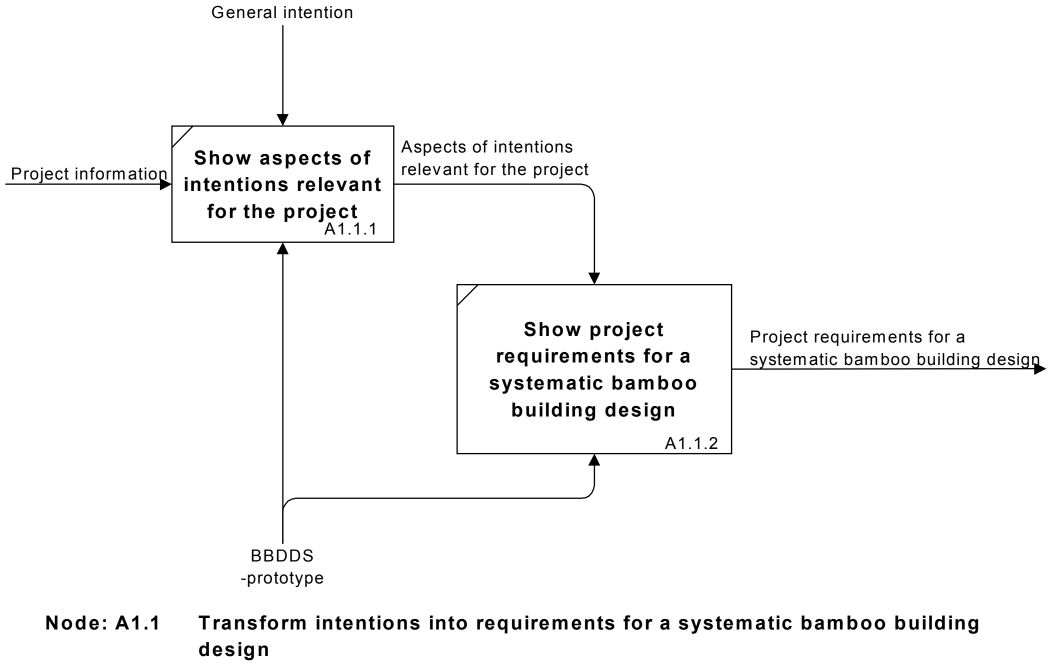

Figure B.4: **Transform intentions into requirements for a systematic bamboo building design**

Activity or arrow name	**Definition**
A1.1.1: Show aspects of intentions relevant for the project	These aspects contain information on the project name, country, city, location, building type, building orientation, number of occupants, type of activities.
A1.1.2: Show project requirements for a systematic bamboo building design	Show the requirements that exist and are dominant for a bamboo building design

Aspects of intentions relevant for the project	All aspects that are relevant for BBDDS
BBDDS –prototype	The demo programme of the BBDDS
General intention	General plan provided from the user or owner of the design product
Project information	General information that can be found from the building surroundings
Project requirements for a systematic bamboo building	Some requirements that have boundaries to the design system

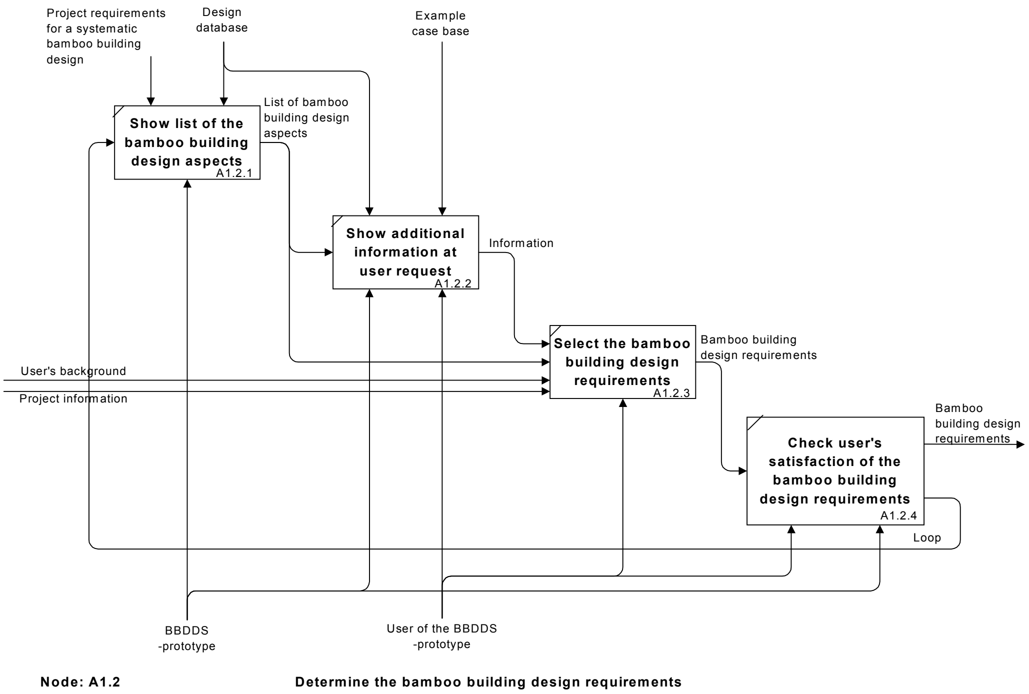

Figure B.5: **Determine the design requirements of bamboo building**

Activity or arrow name	**Definition**
A1.2.1: Show list of bamboo building aspects	Aspects related to space plan, services, skin and structural system
A1.2.2: Show additional information at user request	Theory and application to explain every building aspect
A1.2.3: Select bamboo building design requirements	A value must be selected for each aspect. These aspects can be used as building design requirements
A1.2.4: Check user's satisfaction of the bamboo building design requirements	The user has to indicate whether he wants to continue or make some changes to the bamboo building design requirements

Bamboo building design requirements	Requirements that concern the bamboo building design
BBDDS –prototype	The demo programme of the BBDDS
Design database	Several databases contain data and bamboo knowledge
Example case base	A case study as an example of the BBDDS
Information	Information on theory and application to explain each aspect
List of bamboo building design aspects	All aspects of bamboo building design
Loop	A redirection in the programme
Project information	Specific information on the stage of the project
Project requirements for a systematic bamboo building design	Some requirements that have boundaries to the design system
User's background	Information on the user that is important for the structure of the query and the help-function programme
User of the BBDDS –prototype	The user of the software has to make decisions

