INTELLIGENT DESIGN SUPPORT

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Abstract. Design is a complex process that is information and communication intensive. In a design context, the use of knowledge technologies can assist designers in making informed design decisions. This paper reports on an educational experiment that implements an intelligent urban design aid. This experiment facilitates students to do research in a systematic way by using ICKT methods, techniques and tools in order to improve the quality of their urban design. We outline the process, describe the intelligent techniques, discuss the results of the educational experiment, and explore the approach's potential for real-life design practices.

1. Introduction

Building design is a multi-actor, multi-discipline and multi-criteria process and is therefore complex. In the entire building process, from initiative until demolition, many actors and disciplines contribute their specific knowledge and information. This is valid for architectural design as well as urban design. Designers must consider a large number of issues in order to reach an optimal design. These issues belong to a wide spectrum, including spatial, aesthetic, functional, formal, economic, political, user comfort and changing requirements. A vast amount and variety of information is involved in this process; information varies from qualitative to quantitative, and includes graphical, textual and numerical data. Therefore, communication between experts from all disciplines and the integration of user input in the design decisions is crucial.

The question then arises: in which way should designers be educated to deal with this complexity in order to reach competence within the limited duration of the educational process? In order to tackle this challenge, we are deploying Information, Communication and Knowledge Technologies (ICKT) as a supplement to traditional methods and techniques, with the intention of establishing ICKT as an essential partner in the design process. The use of knowledge technologies, including intelligent or soft computing techniques, assists designers in making informed decisions. Using such an intelligent instrument, we can formalize the relationships between the aspects that are involved in the design process and optimize the solution space with respect to the large number of criteria in a design problem. This solution space embodies the knowledge of the experts for a given situation. These techniques are very valuable for making more rational design decisions.

We have organized an educational experiment in the form of an MSc elective course that implements such a design aid. We have followed a methodology that involves the collective creation of a knowledge model, and the use of this knowledge model for making design decisions in the final design. This paper reports on the courses held in the Spring semesters of 2003 and 2004. It discusses the context of the course, the methodology used, the process, and the results. The paper ends with conclusions and discussion.

2. The Educational Experiment

The educational experiment has been implemented in the form of an MSc elective course and has been offered to the students for the first time in the Spring semester of 2003. The goal of this course is to educate young professionals/scientists to do research in a systematic way by using ICKT methods, techniques and tools in order to improve their design.

In a number of exercises, the students study an urban design situation by collecting and processing information for a knowledge model, and by applying this model. The course lasts 7 weeks and requires 120 hours of work in total. The course is organized in blocks of 4-hour sessions, one session every week, each consisting of a lecture and a practical work part. On average, eight students take the course each Spring semester.

2.1. CONTEXT

The case study for the course is an urban design transformation of the Wijnhaven area in Rotterdam. It is a triangular island at the edge of the Rotterdam city centre and close to the river Meuse (Figure 1). Specifically, the eastern part of the island, with the exception of the three residential towers that have been completed in 2002 and 2004, is considered as the case study for the course. This part of the island has a surface area of approximately 4.4 ha. The urban blocks in this eastern part decrease in size as they approach the Point of the triangle. Because the city centre of Rotterdam was almost completely destroyed during the Second World War, it primarily consists of postwar office blocks, with average height of 5–8 storeys, dating from the 1950s. These form a usable, but unattractive urban design fabric. Generally, the pedestrian zones are very narrow, especially the ones along the waterfront. During the day, cars are parked at the waterfront, mostly blocking half of the space on the sidewalks.

Figure 1. Wijnhaven island. The aerial picture was taken in the late 1990s.

This lack of sufficient public space is aggravated by the absence of any parks or playgrounds. There is a train/metro/tram station and a bus station at approximately 500 metres. There are no health or socio-cultural facilities on the island. Because it is mainly an office district, it is deserted after working hours. The Wijnhaven island is one of the most expensive locations in a downtown area for residences and offices in the Netherlands, both in terms of selling prices and rents.

