Intelligent design support: an educational experiment in knowledge modeling

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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. The goal of this experiment is to educate young professionals/scientists to be able to do research in a systematic way by using ICKT methods, techniques and tools in order to achieve a better, more effective and more efficient urban design. We outline the process, describe the intelligent techniques, and discuss the results.

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 each 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 is crucial.

Due to time limitation, students can merely aim to have an overall view of the various disciplines involved in the entire design process, and achieve knowledge and understanding of some of these fields, and skills in some others. The question then arises: in which way designers should 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 course held in the Spring semester of 2003. It discusses the context of the course, the methodology used, the process, and the results. The paper ends with conclusions and discussion. All the design examples that have been included in this paper belong to one of the groups that followed this course (van Seventer et al. 2003).

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 be able to do research in a systematic way by using ICKT methods, techniques and tools in order to achieve a better, more effective and more efficient urban design. The topic of this course is the application of methods and techniques from ICKT, applied to knowledge-based modeling of urban design principles. The content of
the course has two main parts: urban design and ICKT. The course is organized in blocks of 4-hour sessions, one session every week, each consisting of a lecture and a practical work part.

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 students submit a written report describing how they made use of the model in their design process. The product of the practical work parts, i.e., the design, is also assessed. The course lasts 7 weeks and requires 120 hours of work in total. Students work in groups of 2 or 3 throughout the course and do all the assignments as group work. 10 students took the course, in 4 groups.

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 center and close to the river Meuse (Fig. 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. The urban blocks in this eastern part decrease in size as they approach the Point of the triangle. Because the city center of Rotterdam was almost completely destroyed during the Second World War, it primarily consists of postwar office blocks, dating from the 1950’s. These form a usable, but unattractive urban design fabric. At the end of the 80’s, the quality of the area started to decay as a number of office buildings became obsolete, which led to a rise in vacancies (Christiaanse & van den Born 2002). However, readapting the buildings has presented typological and financial problems. New development is only profitable for building volumes that contain a large number of dwellings and parking facilities. For this reason the area may run the risk of being overloaded with high-rise towers (Christiaanse 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 (Municipality of Rotterdam 2001). 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 meters.

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. An analysis of the current situation on the eastern part of the island is described in the following subsections, under the headings that were used by students to analyze the site (Indriasari & Moen 2003).

2.1.1 Qualitative aspects

Spatial attractiveness. The eastern part of the island has a surface area of approximately 4.4 ha. The average height of buildings is 5-8 storeys. The area around the Point is empty. Generally, the pedestrian zones are very narrow, especially the ones along the waterfront. This lack of sufficient public space is aggravated by the absence of any parks or playgrounds.

Visual attractiveness. The area is characterized by the use of materials such as concrete and brick, and dark colors such as gray and brown. The skyline displays an unattractive homogeneity of building heights and flat roofs. The area is densely developed. There are narrow streets between buildings and there is a high demand for parking. The island has an overcrowded image.

Functional attractiveness. The island is well accessible for private vehicles, but there is no public transportation. There are a train/metro/tram station and a bus station at approximately 500 meters. Parking is mostly provided along the water. Occupancy of the ground floor is generally dominated by supermarkets and small shops. These are concentrated on the street dividing the eastern and western parts of the island. There is no clear distinction between entrances to housing and offices. There are no health or socio-cultural facilities on the island. There is a library, a vocational school, and an art institute very close to the island, but lower schools and daycare facilities are absent.

Safety. The safety on the island is moderate. It is attractive for young people, but unfortunately, it is not very attractive for children or elderly people due to the lack of public transportation and safety provisions along the water. Because it is mainly an office district, it is deserted after working hours.

Access to daylight/sunlight. The sun exposure of the Wijnhaven island is generally good, especially at the southern part, except for the shadow cast by the large, 88 meters high Nedlloyd building.

Access to views. The island has a direct view towards the city center 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

Figure 1. Wijnhaven island. The aerial picture is taken in the late 90’s.
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.

Acceptability of acoustics/noise. Considering the limited variety of activities on the island, the noise is at an acceptable level.

