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COMPUTER-AIDED INSTRUCTION TOOLS FOR ARCHITECTURE: CASE STUDY OF SINAN MOSQUES

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ABSTRACT

This paper introduces an ongoing research about the Computer Aided Instruction (CAI) tool which is based on the master thesis of Tuğrul Yazar from Yıldız Technical University (YTU) Faculty of Architecture Computational Design Graduate Program (BOM). The thesis is named “Expert Systems for Architectural Education: The Expert System of Sinan Mosques” and completed in 2003 under the supervision of Dr. Birgül Çolakoğlu. YTU Department of Computer Engineering supported this research by assigning the graduation project (student: Ali Murat Akkan) as programming the prototype software. The educational tool developed in this research aims to teach Sinan’s mosque architecture by visualizing hypothetical mosque designs.

Keywords: Computer-aided instruction (CAI), architectural education, expert systems, Sinan.

MİMARLIK İÇİN BİLGİSAYAR DESTEKLİ EĞİTİM ARAÇLARI: SİNAN CAMİLERİ ÖRNEĞİ

ÖZET

Bu makale, Tuğrul Yazar’ın Yıldız Teknik Üniversitesi (YTÜ) Mimarlık Fakültesi Bilgisayar Ortamında Tasarım (BOM) Yüksek Lisans Programındaki yüksek lisans tezine dayanan ve devam etmekte olan bir araştırmayı anlatmaktadır. Tezin başlığı “Mimarlık Eğitimi için Uzman Sistemler: Sinan Camileri Uzman Sistemi”dir ve 2003 yılında Dr. Birgül Çolakoğlu’nun yürütücülüğünde tamamlanmıştır. YTÜ Bilgisayar Mühendisliği Bölümü, bu araştırmayı bir öğrencisinin (Ali Murat Akkan) bitirme ödevi olarak prototip aracın programlanmasını organize ederek desteklemiştir. Bu araştırmada geliştirilen eğitim aracı, Sinan’ın cami mimarisini varsayımsal cami tasarımlarını görselleştirerek öğretmeyi hedeflemektedir.

Anahar Kelimeler: Bilgisayar destekli eğitim, mimarlık eğitimi, uzman sistemler, Mimar Sinan.

1. INTRODUCTION

1.1 Context

Recent researches indicate that increasing use of computing in architectural practice has also triggered a paradigm shift in education (1, 2). Especially in the last decade, new multi-disciplinary research areas that support analysis, synthesis and evaluation processes have emerged. Tool development (software engineering) for architectural education is one of such research areas (3). Various approaches for educational tools in architecture can be categorized as;

•Concept-based: These researches aim to find a suitable (useful, flexible or perceptually effective) software platform for a specific instruction subject. For example, educational tools on computational design concepts (4), algorithmic form-finding tools (5), or rule-based design systems (6), are the recent research areas of concept-based approach.

•Tool-based: In this approach, a researcher usually experiments the potentials and limits of a specific software platform for architectural education. Such researches usually define an instruction subject as a case study. For example, game engines (7, 8), or web-based educational tools (9, 10, 11) are the popular areas of tool-based researches.

This paper presents an algorithmic model that could be utilized as a computer-aided instruction (CAI) tool for architecture, focusing on a specific typological subject. The algorithm underpinning the proposed model functions as an expert system[1] which is not essentially computer dependent. However, the realization (case study) of the algorithm requires a prototyping process, including tests with different software platforms and evaluation of their (dis)advantages. Therefore, this research reflects both concept-based and tool-based approaches.

1.2 Statement of Need

The architectural education is not supported by CAI systems effectively. More materials and experiments are needed in this fast developing research area (4, 5). Instead of passive listeners, students of architecture can be transformed into active participants, using computers not only as a representation tool, but also as a design partner.