The sun exposure of the Wijnhaven island is generally good, especially at the southern part, except for the shadow cast by the large, 88-metre high Nedlloyd building. The island has a direct view towards the city centre on the northern side. The view towards the Meuse river is mostly blocked by buildings on the land strip between the island and the river. At the Point, multiple orientations and views are available. The view from the southern part to the northern part is also blocked because of the turns in the narrow streets between building blocks.

At the end of the1980s, the quality of the area started to decay as a number of office buildings became obsolete, which led to a rise in vacancies (Christiaanse and van den Born, 2002). The Municipality of Rotterdam has created a plan to enhance the area’s residential use, and is currently putting the plan into action. Within the Rotterdam Center Development Plan, it is a part of the Waterfront area, which is planned mostly as a residential area. The plan of the city is to build 3750 residential units in downtown Rotterdam by 2010. The maximum height limit for the area is 150 metres.

Considering the complexity of the situation on the site, and its interesting location, an urban renewal project for the Wijnhaven Island with emphasis on the urban design is an ideal case study for the educational experiment.

3. Methodology

The course accommodates theoretical and practical sessions in parallel. In the theoretical track, lectures cover an overview and introduction to ICKT in the urban design process, considering data gathering, information modelling, cooperative design databases, knowledge acquisition, knowledge representation, machine learning, fuzzy logic, genetic algorithms, and approaches to information processing. In the practical work sessions, first, a problem analysis is done. The students collect relevant information from the current situation, and share and manage this information in a cooperative database environment — InfoBase (Stouffs et al., 2003). This information forms the input for a knowledge model, which uses intelligent computational techniques such as fuzzy logic, neural networks and genetic algorithms. The model clarifies the relations between different aspects and allows the user to infer urban design principles from it. The students use these relations and principles in their own design for the area, up to the level of massing studies, and for the specification of functional entities. In the following subsections, we consider each of these steps in detail.

3.1. DATA COLLECTION AND SITUATION ANALYSIS

A list of aspects serves as a data collection form for the students to use in the situation analysis part of the course (Table 1). These aspects also serve as the variables in the knowledge model. They are mainly based on the Birmingham planning policy framework for tall buildings (Birmingham City Council, 2003). This list is extended and/or modified each semester by the students collectively.

TABLE 1. Aspects — Design variables.

1.	Tall buildings should be restricted to special high-rise zones.	
2.	Tall buildings should emphasize the city's topography.	
3.	Tall buildings should help to create a memorable skyline.	
4.	Tall buildings should be located at key arrival points.	
5.	Tall buildings should not be built in conservation areas.	
6.	Tall buildings should be used to mark public facilities.	Context
7.	Tall buildings should be concentrated in the 40–70 metres range.	
8.	Tall buildings should be concentrated in the 70–120 metres range.	
9.	Tall buildings should be concentrated in the 120–150 metres range.	
10.	There should be no height restrictions on tall buildings.	
11.	The ratio of the length and width of the tall building should not exceed 1:3.	
12.	The design at the bottom of buildings should positively respond to local characteristics.	
13.	Tall buildings should always be at an open square.	
14.	Tall buildings should be designed for mixed-use.	
15.	Buildings should provide different types of spaces at ground floor level. that can accommodate commercial and public facilities.	
16.	Design should accommodate pass-ways or galleria.	
17.	Design should support social safety.	
18.	Design should be energy efficient.	Program criteria
19.	Design should be space efficient.	
20.	Design should be flexible.	