Traffic and parking accessibility. During the day, cars are parked at the waterfront, mostly blocking half of the space on the sidewalks. Pedestrians are left with narrow sidewalks with bad surfacing. There is no separation between different traffic types, such as vehicular and bicycle traffic.

2.1.2 Economic Aspects
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. Students have also analyzed costs related to construction and demolition in the area.

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 modeling, 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
The eastern part of the Wijnhaven island area is analyzed according to several aspects, with the aim of getting insights into the relation between qualitative aspects (‘quality of life’) and economic aspects (development of the site). These aspects come up for discussion at several levels: neighborhood, street, and building. In this analysis, independent and dependent variables are defined, and the connecting relations are examined.

A list of such 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. The headings under which the aspects have been grouped are also used by students as headings in order to organize their analysis of the existing situation on the site.

This collection of aspects covers a wide range of design issues including concept, context, architectural design, circulation, and economical concerns. It is a weak point of our students, and designers in general, that they do not incorporate economical aspects in a design effectively. Therefore, we have attempted to incorporate such aspects in the model.

The students went to the site, read articles and did

<table>
<thead>
<tr>
<th>Table 1. Aspects - Design variables.</th>
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<tr>
<td>1 density of development: floor space index</td>
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<td>2 height of buildings</td>
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<td>3 open space index</td>
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<td>4 park space</td>
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<td>5 wide pedestrian zones</td>
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<td>6 material</td>
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<td>13 accessibility to housing</td>
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<td>14 accessibility to employment</td>
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<td>15 accessibility to parking</td>
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<td>16 adequate number of parking spots</td>
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<td>17 accessibility to public transit</td>
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<td>18 sense of safety late at night</td>
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<td>19 image and attractiveness for different age groups</td>
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<td>20 safety for the elderly, or children</td>
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<td>21 rate of burglary, car theft, other crimes</td>
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<td>27 vehicular noise</td>
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<td>28 high-noise property usage e.g. night clubs, discos</td>
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<td>29 noise from normal commercial activity</td>
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<td>30 vehicular traffic - type and density</td>
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<td>32 separation of traffic types</td>
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<td>33 pedestrian safety</td>
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<td>34 income from sales</td>
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<td>39 cost of demolition/relocation</td>
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<td>40 cost of financing</td>
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<td>41 cost of disruption caused by construction</td>
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<td>42 cost of new roads/ cycle paths</td>
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research about the site in relation to these aspects, and each group of students filled out at least 6 data collection forms. Each aspect in the form is marked by selecting one of 7 slots, ranging from highest to lowest, and describing a preferred situation that takes precedence. 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 groups chose were student expert urban designer (i.e., themselves), adult resident, child resident, elderly resident, baker, project developer, yuppie, and businessman. Students chose these roles freely. Interviewing people on the site was also a possibility.

3.2 Preliminary design

During data collection and situation analysis, each group created a preliminary design before using the knowledge model as a design aid (Fig. 2). 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.

3.3 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 this course: artificial neural networks, fuzzy logic, and evolutionary algorithms.

3.3.1 Artificial Neural Networks

Artificial neural networks (ANN’s) are systems that can perform information processing in a manner similar to the human brain (Hush & Horne 1993). This is accomplished by means of a number of basic processors known as artificial neurons, which are inherently nonlinear, highly parallel, robust and fault tolerant. ANN’s can learn from examples and generalize the acquired knowledge to unknown tasks. In this way, they can make remarkably accurate predictions similar to predictions made by a human domain expert. Determining the parameter values in an ANN is called training or learning. This is accomplished adaptively by introducing a data set to the network by the help of a suitable algorithm. The data set comprises a number of data pairs each of which is applied to the input and output of the network.

3.3.2 Fuzzy Logic

Fuzzy logic is a brand name for methodologies of fuzzy systems (Zadeh 1965). Fuzzy set theory underlies the fuzzy logic and fuzzy inference systems. Fuzzy logic explicitly aims to model the imprecise form of human reasoning and decision-making. These are essential to humans’ ability to make rational decisions in situations of uncertainty.