2. THE ALGORITHM

Following principles are utilized to develop the CAI algorithm:

2.1 Learning-by-doing

The project introduced in this paper is based on learning-by-doing, as it is the primary pedagogical approach for the institutional education of architecture (14). The proposed algorithm has a data flow including input and output parameter sets processed simultaneously. The input data is defined by the choices of the user (student) with counseling of the tool. This is based on a sequential question-answer progress that develops a *hypothetical design* of the typological subject (in our case, it is a hypothetical Sinan mosque). The output data is processed by the tool, creating a digital model of the design, calculating the realism value and suggesting automatic parameter inputs.

2.2 Deduction

The system has to produce realistic results without losing control over the fundamental

[1] “Expert Systems” is a branch of applied artificial intelligence (AI) and were developed by AI community in mid 60’s (12). Expert systems are statistical algorithms that organize databases consist of expert knowledge. “Knowledge Engineering” is the discipline that develops expert systems (13).

parameters of the structure. Based on deduction, the system starts developing a model with the main components (in this case, they are the main dome and the baldequin system), then continues to more detailed parts (Figure 1).

2.3 Flexibility

In order to run an expert system, a database of typological examples is needed. In our case, it is a database of the Sinan mosques. The database should be flexible, allowing new examples to be added or existing ones to be changed. Accuracy and sustainability of the expert system depends on this concept.

2.4 User-friendliness

The effective user interaction through a graphical user interface (GUI) is an important aspect of the research. CAI tools for architecture should provide an easily perceivable GUI. This is one of the main concerns of current researches on this area (15).

3. THE CASE STUDY

3.1 Design Subject

Sinan's mosque architecture provides a clear parametric variety, and is used for developing the experimental algorithm and the prototype CAI tool. In most researches, Sinan's mosque architecture is studied as experiments, describing his design expertise in particular periods (16, 17, 18, 19, 20, 21, 22, 23, 24, 25).

3.2 Levels of Deduction

There are five levels of deduction defined in the prototype system. At the first level, minimum required information to create an abstract model is defined. Level 2 includes the general parameters and the typological choice of the model structure. At level 3, plan type and structural components are chosen (Figure 2 and 3). Level 4 includes all details that are not directly related to the size of the model structure. At level 5, additional building parts (minarets, courtyard etc.) are defined and calculated.

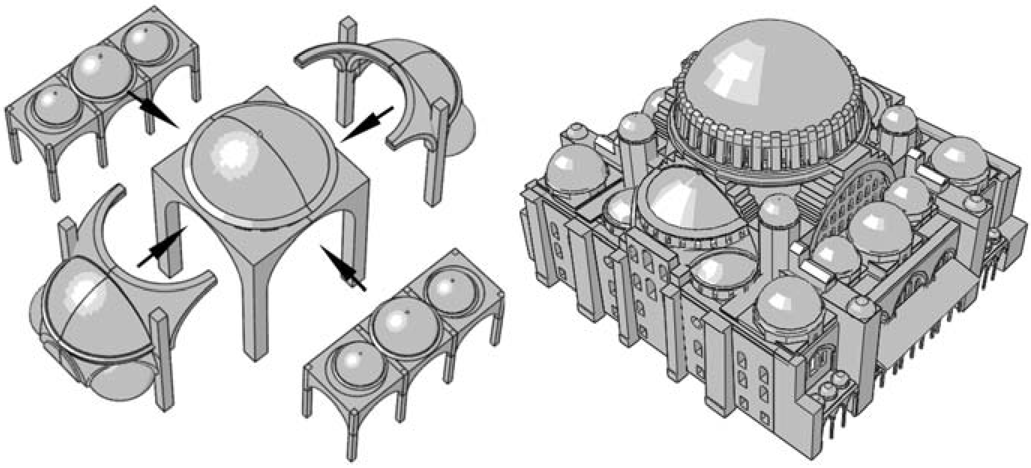

Figure 1. Example of the basic structural reduction derived from the simplified forms of the original components. Süleymaniye Mosque in İstanbul (1557 A.D.)