21.	Design should follow the ‘bouwbesluit’ to ensure the safety of building.	
22.	The buildings design should emphasize the view upon the river.	
23.	The buildings design should emphasize the view upon the skyline of the city.	
24.	Tall buildings should be connected to the main systems of public space.	
25.	Park space should be available at walking distance.	
26.	Tall buildings should meet a proven demand in terms of real estate.	
27.	Location should connect to public transport facilities such as metro and train stations (radius = 500 m).	Impact on surroundings
28.	Special design attention is needed for shadowing.	
29.	Special design attention is needed for wind hindrance.	
30.	The area ratio of the building’s base to its top should be high.	
31.	The quality of architectural form is important.	
32.	The quality of detail is important.	
33.	The quality of materials is important.	
34.	The colour of buildings is important.	
35.	The quality of the design of the top of buildings is important.	
36.	Proposal should encompass a well designed lighting scheme.	Architectural design
37.	Proposal should handle antennae, aerial arrays and installations elegantly.	
38.	The visual complexity of the top of buildings should be high.	
39.	The visual complexity at street level should be high.	
40.	Tall buildings should show variation in form and usage at different height levels.	
41.	Street profiles should be rather closed than open.	
42.	Street profiles should be highly varied.	
43.	Cross town traffic and local traffic should be combined.	
44.	Local traffic and destination traffic should be combined.	
45.	Destination traffic and cross town traffic should be combined.	
46.	Local traffic should only take place on ground level.	
47.	Since the Wijnhaveneiland is an island the amount of bridges and their position should meet the demand of new and existing users.	
48.	Access to site by bridges is important.	
49.	Traffic space should be designed in such a way that cars, bikes and pedestrians will get their clearly defined own space.	On site accessibility
50.	The use of light vehicles should be limited by providing alternatives: public transport, walking or biking.	
51.	Trucks should be able to un- or upload on own terrain or inside buildings.	
52.	Cross town traffic should be avoided.	
53.	Pathways and cycleroutes should make walking and biking easy.	
54.	Routes should be safe, direct and convenient.	
55.	Housing and employment should be directly accessible from the street.	
56.	There should be no stairs or other elements between street and entrance.	
57.	Private parking should be solved on own terrain or inside the building itself.	
58.	Limited facilities for visitor parking can be provided in the public space.	

The students went to the site, read articles and did research about the site in relation to these aspects, and each student filled out at least 6 data collection forms. Each aspect in the form is marked by selecting one of 5 slots, ranging from ‘strongly agree’ to ‘strongly disagree’ as a reaction to the statement made. These marks are later normalized to a value between 0 and 1 and all the values from all the sheets are merged together to form a data matrix for the knowledge model.

The students assumed roles while filling these forms. The roles that the students chose were representative of the population that lives on, works on, or visits the island. Interviewing people on the site was also a possibility.

During data collection and situation analysis, each student created a preliminary design before using the knowledge model as a design aid. The purpose of the preliminary design is for both the students and teachers to see the impact of the knowledge model on the design at the end of the course, and to draw conclusions accordingly.

3.2. KNOWLEDGE MODEL

The knowledge model is based on computational intelligence, or *soft computing*, techniques that allow complex information processing tasks, especially from soft sciences, to be dealt with using the computational power of advanced computer technology. The following methods of soft computing are applied in the knowledge model: artificial neural networks, fuzzy logic, and evolutionary algorithms (Durmisevic, 2002).

The students are asked to form a knowledge model based on the knowledge acquired by considering the location in various aspects. The linguistic variables that are considered in this exercise are presented in Table 1. The knowledge acquired in this manner is put into a knowledge matrix where each column represents a data sample and each row represents one of the design variables in totality. The knowledge matrix elements are the normalized assessments of the design variables in five categories between zero and one. Each category is represented by a gaussian fuzzy membership in the form of a multivariable radial basis function. Note that the number of variables is 58, which is pretty high for a fuzzy model with appropriate membership functions established in a fuzzy logic sense. However, implementation of the fuzzy model is conveniently carried out by means of an RBF network using an Orthogonal Least Squares (OLS) training algorithm (Chen et al., 1991). The number of artificial neurons employed in the final model is taken to be half of the number of data samples as a pragmatic rule, as this is not a critical issue. The most important centres, which are responsible for capturing more than 99 per cent of the information, in the sense of energy delivered to the output, are already included in the hidden layer in a sequence of graded importance. Since the locations of the fuzzy membership functions are not tuned during the knowledge model formation, the meaning of the semantic labels remains intact.