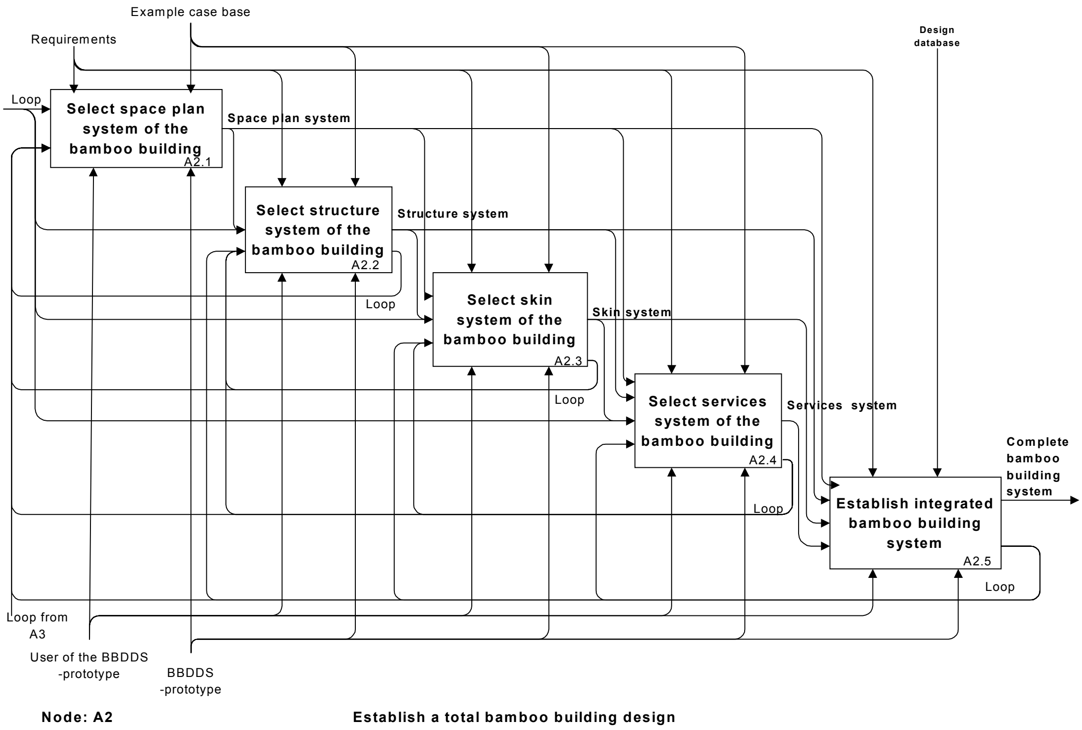

Figure B.6: **Establish a total bamboo building design**

Activity or arrow name	Definition
A2.1: Select space plan system of the bamboo building	Subdivided further, Figure B.7
A2.2: Select structural system of the bamboo building	Subdivided further, Figure B.8
A2.3: Select skin system of the bamboo building	Subdivided further, Figure B.9
A2.4: Select services of the bamboo building	Subdivided further, Figure B.10
A2.5: Establish integrated bamboo building system	Subdivided further, Figure B.11

Bamboo building design requirements	Requirements that concern the bamboo building design
BBDDS –prototype	The demo programme of the BBDDS
Complete bamboo building system	A combination of all possible systems in the bamboo building system to meet the requirements
Design database	Several databases contain data and bamboo knowledge
Example case base	A case study as an example of the BBDDS
Loop	A redirection in the programme
Requirements	All requirements needed for a bamboo building system
Services system	System for the building utilities
Skin system	System for the building skin plan
Space plan system	System for the building space plan
Structural system	System for the building structure
User of the BBDDS –prototype	The user of the software has to make decisions

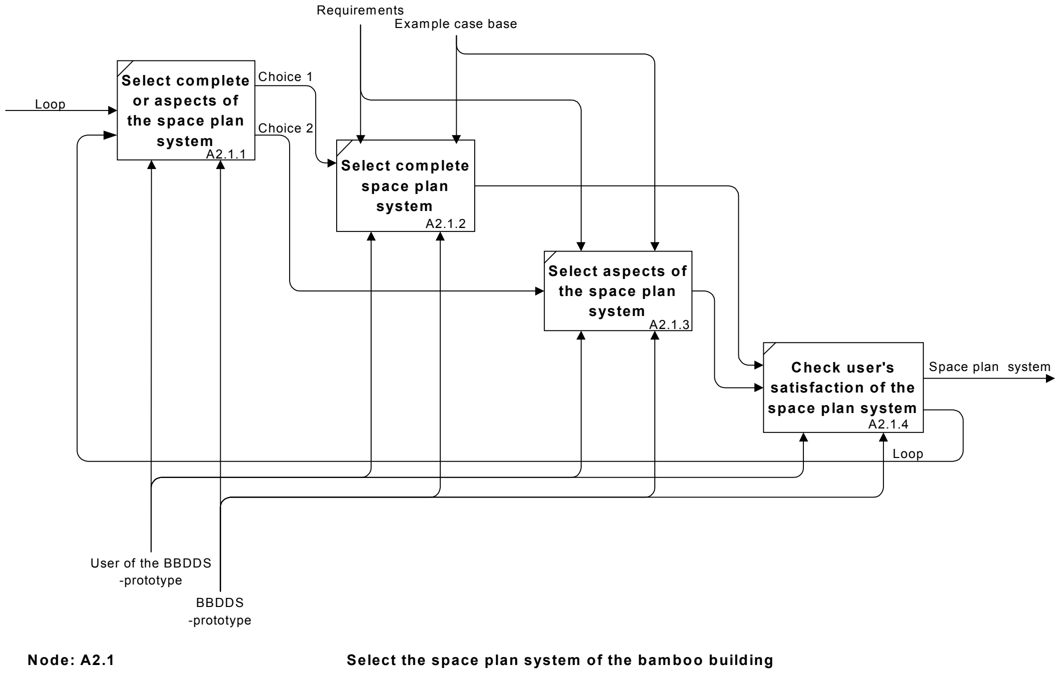

Figure B.7: **Select the space plan for the bamboo building**

Activity or arrow name	Definition
A2.1.1: Select total or aspects of the space plan system	Select whether the user chooses all aspects or various important aspects of the space plan system
A2.1.2: Select total space plan system	Select all aspects of the space plan system
A2.1.3: Select some aspects of the space plan system	Select some aspects of the space plan system which the user needs to design
A2.1.4: Check user's satisfaction of the space plan system	The user has to indicate whether he wants to continue or make some changes to the space plan system

Bamboo building design requirements	Requirements that concern the bamboo building design
BBDDS –prototype	The demo programme of the BBDDS
Choice 1 of the space plan system	First pattern/concept: selection of all aspects of the space plan system
Choice 2 of the space plan system	Second pattern/concept: selection of some aspects of the space plan system
Design database	Several databases contain data and bamboo knowledge
Example case base	A case study as an example of the BBDDS
Loop	A redirection in the programme
Requirements	All requirements needed for a bamboo building system
Space plan system	System for the building space plan
User of the BBDDS –prototype	The user of the software has to make decisions

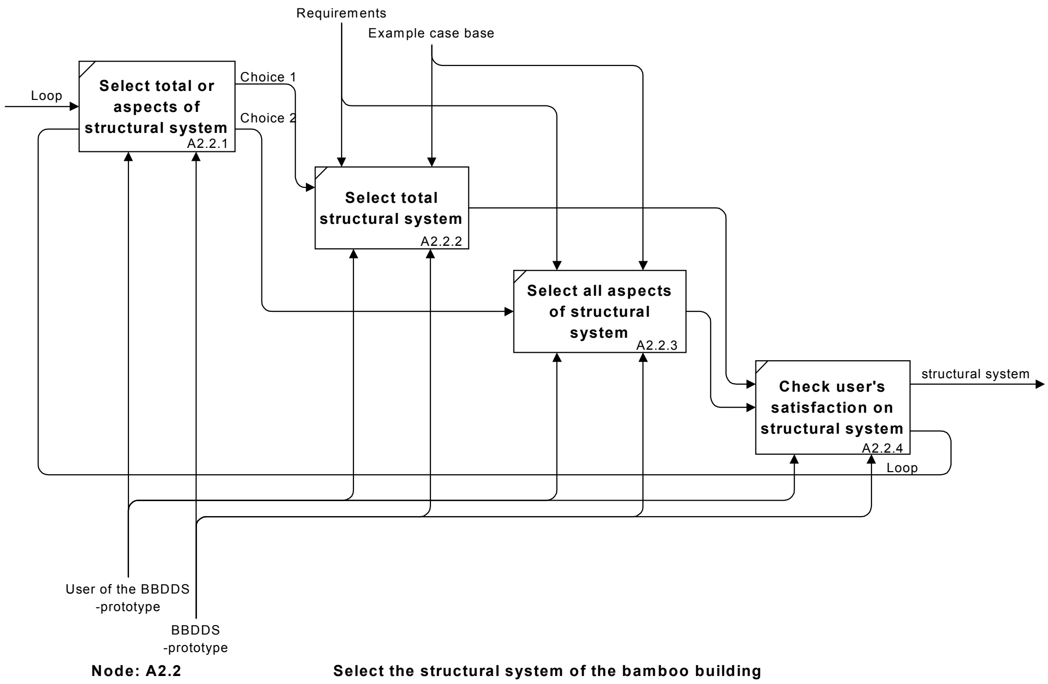

Figure B.8: **Select the structural system of the bamboo building**

Activity or arrow name	Definition
A2.2.1: Select total or aspects of the structural system	Select whether the user chooses all aspects or various important aspects of the structural system
A2.2.2: Select the total structural system	Select all aspects of the structural system
A2.2.3: Select some aspects of the structural system	Select some aspects of the structural system which the user needs to design
A2.2.4: Check user's satisfaction of the structural system	The user has to indicate whether he wants to continue or make some changes to the structural system