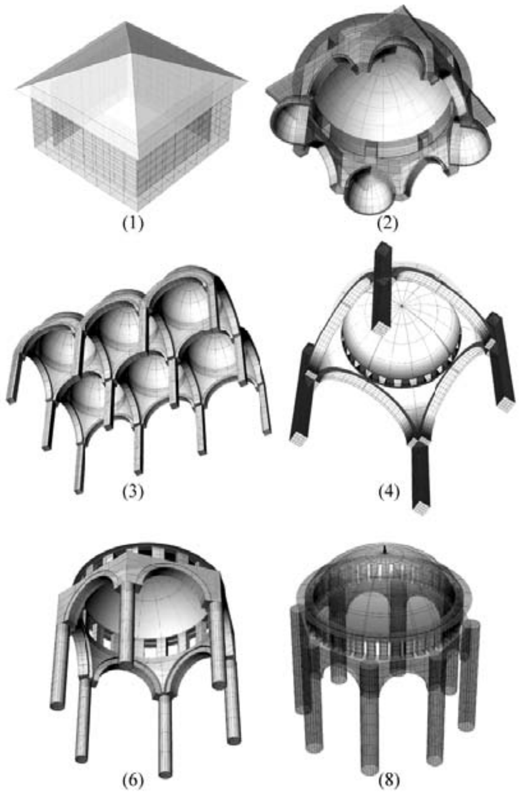

Figure 2. Types of structure
(the b parameter of level 1)

(1): Small mosques with a roof.
(2): Mosques with trombe walls.
(3): Mosques with multiple equal domes.
(4-square), (6-hexagonal) and (8-octagonal) baldequin systems.

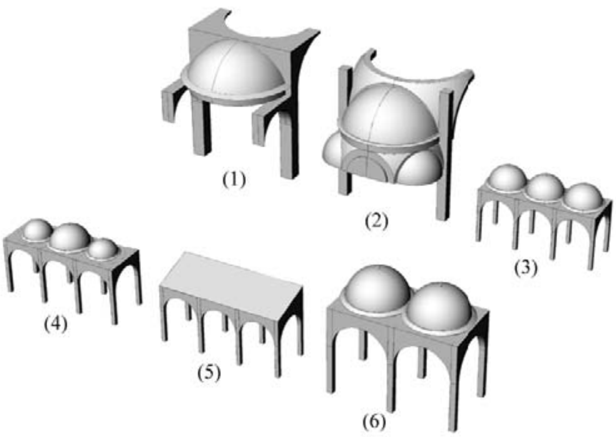

Figure 3. Types of additional components
(the x parameters of level 3)

3.3 The Parameters

The initial system introduces 16 parameters within 5 levels of detail.

T represents the date of construction. It is between 1537 and 1584.

d is the degree of expertise that Sinan has reached at the chosen T parameter (Table 1).

Table 1. Definitions of the possible d values

Degree	d	
Novice	*1*	1538 - 1557 (Süleymaniye)
Expert	*2*	1557 - 1575 (Selimiye)
Master	*3*	1575 -1583

y parameter represents the rank of the investor, effecting the size of the structure (Table 2).

Table 2. Definition of the y parameter, according to various expert knowledge

Type	y	
Small	*1*	the investor is a general
Medium	*2*	the investor is a general or vizier
Large	*3*	the investor is a vizier or prince
Great	*4*	the investor is the emperor

b is the main typological decision of the structure that carries the weight of the main dome. The six possible choices are shown at Figure 2.

R represents the inner diameter of the main dome. There are limits according to the value of the *y* parameter.

H is the height of the building from ground to the rim of the main dome, while H_k is the height of main arches.

x_1, x_2, and x_3 are the additional components to be added to the baldequin structure (defined by *b*). Possible abstracted choices are shown at Figure 3.

K is the width of main columns.

F represents the inner height of the main dome.

P is the number of windows under the main dome.

P_h represents the height of the rim under the main dome.

U is the average thickness of outer walls.

a parameter holds a boolean information (true / false) to define if there is a courtyard on the model structure.

s is the number of domes on the latecomers' place.

m represents the total number of şerefes (balconies) on minarets.

Figure 4 explains some of the parameters. Table 3 shows the database of 20 selected design examples, and Figure 5 describes the sequential question-answer process to create a hypothetical design.