The fundamental concept of fuzzy logic is known as a linguistic variable. A linguistic variable is a variable that takes values from spoken language. It is useful for communicating concepts and knowledge with humans. A linguistic variable can be described both qualitatively, using an expression involving linguistic terms, and quantitatively, using a corresponding membership function.

Fuzzy logic further relies on the use of membership functions as a mathematical tool to convert qualitative statements into quantitative information, which are numerical values that are still imprecise or fuzzy. Numerical values are essential for information handling using a computer. In this way, with soft information and soft computation, final design information is obtained with exact quantities. This process mimics the way humans perform design.

Since we are dealing with soft information, the concept of fuzzy logic is the machinery of the process. However, in fuzzy systems, the accurate determination of fuzzy membership functions is a major issue for the satisfactory functionality of the system, and certain heuristics play an essential role for the final outcome. In fuzzy systems with a few input and output variables, shape and location of the fuzzy membership functions can presumably be determined by domain knowledge rather accurately. However, beyond a few variables, this becomes not feasible and the shape and location determination of the fuzzy membership functions is accomplished by learning. In the soft sciences, the number of variables of concern in an intended fuzzy model is relatively much higher and far beyond the number of variables in conventional fuzzy modeling applications. This is to say that, in soft sciences, fuzzy modeling should be completely accomplished by learning through available information at hand and without need for recourse to domain knowledge. The imperative approach for this is to consider a fuzzy system in the form of a neural network so that one retains the fuzzy concepts in modeling and exercises the beneficial neural network properties to maintain integrity.

Figure 2. Preliminary design of one of the groups.
in the model. The neural network model that is compatible with fuzzy logic concepts is the feed-forward type known as Radial Basis Functions (RBF) network. Fuzzy design information is modeled by this network in the form of a knowledge model by means of which exhaustive design information can be obtained.

3.3.3 Knowledge Modeling by RBF Network
An RBF network consists of a hidden layer followed by a linear output layer in the form of a feed-forward artificial neural network (Broomhead and Lowe 1988). For the sake of simplicity in the representation and description below, a single function \( y = f(x) \) is considered so that a feed forward neural network structure has one output. Consider \( x \in R^d \) is the input vector, \( y = f(x) \in R \) as output, then:

\[
f(x) = \sum_{j=1}^{M} w_j \phi(\|x - c_j\|)
\]

where \( M \) is the number of basis functions; \( w \) is a number referred to as weight; \( c \) id the vector representing the basis function center; and \( \phi \) is the basis function based on a distance metric:

\[
\|x - c_j\|^2 = (x - c_j)^T (x - c_j)
\]

In general, a radial basis function is of gaussian form given by:

\[
\phi = \exp(-\|x - c_j\|^2 / \sigma_j^2)
\]

where \( \sigma_j \) is the \( j \)th width parameter that determines the effective support of the \( j \)th basis function. A nonlinear function \( \phi(x,c) \) is a radial basis function when the function depends only on the radial distance \( \|x-c\| \), which is generally Euclidean, where \( c \) is a vector called center and \( x \) is a vector representing independent variables. Radial functions are a special class of functions. A characteristic feature is that their response decreases (or increases) monotonically with the distance from a central point. Using such functions as a basis, a function given by data points can be represented by means of a continuous function where such a function precisely passes through the given data points. This process is generally referred to as interpolation. Here, we consider radial basis functions due to their suitability for multivariate interpolation (Schwenker et al. 2001).

An RBF network with its local properties is a fuzzy model where the basis functions play the role of membership functions of fuzzy rule antecedents. Ciftcioglu (2003) describes a similar knowledge model as a radial basis function network for multidimensional design information processing. It is interesting to note that this model is obtained with the basis functions representing the local properties via the fuzzy membership function concept. Therefore, each node of the network essentially represents a rule about the functional relationship between each set of input variables and the output variable. In the terminology of fuzzy logic these are called rule antecedents and rule consequents, respectively. Referring to logical foundations, such a model is deemed to be a fine estimation of the true model and therefore design analyses based on this knowledge model reveal the satisfactorily accurate relationships among the variables that are involved in this model. This implies that the study of this knowledge model can reveal additional knowledge about the information at hand.