Bamboo building design requirements	Requirements that concern the bamboo building design
BBDDS –prototype	The demo programme of the BBDDS
Choice 1 of structural system	First pattern/concept: selection of all aspects of the structural system
Choice 2 of structural system	Second pattern/concept: selection of some aspects of the structural system
Design database	Several databases contain data and bamboo knowledge
Example case base	A case study as an example of the BBDDS
Loop	A redirection in the programme
Requirements	All requirements needed for a bamboo building system
Structural system	System for the building structure
User of the BBDDS –prototype	The user of the software has to make decisions

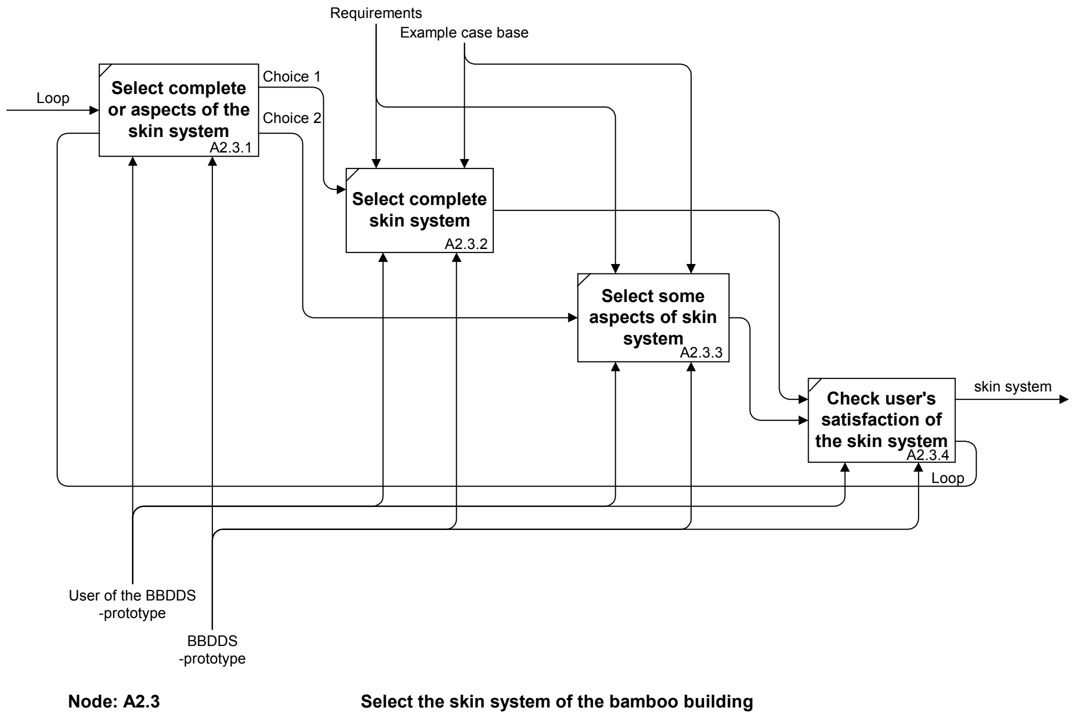

Figure B.9: **Select the skin system of the bamboo building**

Activity or arrow name	**Definition**
A2.3.1: Select total or aspects of the skin system	Select whether the user chooses all aspects or various important aspects of the skin system
A2.3.2: Select the total skin system	Select all aspects of the skin system
A2.3.3: Select some aspects of the skin system	Select some aspects of the skin system which the user needs to design
A2.3.4: Check user's satisfaction of the skin system	The user has to indicate whether he wants to continue or make some changes to the skin system

Bamboo building design requirements	Requirements that concern the bamboo building design
BBDDS –prototype	The demo programme of the BBDDS
Choice 1 of the skin system	First pattern/concept: selection of all aspects of the skin system
Choice 2 of the skin system	Second pattern/concept: selection of some aspects of the skin system
Design database	Several databases contain data and bamboo knowledge
Example case base	A case study as an example of the BBDDS
Loop	A redirection in the programme
Requirements	All requirements needed for a bamboo building system
Skin system	System for the building skin
User of the BBDDS –prototype	The user of the software has to make decisions

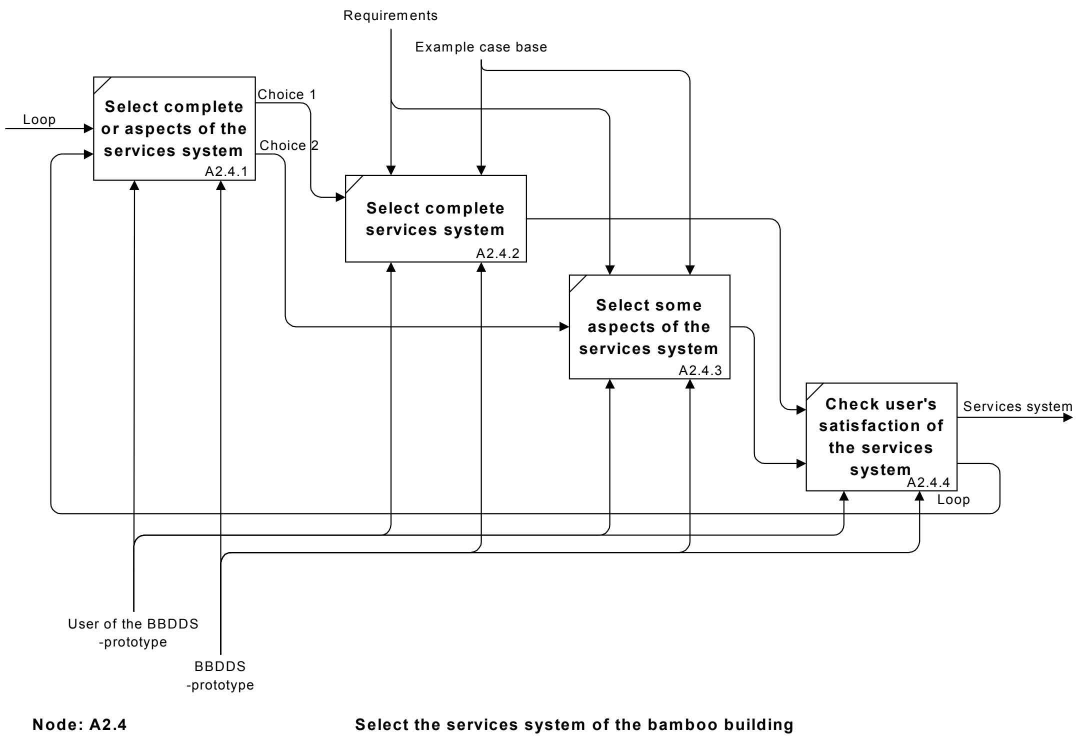

Figure B.10: **Select the services system of the bamboo building**

Activity or arrow name	Definition
A2.4.1: Select complete aspects of the services system	Select whether the user chooses all aspects or various important aspects of the services system
A2.4.2: Select complete services system	Select all aspects of the services system
A2.4.3: Select some aspects of the services system	Select some aspects of the services system which the user needs to design
A2.4.4: Check user's satisfaction of the services system	The user has to indicate whether he wants to continue or make some changes to the services system

Bamboo building design requirements	Requirements that concern the bamboo building design
BBDDS –prototype	The demo programme of the BBDDS
Choice 1 of services system	First pattern/concept: selection of all aspects of the services system
Choice 2 of services system	Second pattern/concept: selection of some aspects of the services system
Design database	Several databases contain data and bamboo knowledge
Example case base	A case study as an example of the BBDDS
Loop	A redirection in the programme
Requirements	All requirements needed for a bamboo building system
Services system	System for the building utilities
User of the BBDDS – prototype	The user of the software has to make decisions