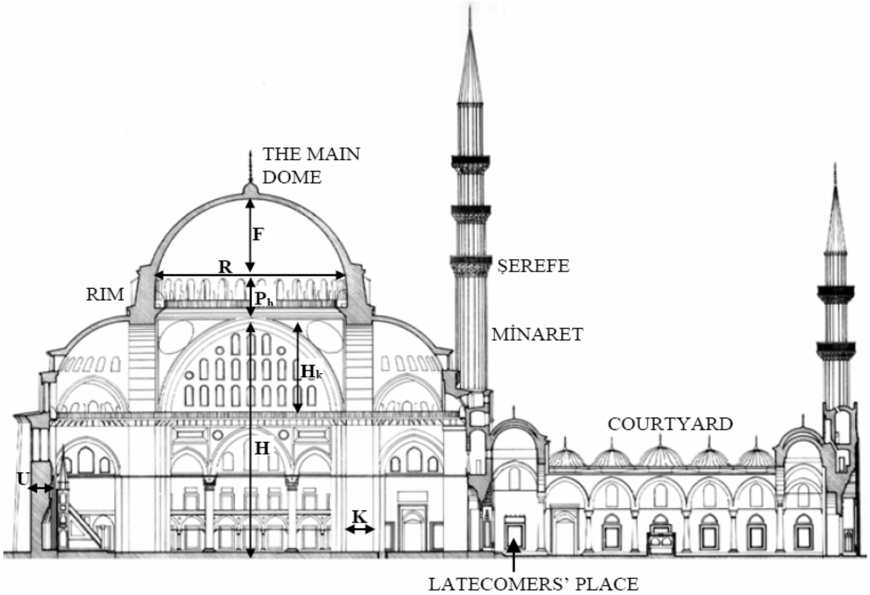

Figure 4. Basic structural parameters used in the initial version of the tool.

Table 3. Initial database of expert knowledge, consisting of 20 example designs [16],[24].

	T	d	y	$b.x_1.x_2.x_3$	R	H	H_k	K	F	P	P_h	U	a	s	m	H/R	H_k/H	F/R	P_h/R	U/H
Çavuşbaşı	1538	1	1	1.0.0.0	1240	700	0	0	340	0	0	120	0	0	1	0.57	0	0.27	0	0.17
Haseki Sultan	1538	1	1	2.1.0.0	1130	1020	390	0	380	8	200	150	0	5	1	0.90	0.38	0.34	0.18	0.15
Ü. Mihrimah Sultan	1548	1	1	4.3.1.1	1100	1700	580	160	420	16	180	230	0	5	2	1.55	0.34	0.38	0.16	0.14
Şehzade Mehmet	1548	1	3	4.4.2.2	1840	2530	980	180	740	24	240	430	1	5	4	1.28	0.39	0.40	0.13	0.17
H. İbrahim Paşa	1551	1	2	2.1.0.0	1200	1530	520	0	410	16	260	300	0	5	1	1.28	0.34	0.37	0.22	0.20
Sinan Paşa	1555	1	2	6.4.6.0	1260	1000	350	150	430	12	190	250	1	5	1	0.79	0.35	0.34	0.15	0.25
Süleymaniye	1557	2	4	4.4.4.2	2580	3880	1940	330	1000	32	350	610	1	9	10	1.50	0.50	0.39	0.14	0.16
K. Ahmet Paşa	1559	2	2	6.4.0.0	1250	1230	460	70	510	16	210	220	1	5	1	0.98	0.37	0.41	0.17	0.18
Rüstem Paşa	1562	2	3	8.4.3.0	1470	1410	450	150	610	20	400	200	0	5	1	0.96	0.32	0.42	0.27	0.14
Molla Çelebi	1566	2	2	6.5.0.0	1180	1650	550	0	480	18	180	110	0	5	1	1.40	0.33	0.40	0.15	0.07
Semiz Ali Paşa	1567	2	3	6.5.0.0	1320	1320	390	0	450	18	200	150	0	5	1	1.00	0.30	0.34	0.15	0.11
E. Mihrimah Sultan	1570	2	3	4.2.3.0	1940	2620	1340	0	700	20	300	400	1	7	1	1.35	0.51	0.36	0.16	0.15
Kadırga Sokollu	1572	2	2	6.4.0.0	1280	1650	470	0	390	16	180	280	1	7	1	1.29	0.37	0.30	0.14	0.17
Piyale Paşa	1573	2	1	3.3.2.0	890	1640	740	100	430	0	0	470	0	0	1	1.84	0.43	0.48	0	0.23
Selimiye	1575	3	4	8.5.5.0	3130	2740	850	390	1030	40	550	250	1	5	12	0.88	0.31	0.33	0.18	0.09
Azapkapı Sokollu	1578	3	2	8.8.5.0	1180	950	290	80	400	24	170	110	0	0	1	0.81	0.31	0.34	0.14	0.12
Z. Mahmut Paşa	1580	3	2	4.3.5.5	1180	1440	960	170	390	20	290	230	1	5	1	1.22	0.67	0.33	0.25	0.16
Kılıç Ali Paşa	1581	3	2	4.4.3.2	1180	1920	810	140	310	24	140	210	0	5	1	1.63	0.42	0.26	0.12	0.11
Şemsi Paşa	1581	3	1	2.2.0.0	820	900	280	0	270	0	0	100	0	0	1	1.10	0.31	0.33	0	0.12
Atik Valide	1583	3	2	6.5.0.0	1260	1260	380	110	380	18	250	110	0	5	2	0.99	0.30	0.30	0.20	0.09