Once the knowledge model is established, the design exercise aims to obtain a certain design guide providing a *quality of life*, which is desirably high. The definition of quality of life is left up to each student. For example, in one student's final definition, the *quality of life determinants* as shown in Figure 2 were:

Tall buildings should be located at key arrival points — 0.9
Design should accommodate pass-ways or galleria — 0.8
The area ratio of the building's base to its top should be high — 0.7
Traffic space should be designed in such a way that cars, bikes and pedestrians will get their clearly defined own space — 0.6

In order to fulfill these constraints, the four determinants are taken to be at the output of the knowledge model where the rest of the variables are at the input. Having established the knowledge model as such, the pattern of the input variables, which yields the satisfaction of the quality of life criterion, is searched by means of a genetic algorithm. In the genetic algorithm, a fitness function is defined which is a measure of the quality of life and during the search this measure is pursued to be high. After 100 iterations, the genetic algorithm reached the following values: 0.819, 0.671, 0.676, 0.620.

3.3. USE OF THE KNOWLEDGE MODEL—FINAL DESIGN

The knowledge model is presented to the students as an easy to use application. The user interface has been developed as a Java application, with flexible input and output options (Figure 2). Students can identify their *quality of life* definition by selecting a number of aspects and their values as weights. This definition is in fact the designer's choice about which aspects should get specific attention in the final design for the specific site. Since they have already made a preliminary design, they have a clear idea of what aspects should be accentuated.

The students receive the results from the knowledge model as a graph that shows the input variables and their values according to the selection and values of the output variables (Figure 3). The graphs were particularly clear and readable, because in the results of all the students there was a strong variation between the results: some aspects got a high value, whereas others scored quite low. This offered the students the possibility to particularly emphasize a number of the aspects, and in the same way, to minimize or specifically address some others.

The teachers advised the students to select between two and six output variables for their quality of life definition, and required them to document the whole selection process. This process differed from student to student. Some tried out a number of combinations, and selected the result they deemed best. Others chose a more rigorous approach by starting with one variable, trying out a number of values, and later systematically adding more variables to the selection.

The interpretation of the results was mostly done by selecting an upper and a lower borderline on the graph as shown in Figure 3. The values above and below these borderlines were taken into consideration in the final design. Students interpreted the results of the knowledge model in various ways. Most of them used these results to improve their preliminary design. Some students modified their preliminary design considerably, while others performed minor changes. In either