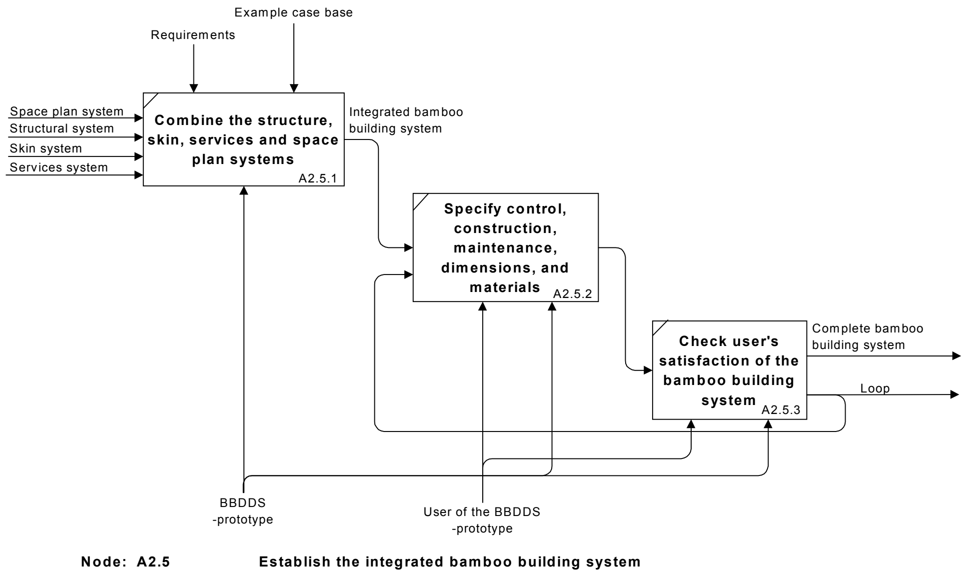

Figure B.11: **Establish the integrated bamboo building system**

Activity or arrow name	**Definition**
A2.5.1: Combine the structural, skin, services, and space plan systems	The chosen structure, skin, services, and space plan system are combined to build an integrated building system
A2.5.2: Specify control, construction, maintenance, dimensions, and materials	The user has to specify control, construction, maintenance, dimensions and materials
A2.5.3: Check user's satisfaction of the bamboo building system	The user has to indicate whether he wants to continue or make some changes to the bamboo building system

Bamboo building design requirements	Requirements that concern the bamboo building design
BBDDS –prototype	The demo programme of the BBDDS
Choice 1 of space plan system	First pattern/concept: selection of all aspects of the space plan system
Choice 2 of space plan system	Second pattern/concept: selection of some aspects of the space plan system
Complete bamboo building system	A combination of all possible systems in the bamboo building system to meet the requirements
Design database	Several databases contain data and bamboo knowledge
Example case base	A case study as an example of the BBDDS
Integrated bamboo building system	A combination of all building systems
Loop	A redirection in the programme
Requirements	All requirements needed for a bamboo building system
Services system	System for the building utilities
Skin system	System for the building skin
Space plan system	System for the building space plan
Structural system	System for the building structure
User of the BBDDS –prototype	The user of the software has to make decisions

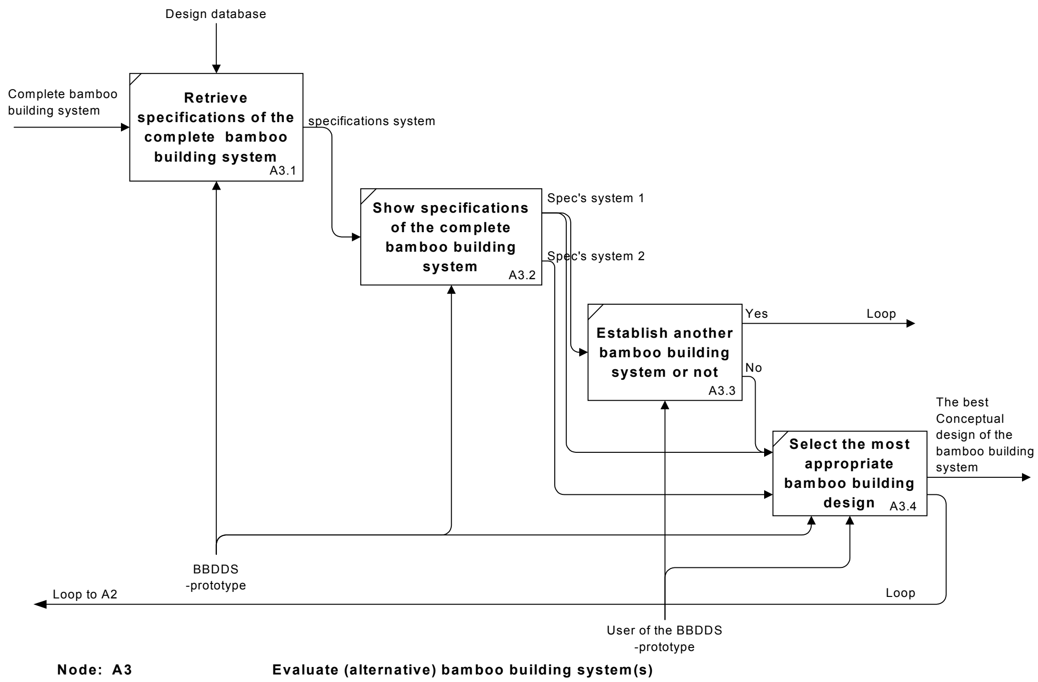

Figure B.12: **Evaluate (alternative) bamboo building system(s)**

Activity or arrow name	**Definition**
A3.1: Retrieve specifications of the complete bamboo building system	Retrieve the specification of the found bamboo building system
A3.2: Show specifications of the complete bamboo building system	Show the specific performances of the bamboo building system
A3.3: Establish another bamboo system or not	Determine whether or not the user wants to establish another bamboo building system
A3.4: Select the most complete bamboo building design	Select the most appealing total bamboo building design

Appropriate conceptual design of bamboo building system	Requirements that concern the bamboo building design
BBDDS –prototype	The demo programme of the BBDDS
The Best conceptual design of bamboo building system	An integrated bamboo building system which fulfils the user's requirements
Complete bamboo building system	A combination of all possible systems in the bamboo building system to meet the requirements
Design database	Several databases contain data and bamboo knowledge
Loop	A redirection in the programme
Specifications system	Specific performances of the bamboo building system
Spec's system 1	First pattern of the specific performances of the bamboo building system
Spec's system 2	Second pattern of the specific performances of the bamboo building system
User of the BBDDS –prototype	The user of the software has to make decisions

Appendix C:

Sub-table 2.1
Determined Value:
Connection Type: One Dimension
Connection Form: I
Member Material: Full Culm

From result	2.1									
Condition ...[*)]	X									
Structure Type	Truss					Frame				
Connection Force (s)	Com press ion	Tensi on	She- ar	Ben- ding Mom ent	Don't Care	Com pres sion	Tens ion	She- ar	Bend ing Mom ent	Don't Care
Show existence of the connection	X	X	-	-	X	-	-	-	X	X
Result	3.1	3.2			3.3				3.4	3.5

Condition of the connection existence from previous sub-table
……
... ...

Sub-table 2.25
Determined value:
Connection Type: Three Dimensions
Connection Form: III
Member Material: Plybamboo
Note: we assume that sub-table 2.24 ends with result 3.49

From result	2.25									
Condition ...[*)]	X									
Structure Type	Truss					Frame				
Connection Force (s)	Comp ress- ion	Tension	Shear	Bend- ing Mo- ment	Don't Care	Com press ion	Tension	Shear	Bend- ing Mo- ment	Don't Care
Show existence of the connection	X	X	-	-	X	-	-	-	X	X
Result	3.50	3.51			3.52				3.53	3.54

[*)] The complete text: "Condition of the connection existence from previous sub-table"
[*)] The complete text: "Condition of the connection existence from previous sub-table"

Sub-table 3.1

Determined Value:

Connection Type: One Dimension
Connection Form: I
Member Material: Full Culm
Structure Type: Truss
Connection Force(s): Compression

From result	3.1			
Condition ...*)	X			
Connection Filler	Wood OR Laminated bamboo OR Ply-bamboo	Full Culm Bamboo	Half Culm Bamboo	Steel Plate
Show existence of the connection	X	X	X	X
Result	4.1	4.2	4.3	4.4

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Sub-table 3.54

Determined Value:

Connection Type: Three Dimensions
Connection Form: III
Member Material: Plybamboo
Structure Type: Frame
Connection Force(s): Don't care

From result	3.54			
Condition ... *)	X			
Connection Filler	Wood OR Laminated bamboo OR Ply-bamboo	Full Culm Bamboo	Half Culm Bamboo	Steel Plate
Show existence of the connection	-	-	-	X
Result				4.??