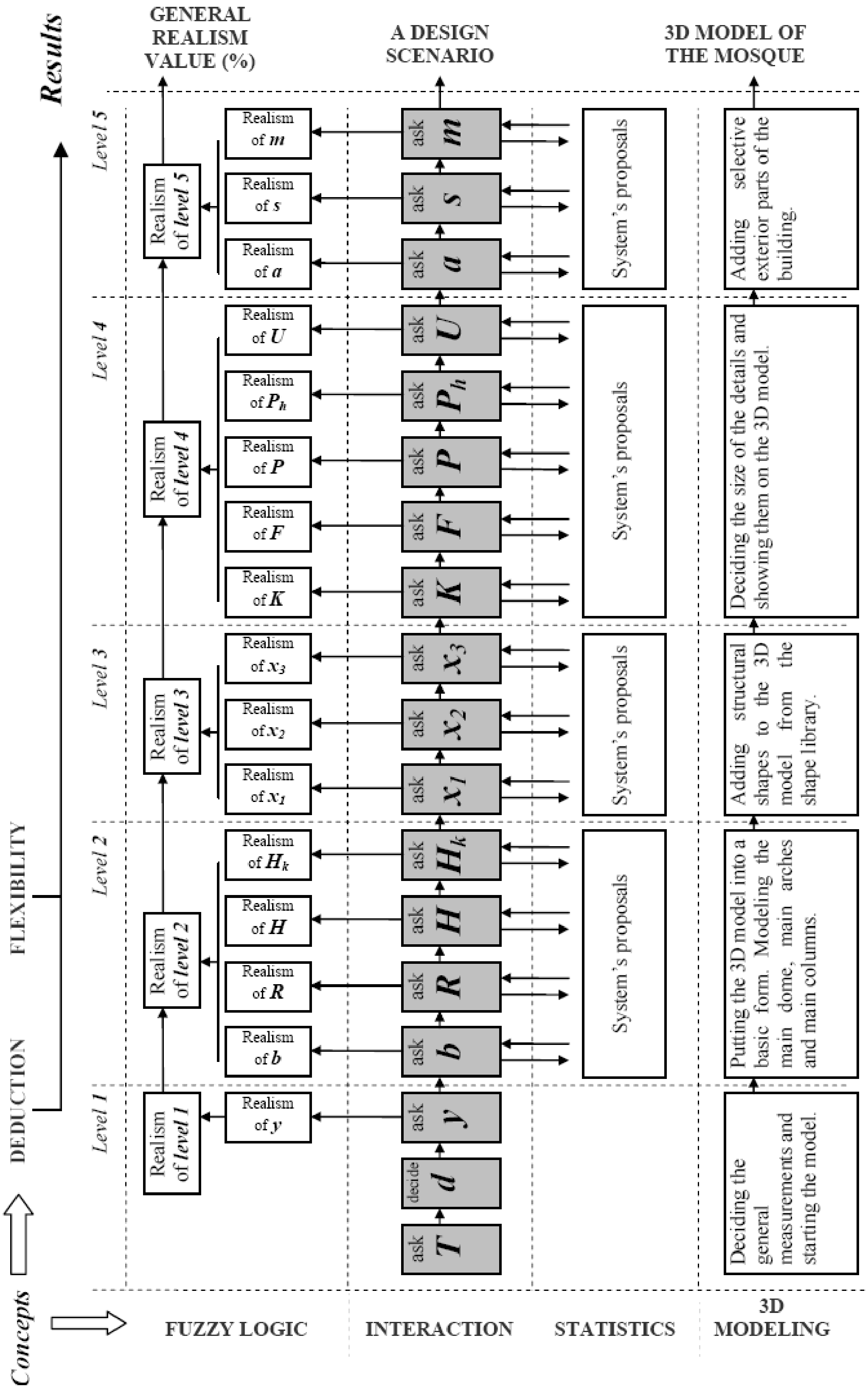

Figure 5. Diagram of the proposed CAI algorithm.

3.4 Automatic Parameter Input

The user does not have to answer all of the questions described in Figure 5. There is a choice to use the automatic answers. This is realised by using the database of example mosques. After the first level, the system can calculate statistical values of the database, developing an automatic answer to the following questions. There are 16 automatic answering cases at the prototype system. One of them is explained below;

In order to calculate an automatic input to *b* parameter, all *b* parameters of the example designs are collected in a table by taking *d* and *y* values into consideration (Table 4).

Table 4. *b* values of the example mosques distributed according to *d* and *y*.

	y=1	*y*=2	*y*=3	*y*=4
d=1	1,2,4,2	6	4	-
d=2	3	6,6,6	8,6,4	4
d=3	2	8,4,4,6	-	8

According to the database, Sinan did not design octagonal (*b*=8) mosques at his novice degree (*d*=1). At his expert degree (*d*=2), he is concentrated on hexagonal mosques and his greatest work (Sultan mosque at his master degree, *d*=3 and *y*=4) is an octagonal baldaquin structure (*b*=8) (Selimiye). While new examples are added to the database, this table updates automatically. Table 5 shows the result after the optimization. Using this table, the system offers a value to the *b* parameter. For example, if the user chose a Sultan mosque in "Novice" period, the system offers 4 (square) baldequin value to the *b* parameter.

Table 5. Optimized table for *b* values.