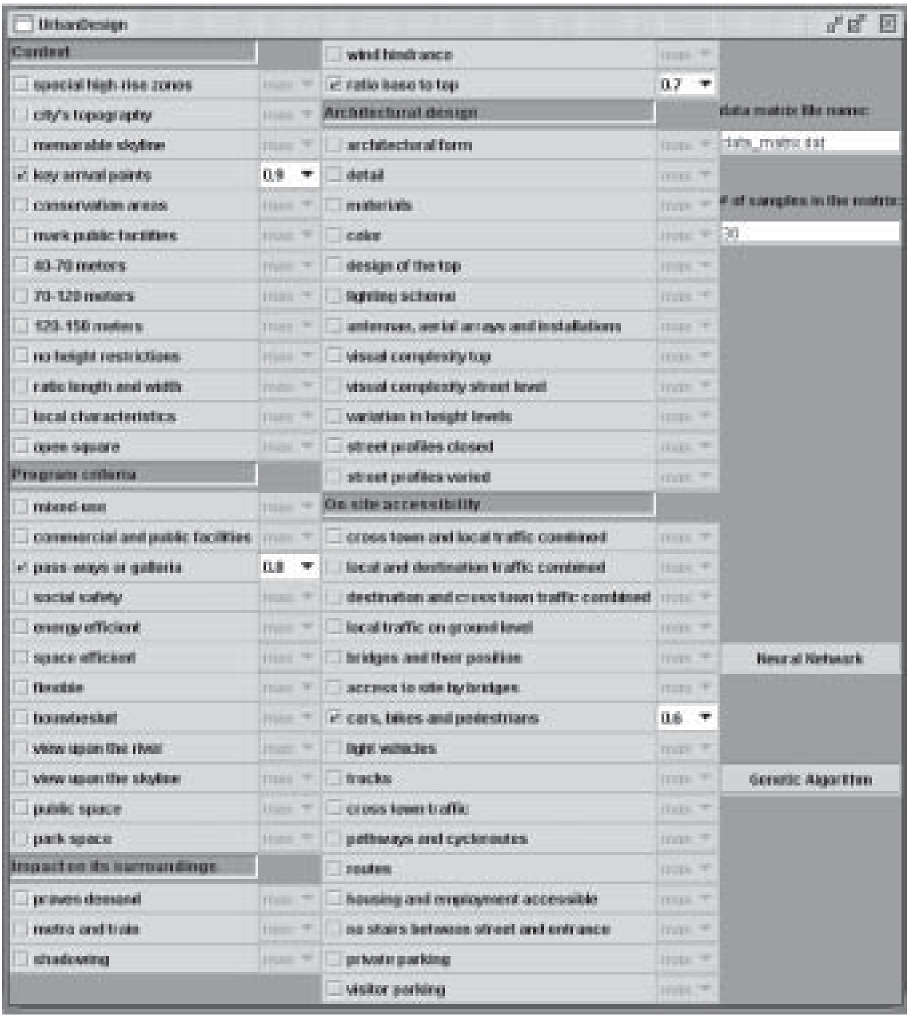

Figure 2. The application for selecting variables and their values in order to define ‘quality of life’, and for operating the knowledge model (result by Wout Stilma, Spring 2004).

case, students were required to reason about and document clearly what changes they made to their design in relation with what the knowledge model advised them. They generally used this advice to analyze their preliminary design and see if it met the necessary criteria. Figure 4 shows some snapshots from exemplary final designs.

In their preliminary design, the students tried to take into account a little bit of every aspect. In the final design, some aspects were especially taken into account, and some minimized, according to the result suggested by the knowledge model. Therefore, it is the general opinion of both the students and the instructors that the final design has more quality, because no consideration was made in the preliminary

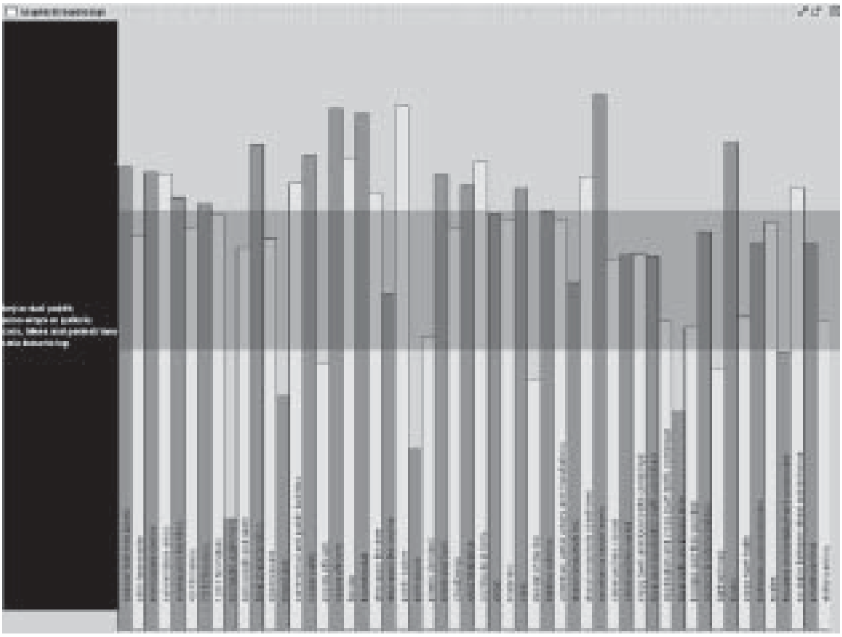

Figure 3. The outcome showing the values of the input variables as the product of the knowledge model (result by Wout Stilma, Spring 2004). The gray area on the graph is chosen by the student as the group of variables that are not focused on in the design.