*) The complete text: "Condition of the connection existence from previous sub-table"
*) The complete text: "Condition of the connection existence from previous sub-table"

Sub-table 4.1

Determined Value:
Connection Type: One Dimension
Connection Form: I
Member Material: Full Culm
Structure Type: Truss
Connection Force(s): Compression
Connection Filler: Wood OR Laminated bamboo OR Ply-bamboo

From result	4.1					
Condition ... *)	X					
Connection Material	Wood OR bamboo pin	Steel bolt	Natural ropes	Glue	Nail	Combina-tion
Show existence of the connection	X	X	-	-	-	X
Show Image	X	X	-	-	-	X
Result	5.1	5.2				5.3

... ...
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……

Sub-table 4.??

Determined Value:
Connection Type: Three Dimensions
Connection Form: III
Member Material: Plybamboo
Structure Type: Frame
Connection Force(s): Don't care
Connection Filler: Steel Plate

From result	4.??					
Condition ... *)	X					
Connection Material	Wood pin OR bamboo pin	Steel bolt	Natural ropes	Glue	Nail	Combina tion
Show existence of the connection	-	X	-	-	-	-
Show Image	-	X	-	-	-	-
Result		5.???				

*) The complete text: "Condition of the connection existence from previous sub-table"
*) The complete text: "Condition of the connection existence from previous sub-table"

Appendix D1:

Satisfaction questionnaire

This questionnaire contains statements concerning your background and your results after using the software. Please complete this questionnaire and return it. The results will be used to improve the prototype.
If a question or a statement does not apply to your situation, please fill in the "not applicable option".
Please mark the box of your choice with an "X". For example.:

….[ ]…….[X]…….[ ]…….[ ]…….[ ]…….

A. Your background

1. What is your main work?
   a. Building Designer
   b. Construction worker
   c. Maintenance worker
   d. Public officer
   e. Bamboo Artisan
   f. Other, please specify ……………………………………..

2. Please, indicate your familiarity with computers
   a. Poor
   b. Less than fair
   c. Fair
   d. More than fair
   e. Good

3. Please, indicate your level of experience in *architectural-design projects of a bamboo building*.
   a. Building layout

Not applicable	Poorly skilled	A little bit skilled	Fairly skilled	Quite skilled	Highly skilled
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

   b. Building space plan

Not applicable	Poorly skilled	A little bit skilled	Fairly skilled	Quite skilled	Highly skilled
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

c. Building structure

Not applicable	Poorly skilled	A little bit skilled	Fairly skilled	Quite skilled	Highly skilled
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

d. Building skin

Not applicable	Poorly skilled	A little bit skilled	Fairly skilled	Quite skilled	Highly skilled
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

e. Building services

Not applicable	Poorly skilled	A little bit skilled	Fairly skilled	Quite skilled	Highly skilled
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

4. Please, indicate your level of experience in bamboo-building *construction projects*

a. Building layout

Not applicable	Poorly skilled	A little bit skilled	Fairly skilled	Quite skilled	Highly skilled
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

b. Building space plan

Not applicable	Poorly skilled	A little bit skilled	Fairly skilled	Quite skilled	Highly skilled
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

c. Building structure

Not applicable	Poorly skilled	A little bit skilled	Fairly skilled	Quite skilled	Highly skilled
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

d. Building skin

Not applicable	Poorly skilled	A little bit skilled	Fairly skilled	Quite skilled	Highly skilled
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

e. Building services

Not applicable	Poorly skilled	A little bit skilled	Fairly skilled	Quite skilled	Highly skilled
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

B. Your satisfaction with the prototype

1. Please indicate how satisfied you were regarding the design process of wall-parts related to the following aspects
   a. Wall shape

Not satisfied	A little bit satisfied	Fairly satisfied	Quite satisfied	Very satisfied
[ ]	[ ]	[ ]	[ ]	[ ]

   b. Wall opening

Not satisfied	A little bit satisfied	Fairly satisfied	Quite satisfied	Very satisfied
[ ]	[ ]	[ ]	[ ]	[ ]

   c. Wall frame

Not satisfied	A little bit satisfied	Fairly satisfied	Quite satisfied	Very satisfied
[ ]	[ ]	[ ]	[ ]	[ ]

   d. Wall filler

Not satisfied	A little bit satisfied	Fairly satisfied	Quite satisfied	Very satisfied
[ ]	[ ]	[ ]	[ ]	[ ]

   e. Wall connection

Not satisfied	A little bit satisfied	Fairly satisfied	Quite satisfied	Very satisfied
[ ]	[ ]	[ ]	[ ]	[ ]

2. Please indicate how satisfied you were regarding the treatment of the interrelationship between the elements of the wall (shape, opening, frame, filler, and connection).

Not satisfied	A little bit satisfied	Fairly satisfied	Quite satisfied	Very satisfied
[ ]	[ ]	[ ]	[ ]	[ ]

3. Please indicate your freedom in selecting and discovering the design process in this prototype.

Not free	A little bit free	Fairly free	Quite free	Very free
[ ]	[ ]	[ ]	[ ]	[ ]

4. Please indicate how satisfied you were regarding the support of the design process while using this prototype.

Not satisfied	A little bit satisfied	Fairly satisfied	Quite satisfied	Very satisfied
[ ]	[ ]	[ ]	[ ]	[ ]

5. Please indicate whether your design improved due to the use of the prototype.

Not improved	A little bit improved	Fairly Improved	Quite improved	Very much improved
[ ]	[ ]	[ ]	[ ]	[ ]

6. Please indicate the suitability of the knowledge for the design or construction problems provided in this prototype.

Not important	A little bit important	Fairly Important	Quite important	Very important
[ ]	[ ]	[ ]	[ ]	[ ]

7. Does this prototype really help you in designing a bamboo building?

Not helpful	A little bit helpful	Fairly helpful	Quite helpful	Very helpful
[ ]	[ ]	[ ]	[ ]	[ ]

8. Please indicate how satisfied you were with the layout of the user interface of this prototype.

Not satisfied	A little bit satisfied	Fairly satisfied	Quite satisfied	Very satisfied
[ ]	[ ]	[ ]	[ ]	[ ]

9. Do you agree that this prototype can improve the quality of a design?

Disagree	Disagree more than agree	Neutral	Agree more than disagree	Agree
[ ]	[ ]	[ ]	[ ]	[ ]

10. Do you have any other opinions about this prototype? (for example: strong and weak points of the prototype, user interface of the prototype, etc.). (You may write on additional paper if required)

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11. Do you have any suggestions for improvements of this prototype?
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Appendix D2:

Values given for the questionnaires answers

A linear value was given for each of the selected answers from the questionnaire, as follows:

1. Question A2:

	Answer	Value
a	Poor	1
b	Less than fair	2
c	Fair	3
d	More than fair	4
e	Good	5

2. Question A3a, A3b, A3c, A3d, A3e, A4a, A4b, A4c, A4d, and A4e

	Answer	Value
a	Poorly skilled	1
b	A little bit skilled	2
c	Fairly skilled	3
d	Quite skilled	4
e	Highly skilled	5

3. Question B1a, B1b, B1c, B1d, B1e, B2, B4, and B8

	Answer	Value
a	Not satisfied	1
b	A little bit satisfied	2
c	Fairly satisfied	3
d	Quite satisfied	4
e	Very satisfied	5

4. Question B3

	Answer	Value
a	Not free	1
b	A little bit free	2
c	Fairly free	3
d	Quite free	4
e	Very free	5

5. Question B5

	Answer	Value
a	Not improved	1
b	A little bit improved	2
c	Fairly improved	3
d	Quite improved	4
e	Very improved	5

6. Question B6

	Answer	Value
a	Not important	1
b	A little bit important	2
c	Fairly important	3
d	Quite important	4
e	Very important	5

7. Question B7

	Answer	Value
a	Not helpful	1
b	A little bit helpful	2
c	Fairly helpful	3
d	Quite helpful	4
e	Very helpful	5

8. Question B9

	Answer	Value
a	Disagree	1
b	Disagree more than agree	2
c	Neutral	3
d	Agree more than disagree	4
e	Agree	5

Appendix D3:

Table D3.1: Working area of the respondents

Participant number	Working area of the Participants
1	Social Department for Relief and Rehabilitation
2	NGO Leader
3	Industrial Designer
4	Bamboo board Industry
5	Wood scientist
6	Social worker (NGO)
7	Builder/Bamboo enthusiast
8	Building Designer
9	Product Designer
10	Public officer
11	Civil Engineer
12	Landscaping and farming
13	Forester (Officer of Forest Department)
14	Building Designer
15	Building Designer
16	Bamboo & Rattan Development
17	Public officer
18	NGO
19	Building Designer
20	NGO
21	Bamboo artisan
22	Building Designer
23	Construction worker
24	Bamboo Artisan
25	Public officer
26	Construction worker (Contractor)
27	NGO in Mizoram
28	Construction worker
29	Public officer
30	Bamboo artisan
31	Public officer
32	Social worker
33	Building designer
34	NGO
35	Construction worker
36	Social worker for rural area

Table D3.2: **The questionnaire results for all Participants**

Partici-pant number	Working area of the Participants	Participant's Background												Participant's satisfaction											
		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
1	Social Department for Relief and Rehabilitation	1	2	2	2	2	3	3	3	2	3	3	2	2	2	2	2	3	2	0	3	2	3	3	4
2	NGO Leader	5	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3
3	Industrial Designer	4	3	5	3	3	4	3	4	3	3	3	4	4	5	4	4	4	5	5	4	5	5	5	5
4	Bamboo board Industry	4	1	2	2	1	1	2	2	2	2	1	3	3	3	3	3	3	4	4	4	0	5	4	3
5	Wood scientist	3	1	2	2	2	2	2	2	2	2	2	4	3	4	4	4	3	3	4	4	5	5	4	5
6	Social worker (NGO)	1	1	2	2	2	2	2	2	2	3	1	2	2	1	2	1	3	2	3	2	2	3	2	2
7	Builder/Bamboo enthusiast	4	3	3	3	2	3	3	3	2	2	3	4	4	4	3	4	3	4	4	3	5	5	4	5
8	Building Designer	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5
9	Product Designer	3	3	3	3	3	4	3	2	3	4	4	4	3	5	4	5	4	5	5	4	5	4	3	5
10	Public officer	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5

Continued→

Partici-pant number	Working area of the Participants	Participant's Background												Participant's satisfaction										
		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
11	Civil Engineer	1	2	2	2	2	2	1	1	1	1	1	2	2	2	2	2	2	4	3	3	3	4	4	5
12	Landscaping and farming	2	1	1	1	1	1	1	1	1	1	1	5	5	4	4	5	5	5	4	4	4	4	5	5
13	Forester (Officer of Forest Department)	1	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	5	5	1	2	5	5	5	5
14	Building Designer	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	3	5
15	Building Designer	5	4	5	5	4	4	2	3	3	3	3	4	4	4	5	5	5	5	4	4	4	4	4	4
16	Bamboo & Rattan Development	2	3	3	2	2	3	3	3	3	3	3	4	5	5	4	4	4	5	4	4	5	4	4	5
17	Public officer	5	3	3	3	3	3	2	2	2	2	2	5	5	5	5	5	4	5	5	4	4	4	4	5
18	NGO	2	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	4	5	5	4	4	5
19	Building Designer	5	4	4	5	5	4	4	4	4	4	3	4	4	5	4	4	5	5	5	4	4	5	3	5
20	NGO	3	1	1	2	2	1	2	2	2	2	1	4	4	4	4	4	3	4	5	4	4	5	4	5
21	Bamboo artisan	3	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	5	4	5	5	5	5	5	5

Continued→

Partici-pant number	Working area of the Participants	Participant's Background												Participant's satisfaction										
		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
22	Building Designer	3	4	4	5	4	4	4	4	4	4	4	3	4	3	3	3	4	4	4	4	5	4	5	4
23	Construction worker	4	5	5	5	5	4	4	4	4	4	3	5	5	5	5	5	5	4	4	5	4	5	4	4
24	Bamboo Artisan	2	3	3	4	4	3	4	4	5	5	4	5	5	4	5	5	4	4	4	5	5	4	4	4
25	Public officer	3	2	2	2	2	2	3	3	4	3	4	4	4	4	4	4	5	4	4	4	3	4	4	4
26	Construction worker (Contractor)	2	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	4	4	4	4	4	5
27	NGO in Mizoram	1	2	2	2	2	2	3	3	3	3	2	4	4	3	4	3	4	4	3	2	5	4	5	5
28	Construction worker	4	3	3	3	3	3	4	4	4	3	3	3	3	3	3	2	4	3	4	4	4	3	4	5
29	Public officer	3	2	2	2	1	1	2	2	2	2	2	3	3	3	4	3	4	3	4	2	3	4	4	5
30	Bamboo artisan	2	3	3	3	3	3	2	2	2	2	2	3	3	4	3	3	4	4	3	3	3	4	4	4
31	Public officer	1	2	2	2	2	2	3	3	3	3	3	4	4	3	4	4	3	4	3	3	4	4	4	5
32	Social worker	1	3	3	3	3	2	2	2	2	2	2	3	3	2	3	3	3	4	3	3	4	4	4	5

Continued→

Partici-pant number	Working area of the Participants	Participant's Background												Participant's satisfaction											
33	Building designer	4	3	3	3	2	2	3	3	2	2	2	3	4	4	4	5	5	5	3	4	3	4	5	5
34	NGO	3	1	1	1	1	1	2	2	2	2	1	3	3	3	4	5	4	4	3	3	3	4	4	4
35	Construction worker	2	3	3	3	3	2	3	3	3	3	2	4	4	4	4	4	5	5	3	3	4	5	4	4
36	Social worker for rural area	4	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	5	5	5	4	5
Question number		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
Overall average		2.89	2.56	2.72	2.75	2.58	2.56	2.69	2.78	2.75	2.78	2.56	3.58	3.61	3.58	3.64	3.67	3.92	4.03	3.61	3.61	3.86	4.17	3.97	4.56

Table D3.3: **The questionnaire results for Participants belong to Group 1 (Public officer, social worker, or NGO)**

Partici-pant number	Working area of the Participants	Participant's Background												Participant's satisfaction											
		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
1	Social Department for Relief and Rehabilitation	1	2	2	2	2	3	3	3	2	3	3	2	2	2	2	2	3	2	0	3	2	3	3	4
2	NGO Leader	5	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3
6	Social worker (NGO)	1	1	2	2	2	2	2	2	2	3	1	2	2	1	2	1	3	2	3	2	2	3	2	2
10	Public officer	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5
17	Public officer	5	3	3	3	3	3	2	2	2	2	2	5	5	5	5	5	4	5	5	4	4	4	4	5
18	NGO	2	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	4	5	5	4	4	5
20	NGO	3	1	1	2	2	1	2	2	2	2	1	4	4	4	4	4	3	4	5	4	4	5	4	5
25	Public officer	3	2	2	2	2	2	3	3	4	3	4	4	4	4	4	4	5	4	4	4	3	4	4	4
27	NGO in Mizoram	1	2	2	2	2	2	3	3	3	3	2	4	4	3	4	3	4	4	3	2	5	4	5	5
29	Public officer	3	2	2	2	1	1	2	2	2	2	2	3	3	3	4	3	4	3	4	2	3	4	4	5
31	Public officer	1	2	2	2	2	2	3	3	3	3	3	4	4	3	4	4	3	4	3	3	4	4	4	5
32	Social worker	1	3	3	3	3	2	2	2	2	2	2	3	3	2	3	3	3	4	3	3	4	4	4	5
34	NGO	3	1	1	1	1	1	2	2	2	2	1	3	3	3	4	5	4	4	3	3	3	4	4	4
36	Social worker for rural area	4	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	5	5	5	4	5
Question number		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
Overall average		2.89	2.56	2.72	2.75	2.58	2.56	2.69	2.78	2.75	2.78	2.56	3.58	3.61	3.58	3.64	3.67	3.92	4.03	3.61	3.61	3.86	4.17	3.97	4.56
Average for Group 1		2.67	1.87	1.93	2.00	1.93	1.87	2.27	2.27	2.27	2.33	2.07	3.13	3.13	2.87	3.27	3.13	3.33	3.33	3.07	3.00	3.27	3.53	3.4	4.13