	y=1	*y*=2	*y*=3	*y*=4
d=1	2	6	4	4
d=2	3	6	6	4
d=3	2	4	8	8

3.5 Realism Statements

Realism statements help calculate the similarity of a hypothetical design to a real Sinan mosque. There are 32 realism statements at the prototype system. Each of them may be given boolean values of 1 or 0. One of these statements is explained below;

Example statement: Sinan did not design a mosque for a Sultan at his novice degree of experience. Algorithmically this means;

If *d*=1 and *y*=4 then $[G^{01}]=0$
else $[G^{01}]=1$

While the system is gathering information about the hypothetical design, each level's degree of realism is calculated. This value is the average of all values at that particular level. After the last parameter, system calculates the total realism value using the following function;

G=(((((((Level 5+Level 4)/2)+Level 3)/2)+Level 2)/2)+Level 1)/2

In this method, the last level (level 5) has the minimum effect and the first level (level 1) has the maximum effect on the total realism value.

4. THE PROTOTYPE

The prototype is an ongoing experiment. It is not accurate enough for a test on students of architecture at the time of this paper's preparation. Further development of the prototype includes experiments using scripting instead of programming languages to create more effective graphical outputs. Figures 6,7,8, and 9 shows the screenshots of the initial CAI tool, developed in collaboration with a student from YTU Department of Computer Engineering. The prototype is developed in C++ language, using OpenGL for 3D modeling.