3.3.4 Evolutionary Algorithms
Evolutionary computation is based on computational models of natural selection and genetics. Their feature is the ability for optimization through parallel search of the state space, in contrast to the point-by-point search in conventional optimization.

Evolutionary computation simulates evolution on a computer and searches eventual optimal solutions for a given problem while step by step improving the solutions. The most applicable form of evolutionary algorithm is known as Genetic Algorithm (GA). Genetic algorithms are robust and effective multi-objective optimization techniques by the mechanism of evolution and natural genetics (Holland 1975, Goldber 1989). They are characterized by a parallel combinatorial search of the search space in contrast to the analytical optimization techniques. The parallel search is maintained by keeping a set of possible solutions to the problem that is subject to optimization. These solutions are called the population. The individuals in the population are evaluated by some fitness measure. The search algorithm is used to find a certain RBF network input pattern which causes a desired network output pattern of a trained network.

3.4 Application of the knowledge model
To demonstrate the effectiveness of the method described above in a complex design task, 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 seven 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 45, 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 centers, which are responsible for capturing more than 99 percent 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 group. In the selected group’s definition, the quality of life determinants were:

- open space index (aspect 3) → 0.5
- ground floor occupancies (aspect 10) → max
- view towards the city (aspect 25) → max
- view towards water (aspect 26) → max

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 genetic algorithms. In the GA, 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. In Figure 3, the course of the search algorithm is shown. The uppermost plot shows the variation of the quality of life throughout the genetic search iterations and the middle plot shows the variations of determinants corresponding to the quality of life. The lowermost plot is the optimal input pattern providing the desired quality of life figure. This pattern is the ultimate information for the designer as advice from an intelligent partner.

### 3.5 Use of the knowledge model

After the students defined the quality of life and received the results from the knowledge model, they imported these into a spreadsheet and made a graph (Fig. 4). The graphs were particularly clear and readable, because in the results of all the groups 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 some others.

Figure 4 shows the results of one of the groups. The aspects that were very important (value above 0.8) according to the knowledge model are:

- height of buildings
- park space
- wide pedestrian zones
- access to site [by bridges]
- accessibility to housing
- accessibility to parking
- adequate number of parking spots
- orientation
- cost of construction
- cost of demolition/relocation

The aspects that were not important (value under 0.3) according to the knowledge model are:

- accessibility to employment
- rate of burglary, car theft, other crimes
- vehicular traffic - type and density
- cost of financing
- cost of new schools
- cost of new parking

### 3.6 Final design

The students found the relationship between the input variable values provided by the knowledge model and the output variable values that make up
their quality of life definition (fitness function) quite logical and explanatory. For the example group, two of the quality of life criteria were having good views over the water and the city. Two of the most important variables that came out of the model were “height of the buildings” and “orientation”, which is perfectly appropriate. It is surprising, on the other hand, that “shadow from the buildings” scored low. This was interpreted by the designers as follows: “We will make the buildings very high, such that the view is maximal. But, we do not need to take the sun into account; a building can cast shadow somewhere else. It is much more important that buildings do not block each other’s view” (van Sevenet et al. 2003) (Fig. 5a, b).

Another output variable for this group was the “ground floor occupancies”. This takes care of liveliness on the one hand, and of security on the other hand. Furthermore, people find it convenient and enjoyable to live close to facilities where they can get their daily supplies. Therefore, it is logical that “accessibility of housing” and “accessibility to parking” scored high according to the knowledge model. For this reason, the students designed the entrances of the dwellings and the parking lots on the street side, on the ground floor. One enters from the residence (complex) directly into the facilities level.

Compared to the above, the rather low score for “accessibility to employment” is slightly contradictory. One interpretation of the reason for this outcome is that on the ground floor, except for cafes, restaurants, and stores for daily supplies, there are no office spaces. The design solution was to put the offices on the second up to the fourth floor to give the area a mix of functions. This way the area attracts several target groups at all moments of the day. This also promotes the feeling of security.