Table D3.4: **The questionnaire results for Participants belong to Group 2 (Industrial designer, bamboo board industry, product designer)**

Partici-pant number	Working area of the Participants	Participant's Background												Participant's satisfaction											
		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
3	Industrial Designer	4	3	5	3	3	4	3	4	3	3	3	4	4	5	4	4	4	5	5	4	5	5	5	5
4	Bamboo board Industry	4	1	2	2	1	1	2	2	2	2	1	3	3	3	3	3	3	4	4	4	0	5	4	3
5	Wood scientist	3	1	2	2	2	2	2	2	2	2	2	4	3	4	4	4	3	3	4	4	5	5	4	5
9	Product Designer	3	3	3	3	3	4	3	2	3	4	4	4	3	5	4	5	4	5	5	4	5	4	3	5
13	Forester (Officer of Forest Department)	1	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	5	5	1	2	5	5	5	5
16	Bamboo & Rattan Development	2	3	3	2	2	3	3	3	3	3	3	4	5	5	4	4	4	5	4	4	5	4	4	5
Question number		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
Overall average		2.89	2.56	2.72	2.75	2.58	2.56	2.69	2.78	2.75	2.78	2.56	3.58	3.61	3.58	3.64	3.67	3.92	4.03	3.61	3.61	3.86	4.17	3.97	4.56
Average for Group 2		2.83	2.17	2.83	2.33	2.17	2.67	2.17	2.50	2.50	2.67	2.50	3.50	3.33	4.00	3.50	3.67	3.83	4.50	3.83	3.67	4.17	4.67	4.17	4.67

Table D3.5: **The questionnaire results for Participants belong to Group 3 (Builder, construction worker, and bamboo artisan)**

Partici-pant number	Working area of the Participants	Participant's Background												Participant's satisfaction											
		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
7	Builder/Bamboo enthusiast	4	3	3	3	2	3	3	3	2	2	3	4	4	4	3	4	3	4	4	3	5	5	4	5
21	Bamboo artisan	3	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	5	4	5	5	5	5	5	5
23	Construction worker	4	5	5	5	5	4	4	4	4	4	3	5	5	5	5	5	5	4	4	5	4	5	4	4
24	Bamboo Artisan	2	3	3	4	4	3	4	4	5	5	4	5	5	4	5	5	4	4	4	5	5	4	4	4
26	Construction worker (Contractor)	2	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	4	4	4	4	4	5
28	Construction worker	4	3	3	3	3	3	4	4	4	3	3	3	3	3	3	2	4	3	4	4	4	3	4	5
30	Bamboo artisan	2	3	3	3	3	3	2	2	2	2	2	3	3	4	3	3	4	4	3	3	3	4	4	4
35	Construction worker	2	3	3	3	3	2	3	3	3	3	2	4	4	4	4	4	5	5	3	3	4	5	4	4
Question number		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
Overall average		2.89	2.56	2.72	2.75	2.58	2.56	2.69	2.78	2.75	2.78	2.56	3.58	3.61	3.58	3.64	3.67	3.92	4.03	3.61	3.61	3.86	4.17	3.97	4.56
Average for Group 3		2.87	3.25	3.25	3.37	3.25	3.00	3.50	3.50	3.50	3.37	3.12	4.12	4.12	4.12	4.00	4.00	4.37	4.12	3.87	4.00	4.25	4.37	4.12	4.50

Table D3.6: **The questionnaire results for Participants belong to Group 4 (Building designer)**

Partici-pant number	Working area of the Participants	Participant's Background												Participant's satisfaction											
		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
8	Building Designer	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5
11	Civil Engineer	1	2	2	2	2	2	1	1	1	1	1	2	2	2	2	2	2	4	3	3	3	4	4	5
12	Landscaping and farming	2	1	1	1	1	1	1	1	1	1	1	5	5	4	4	5	5	5	4	4	4	4	5	5
14	Building Designer	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	3	5
15	Building Designer	5	4	5	5	4	4	2	3	3	3	3	4	4	4	5	5	5	5	4	4	4	4	4	4
19	Building Designer	5	4	4	5	5	4	4	4	4	4	3	4	4	5	4	4	5	5	5	4	4	5	3	5
22	Building Designer	3	4	4	5	4	4	4	4	4	4	4	3	4	3	3	3	4	4	4	4	5	4	5	4
33	Building designer	4	3	3	3	2	2	3	3	2	2	2	3	4	4	4	5	5	5	3	4	3	4	5	5
Question number		A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
Overall average		2.89	2.56	2.72	2.75	2.58	2.56	2.69	2.78	2.75	2.78	2.56	3.58	3.61	3.58	3.64	3.67	3.92	4.03	3.61	3.61	3.86	4.17	3.97	4.56
Average for Group 4		3.75	3.12	3.25	3.5	3.12	3.00	2.75	2.87	2.75	2.75	2.62	3.50	3.75	3.62	3.62	3.87	4.12	4.37	3.75	3.87	3.87	4.25	4.25	4.75

Table D3.7: **Means value of the Participants answers according to its category**

	Participant's Backgrounds											Participant's satisfactions												
	A2	A3a	A3b	A3c	A3d	A3e	A4a	A4b	A4c	A4d	A4e	B1a	B1b	B1c	B1d	B1e	B2	B3	B4	B5	B6	B7	B8	B9
Average for all (36 persons)	2.89	2.56	2.72	2.75	2.58	2.56	2.69	2.78	2.75	2.78	2.56	3.58	3.61	3.58	3.64	3.67	3.92	4.03	3.61	3.61	3.86	4.17	3.97	4.56
Average for Group 1 (14 persons)	2.67	1.87	1.93	2.00	1.93	1.87	2.27	2.27	2.27	2.33	2.07	3.13	3.13	2.87	3.27	3.13	3.33	3.33	3.07	3.00	3.27	3.53	3.4	4.13
Average for Group 2 (6 persons)	2.83	2.17	2.83	2.33	2.17	2.67	2.17	2.50	2.50	2.67	2.50	3.50	3.33	4.00	3.50	3.67	3.83	4.50	3.83	3.67	4.17	4.67	4.17	4.67
Average for Group 3 (8 persons)	2.87	3.25	3.25	3.37	3.25	3.00	3.50	3.50	3.50	3.37	3.12	4.12	4.12	4.12	4.00	4.00	4.37	4.12	3.87	4.00	4.25	4.37	4.12	4.50
Average for Group 4 (8 persons)	3.75	3.12	3.25	3.5	3.12	3.00	2.75	2.87	2.75	2.75	2.62	3.50	3.75	3.62	3.62	3.87	4.12	4.37	3.75	3.87	3.87	4.25	4.25	4.75

TERMINOLOGY USED IN THIS THESIS

Artefact

An artefact is a useful object that is going 'to be made' for a specific purpose. In this thesis artefact is used to define a building, or parts of a building as the final result or intermediate results during the design process.

Backward chaining *)

Backward chaining is an inference technique that starts with a hypothetical solution (a goal) and works backwards, matching rules from the rule base with facts from the database until the goal is either verified or proven wrong. It is also referred to as Goal-driven reasoning.

Bamboo Building System

A bamboo building system is a building system that uses bamboo as one of its materials.

Building System

A building system is a set of devices, parts or components of a building based on a certain number of rules; each part has a function in the building, both on its own and when combined with the other parts.`

Data

Data is a set of values corresponding to the attributes of a single object. A data record is a row in a database. It is also referred to as Record.

DDSS

DDSS is an abbreviation of 'Design Decision Support System', a system to support decision-making processes in design.

DDST

DDST is an abbreviation of 'Design Decision Support Tool', a tool to support decision-making processes in design.

DSS

DSS is an abbreviation of 'Decision Support System', a system to support decision-making processes in many fields, such as design, construction, maintenance and management. It is usually an interactive computer-based system designed to help a person or a group of people to make a decision in a specific domain.

Forward chaining *)

Forward chaining is an inference technique that starts from known data and works forward, matching the facts from the database with production rules from the rule base until no further rules can be fired. It is also referred to as Data-driven reasoning.

Inference engine *)

A part of an expert system that contains the inference and control strategies. It determines the order in which the rules fire. The inference engine also includes the knowledge acquisition, explanation, and user interface sub-systems.