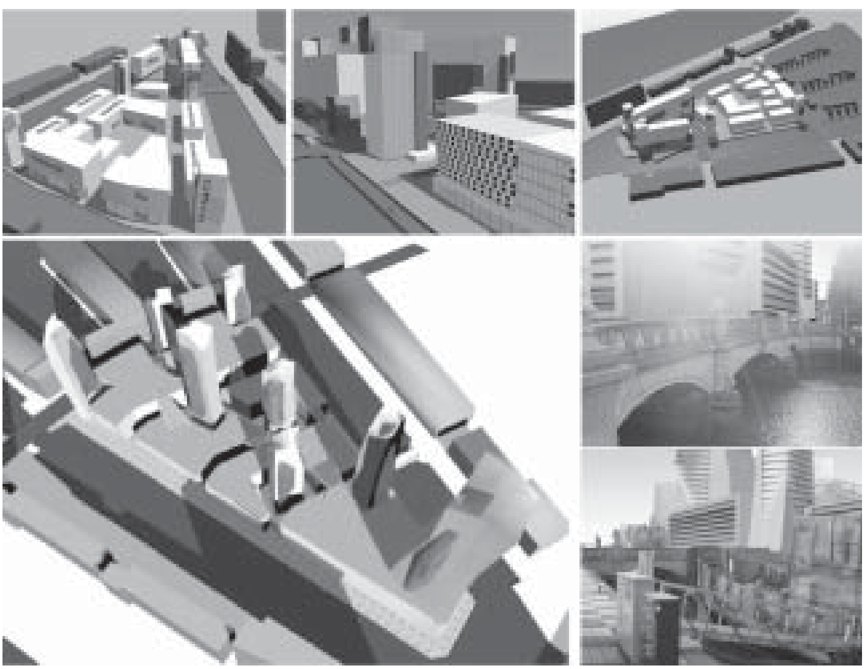

Figure 4. Snapshots from two exemplary final designs, top row by Ewoud Ruifrok, bottom row by Wout Stilma, Spring 2004.

design as to which aspects were the most important. It was also noted by the students that there is a danger that comes forward by only considering the most important aspects in the design, that is, the exclusion of some target groups. Therefore, the possibility exists that the design becomes less sustainable. A solution to this is to guarantee the ideal distribution of roles, representing the intended population on the site, during the information collection phase.

4. Conclusion and discussion

In this paper, we have reported on an educational experiment, which has been offered in the MSc program of our design curriculum. This experiment presents a design process where the students use an intelligent knowledge model as a partner that gives them advice on their design decisions. After using both design methods, with and without a knowledge model, the latter proved to have both advantages and disadvantages. As part of their course requirements, we requested the students to submit a final report in which they discussed the potential value of using an intelligent knowledge model as a partner in real-life design practice. The students expressed some of the advantages of working with a knowledge model as a design partner as follows:

> Defining quality of life provides a guide in the design process.
> It is fun.
> The output of the knowledge model:
> provides an overview of all aspects
> integrates all the collected knowledge in a design, even if one is not aware of it
> can be described as a management tool for dealing with knowledge in support of design
> helps one to determine the critical design factors in complex situations, distinguishing main issues from side issues
> helps one to evaluate the missing issues from a first concept design and which should be adapted
> forces one to think in a certain direction, providing an interesting and eye-opening experience
> does not impose how to design certain things or provide a concrete solution
> directs group discussions and prevents endless arguments.

The students also expressed the following challenges of working with a knowledge model and this specific software:

> The collection of design variables already determines the issues that play an important role in the design.
> It is very important to choose the design variables well and state them specifically enough, such that there is little room for ambiguity when interpreting the results of the model.

Data must be collected with great care.
The interpretation of the outcome is not straightforward, especially when there are conflicting situations, or when a value is very low.
The model offers no spatial contributions.
The user interface needs to be more userfriendly.
Doubts exist about the practical use of these kinds of models in the real world in the near future.

As a conclusion, students find this approach very valuable for testing their design against certain criteria. They find that the knowledge model offers an excellent design guide, but it will not magically produce a revolutionary design.

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