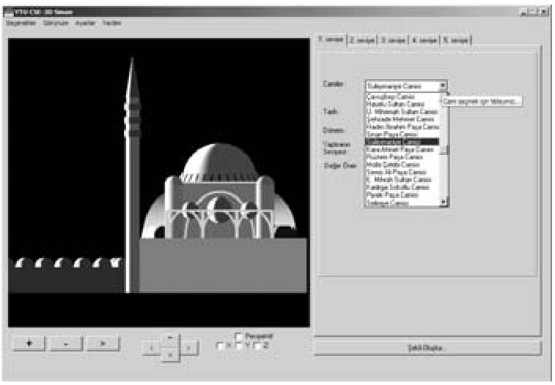

Figure 6. User is chosing one of the example mosques to see its parametric model. This process uses the database values of the example mosques and develops the model using these parameters. (They are not stored as 3D objects).

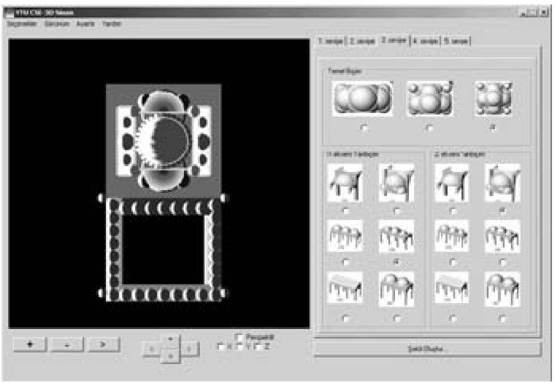

Figure 7. Level 3 is tested. The user can choose the type of structure and shapes to be placed into while seeing the visual result at the model.

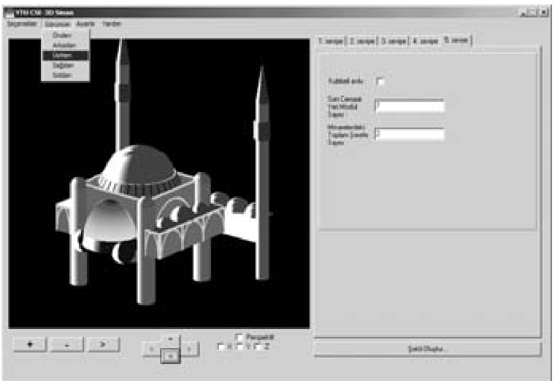

Figure 8. User is looking at the structure from perspective and selecting the one of the other view modes (top view, right view, etc…).

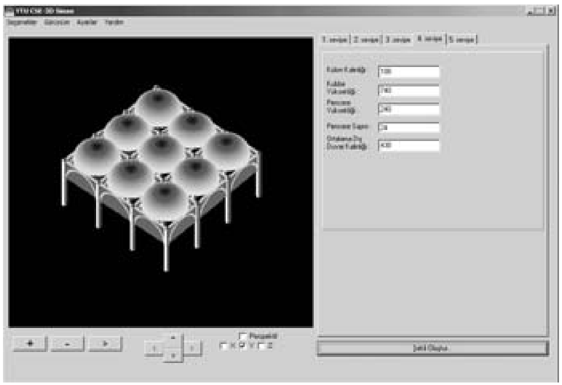

Figure 9. User chose 3 to the b parameter and looking at the parameters of level 4.

5. FURTHER RESEARCH

This research can be expanded by studying Külliye complexes and 2D ornaments inside of the mosques. Also, creating more detailed digital models can improve visual quality of the tool.

The algorithm underpinning the tool may be improved by using scripting instead of programming languages. This would reduce the coding effort, creating better visual outputs as well. Also, calculation of the actual structural balance is another topic of further research.

As an interactive educational tool, this system aims to teach Sinan's structural configurations, and historical periods in mosque architecture. This interactive system offers endless dynamic combinations and experiences about Sinan's design methodology. It transforms students from passive learners to active self-learners.

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