Knowledge Base *)

A part of an expert system consisting of facts and heuristics about a domain. A knowledge base contains rules, facts, and various constructs to guide inferencing and questioning.

Knowledge-based system

A system that uses stored knowledge for solving problems in a specific domain. A knowledge-based system is usually evaluated by comparing its performance with the performance of a human expert.

Programme Developer

A programme "not a person" used to build an application programme. In this thesis the programme developer is 'XpertRule Knowledge Builder'.

Prototype

A prototype is an initial version of a system that is developed to test the effectiveness of the overall knowledge representation and inference strategies being employed to solve the particular problem.

Rule

A rule gives a description of an interrelationship between concepts, so it can be considered as the abstraction or generalisation of cases. Rules provide inferences for standard situations, while cases can be used in the absence of rules. Rules can be extracted from cases by induction.

Taxonomy

Taxonomy is a hierarchical classification and naming of things such as buildings and processes in groups within a larger system, according to their similarities and differences. In this thesis taxonomy is used to describe aspects of design problems and possible solutions in bamboo building design activities.

Trigger

A special type of stored procedure that is executed by the programme when an insert, modify, or delete operation is performed against a given table. If the trigger fails the request, the information update is refused and an error message is returned to the application attempting the transaction.

Validation *)

Building the right system, that is, writing specifications and checking performance to make sure that the system does what it is supposed to do. It determines the correctness of an end product conformance of the output with the customer's established requirements and completeness of the system.

Verification *)

Building the system right, that is, ensuring that the system correctly implements the specifications. It determines the conformance of the knowledge base to its design requirements and with the software syntax from which it was built. It also guarantees the consistency of the product at the end of each phase, with itself and with the previous prototypes. In other words, it guarantees the honest and smooth transition from one prototype to another.

*) Bahill, A.T. (1991) Verifying and Validating Personal Computer based Expert System, Prentice Hall Inc., Englewood Cliffs.

SUMMARY

Bamboo is the fastest growing woody plant that can be used as a renewable resource for agroforestry production. It is useful as a building material, being structurally stronger than steel, lightweight, easily workable and with good vibration damping properties. Bamboo comes in culms, ‘pre-finished’ by nature, and can be used without much processing.

The application of bamboo as a building material suffers greatly from the lack of applied scientific research. Bamboo and bamboo-based products should be brought up to the level of other accepted building materials. This would enable the bamboo-sector to benefit from the enormous design expertise and product range available in the building industry. Bamboo can gain entry into the building products market as an environmentally friendly material, a wood substitute, and an alternative for other building materials. The current technology of bamboo buildings is at the level of poor, rural households, making bamboo buildings without the help of modern tools. The final technology of bamboo buildings could be at industry level. This PhD-project could contribute to better housing in developing countries.

Each bamboo growing country has a different kind of vernacular bamboo building tradition, without professional intervention or support, without the guidance of designs or plans, without the possibility of learning from experience abroad. Though the number of examples of splendid bamboo architecture is growing, and an increasing (but still small) number of architects and structural designers are specialising in designing bamboo buildings, the availability and dissemination of appropriate design knowledge, competence and experience needed to improve the quality of bamboo buildings is still far from sufficient. Several books do provide important detailed information about houses, clinics, schools and other small buildings made from bamboo. These books simply list facts about the buildings and do not offer a systematic approach. Furthermore, they only describe existing bamboo buildings, while giving hardly any information or guidance on how to design them. A systematic design-oriented approach is lacking. These three facts (the lack of transfer, system and design support) constrain the improvement of bamboo building designs.

The objective of this PhD-project is to contribute to a solution to this constraint by providing a bamboo building design decision support tool, based on knowledge of bamboo and design, to be used as a guide for designers and practitioners to make decisions in their design, construction and maintenance activities. The results will be published as a thesis and as a practical tool (book and software), and will be distributed to groups in developing countries.

The thesis starts with a description of the preliminary conditions: climate, cultural habits, earthquake hazards, locally available bamboo species, etc. It analyses the common design and bamboo building practices with an emphasis on the issues in which the designer should be supported. All these aspects are mapped out systematically. The relevance of knowledge-based systems and decision support systems for design are described. Much attention is given to the user interface. Design activities are described in an IDEF0 format. Software selection criteria are formulated for this purpose. Software is selected and, using the best option, the tool is developed: a design decision support tool based on bamboo building knowledge. Verification and validation are discussed, as well as the reactions of a group of users. A working prototype for the design of a wall for a bamboo house shows the options and the capabilities of the described tool. The thesis ends with conclusions and recommendations.

SAMENVATTING

Bamboe is een snel groeiende plant die een grote rol kan spelen als een hernieuwbare bron van bouwmateriaal. Het is sterk, licht van gewicht, en makkelijk verwerkbaar. Bamboestammen kunnen gebruikt worden zonder verdere bewerking.

De toepassing van bamboe als bouwmateriaal lijdt onder een achterstand in toegepast wetenschappelijk onderzoek. Bamboe zou een algemeen aanvaard bouwmateriaal moeten zijn. Het is milieu vriendelijk, en het kan hout en andere materialen vervangen. De verwerking van bamboe begint op dorpsniveau, en eindigt op industrieel niveau.

In elk land waar bamboe inheems is bestaat een eigen bouwtraditie, zonder beroepsmatige ondersteuning, en zonder overdracht van kennis van elders. Hoewel er een vooruitgang te zien is in het aantal architecten dat zich bezig houdt met bouwen in bamboe, is de beschikbare kennis over ontwerpen ver van voldoende. Er bestaan verschillende handboeken over bouwen met bamboe, maar een systematische aanpak van het ontwerpen ontbreekt. Het gebrek aan kennisoverdracht en aan systematische aanpak van het ontwerp beperken de verbetering van ontwerpen van bamboe gebouwen.

Het doel van dit proefontwerp is een bijdrage te leveren aan genoemde verbetering, door het ontwikkelen van een hulpgereedschap dat de ontwerper bij het nemen van beslissingen tijdens het ontwerpen bijstaat. Dit gereedschap is gebaseerd op kennis van bamboe en op kennis van ontwerpen.

De documentatie van het proefontwerp begint met een beschrijving van de randvoorwaarden waaraan een ontwerp moet voldoen. Het geeft een analyse van alle eisen waaraan een ontwerp moet voldoen, en hoe de ontwerper hierin gesteund kan worden. Een taxonomie is behulpzaam bij het opstellen van een volledig overzicht. Systemen gebaseerd op kennis en op ondersteuning bij het nemen van beslissingen worden beschreven. Veel aandacht wordt besteed aan gebruikersvriendelijkheid. Voor het beschrijven van ontwerp activiteiten wordt IDEFØ gebruikt. Na een verkenning van beschikbare programma's wordt een keuze gemaakt welk programma de voorkeur verdient voor de ontwikkeling van het ontwerpgereedschap. Tenslotte wordt nagegaan of het gereedschap doet wat ervan wordt verlangd, en of het dit op correcte wijze doet. Een werkend prototype is voorgelegd aan een groep ontwerpers, en over hun bevindingen wordt verslag gedaan.

Curriculum Vitae

Fitri Mardjono was born on 9 April 1959 in Boyolali, central Java, Indonesia. He left high school in December 1976 in his hometown, and then studied civil engineering at the Faculty of Engineering, Gadjah Mada University in Yogyakarta, Indonesia. He completed his bachelor degree in October 1980, and his "ingenieurs" exam in July 1982. He has worked at the Faculty of Engineering, Gadjah Mada University as a lecturer from 1983 to the present day. From April 1988 to March 1990 he continued his studies in a masters programme at the Civil Engineering Department at Nagaoka University of Technology, in Nagaoka, Japan; he completed his masters degree in March 1990. Between 1981 and 1987 he was involved in several transmigration/road design projects in several provinces in Indonesia. He was also involved in appraisal projects for several airport pavements in Indonesia between 1990 and 1997. His interest in bamboo structures started in 1992. In the period from August 1998 until December 2002 he was employed as a PhD student in the Structural Design Group, Faculty of Architecture, Building and Planning, at Eindhoven University of Technology, working on his PhD design project to make a Bamboo Building Design Decision Support System.