The last one of the output variables is the “open space index”. When there is comparatively sufficient and well arranged public space, the space will give a synoptic and safe feeling. This is perhaps also the reason why the knowledge model gave a lot of importance to security and criminal activities. When the open space index is sufficient, thus not too high nor too low, crime should automatically remain low.

Another outcome to be expected, as seen in the graph, is a high value for “park space” and “broad pedestrian areas”. Therefore, in order to get a correct open space index, one must make space for trees and other green, and supply street furniture and other attractions on pedestrian routes for residents and visitors. Because “security of the pedestrians” also received a relatively high score, the students arranged the whole Point area as a park, only accessible for slow traffic. Underground parking places connect to the buildings, such that here too the accessibility of houses is optimal.

“Access to site [by bridges]” also received a high score. An explanation for this was that if one wants to keep the facilities at the ground floor optimal and profitable, the location must be well accessible by many people. The area must be attractive especially to pedestrians, because it is a downtown area where cars should get a less prominent role. A new pedestrian bridge ensures extra accessibility and reinforces the view from the ground floor level to the river (Fig. 5c, d, e).

Furthermore, from the model, “adequate number of parking spots” was important. This can only be achieved with underground parking, which also helps to improve the quality of the public space. “Cost of new parking” got a low score, therefore, the students considered this as not being important enough to take it into account in the design.

The two economic aspects that scored very high were “cost of construction” and “cost of demolition/relocation.” The first one was interpreted as the need for a good balance between quality and costs. The latter was interpreted as the balance between demolition and new development and renovation needs consideration.

4 CONCLUSIONS 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, without and with a knowledge model, the latter proved to have both advantages and

Figure 5. (a) Each building has a view over the water and/or over the city, (b) Placing of the buildings in relation to each other, (c) A new pedestrian bridge, (d) Wide pedestrian zones along the water, (e) A park area on the eastern part.
disadvantages. The students expressed some of the advantages and disadvantages of working with a knowledge model as a design partner as follows:

- When working with a knowledge model, the designer must be very precise and consistent when collecting the initial data. At the same time, the list of aspects must be very specific, and aspects must be independent of each other. This way, there will be less space for ambiguity at the interpretation of the outcome.
- Designing with the help of a knowledge model can give more quality to a design.
- The knowledge model can help to distinguish between design priorities and side issues.
- A design without a knowledge model is primarily subjective.
- A design with a knowledge model provides a programmatic outcome to the subjective inputs.
- In spite of some marginal comments for model improvement, it is nice to see what the use of a knowledge model can mean to an urban development design.

In their preliminary design, the students tried to take into account a little bit of every aspect. In the new 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 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, and that is the exclusion of some target groups. Therefore, the possibility exists that the design becomes less sustainable. A solution for this is to guarantee the ideal distribution of roles, representing the intended population on the site, during the information collection phase.

Interpreting the values of the output variables was the most difficult part for the students. This was because the aspects were not specific enough; they need to be made more precise. Also, the economic aspects are very difficult to take into account in the design.

The course experienced some growing pains, because it was offered for the very first time. We have learned from the experience and have already implemented improvements. In the new version of this course that is currently in progress, we created a new list of aspects, which are formulated as statements. This leaves less room for discussion when interpreting the results. The new aspects concentrate on tall buildings, because it is realistic for our site (Birmingham City Council 2003). We have also created a graphical user interface in the new version of the course for the genetic algorithm, which is optimization part of the software, since this is the most relevant part for designers. With this new software, designers can try out various definitions of quality of life and explore design variations accordingly.

ACKNOWLEDGEMENTS

We would like to acknowledge the valuable inputs of the remaining instructor of the course entitled “BKMVK21: Intelligent Support for Urban Design”: Frank van der Hoeven, who is responsible for the urban design content. We would also like to acknowledge the excellent work delivered by all the students who have completed this course. We would like to thank Rudi Stouffs for his valuable comments on this paper.

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