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INTELLIGENT KNOWLEDGE-BASED REPOSITORY TO SUPPORT INFORMED DESIGN DECISION MAKING

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SUMMARY: *Research highlights that architectural design is a social phenomenon that is underpinned by critical analysis of design precedents and the social interaction between designers including negotiation, collaboration and communication. CAAD systems are continuously developing as essential design tools in formulating and developing ideas. Researchers such as (Rosenman, Gero and Oxman 1992) have suggested suggest that knowledge based systems can be integrated with CAAD systems to provide design knowledge that would enable recalling design precedents that maybe linked to the design constraints. Currently CAAD systems are user centric being focused on architects rather than the end product. The systems provide limited assistance in the production of innovative design. Furthermore, the attention of the designers of knowledge based systems is providing a repository rather than a system that is capable to initiate innovation. Most of the CAAD systems have web communication tools that enable designers to communicate their design ideas with colleagues and partners in business. However, none of these systems have the capability to capture useful knowledge from the design negotiations. Students of the third to fifth year at College of Architecture, University of Dammam were surveyed and interviewed to find out how far design tools, communications and resources would impact the production of innovative design projects. The survey results show that knowledge extracted from design negotiations would impact the innovative design outcome. It highlights also that present design precedents are not very helpful and design negotiations between students, tutors and other students are not documented thus fully incorporated into the design scheme. The paper argues that the future CAAD systems should be capable to recognize innovative design precedents, and incorporate knowledge that is resulted from design negotiations. This would help students to gain a critical mass of knowledge that would underpin informed design decisions.*

KEYWORDS: *intelligent CAAD system, BIM, innovation, multi-criteria decision analysis, design precedents, design negotiations*

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1. INTRODUCTION

Architecture studio's education involves a number of varied activities. Before the project begins, the tutor(s) may establish the goals, expectations, general procedure, and assessment criteria he/she will employ for the project. During each semester, tutors meet students either individually or in groups for design-related discussions and clarifications. The design studio should not be considered a safe haven - as one would imagine - as conflicts regarding design ideas are very likely to take place between students and tutors and between tutors themselves. This research is driven by growing concerns from the design studios' tutors and the discussions of the board of the department of Architecture, college of Architecture, University of Dammam on finding methods to support and enhance the students design creativity. Tutors from all academic levels repeatedly claim that students produce design projects but very few of them can actually produce innovative projects (Sidawi 2009a, Sidawi 2009b). Previous research links studio teaching methods to student's perceptions of means of acquiring knowledge. It also highlights the disagreement of experts and academics in respect of the definition of the creative design product, the differences in emphasis and sometimes conflicting opinions (for instance Gero vs. Lawson and Casakin vs. Schon) on various issues that affect creativity. Researchers point out to an educational culture where the teacher serves as the "fount of knowledge" and the students are the empty, open containers anxiously awaiting knowledge to be poured in (Warr 2007). Other researchers such as Edmonds et al (1999), Fischer (2003), Mamykina (2002) and Shneiderman (2000) have put emphasis on collaboration, communication and how the social interaction/ dialogue would support/ initiate creativity. Schön (1985) identifies a number of key elements that would improve the interaction between the tutors and students, and thus the architectural education. He emphasises firstly, the necessity for students to engage in studio-based projects that simulated the complexities of real-life projects and secondly the importance of reflection in the design process that was comprised: reflection-in-action, reflection-on-action and, most critically, reflection-on-action that allowed students to observe and to realign their thinking with the 'expert' thinking of their tutors. Casakin (2007) argues that designers should explore unfamiliar and unconventional design solutions. However, they need creative skills that enable them to transcend conventional knowledge domain(s) so as to investigate new ideas and concepts which may lead to innovative solutions. This enables the designer to perceive a problem from unorthodox and innovative perspectives (Casakin 2007).

Paker (2007) suggests that the role of the studio instructor is to create an organizational style in studio education and this would help in developing creative strategies in the design studio. A number of approaches have been suggested to improve the design studio's teaching. It encourages educators to spark creative ideas, encourage follow-up of creative ideas, and evaluate and reward creative ideas (Sternberg& Lubart1991). Parkinson& Robertson (1999) suggest the Olympic Model that constitutes of personal and environmental components and this model can be used in establishing effective communications and development of creative individuals. On the other hand, researchers investigate the impact of CAAD tools on the production of innovative products and point out their potentiality to improve design skills of the designer and help in the producing innovative design products (Elkær 2009, Iordanova et al 2009, Kan& Gero 2008, Sosa et al 2002, Asanowicz 2008, Company 2009, and Boland 2007). Nevertheless, the same literature shows that these CAAD systems still have limited capabilities regarding the production of innovative design products. Researchers suggest possible integration of knowledge based system, expert system, and/ or design cases database into CAAD system so these systems would provide the designer with specific and filtered design precedents. The knowledge based systems and databases focus on design cases, analysis, problem/ solutions, constraints etc. (Rosenman, Gero and Oxman 1992) but they are incapable of recognizing/identifying the innovative aspect'(s) of each design case. Furthermore, these systems concentrate on the architect rather on how to achieve an innovative design product (Reffat 2006). At present, web based and networked communication tools consists an integral part of many CAAD systems. For example, chat line, whereas communication is engaged in text mode, appears to support the development of richer design investigation through continuing development of ideas (Kvan and Gao, 2005). Virtual collaboration does not only enhance the design process but also changes the tools allowing designers to work together remotely or co-located (Reffat 2006). Nonetheless these systems still do not have the capability to extract the communications' outcome between participants and evaluate it regarding to certain innovation criteria, thus integrate and utilize it in the design scheme. This research explores design resources and communications factors that would hinder/ support the production of innovative design projects. It examines how these factors interact within the design studio's environment and how it can be implemented in CAAD systems.

2. CREATIVITY AND ARCHITECTURAL DESIGN

2.1 Creativity and creative design projects' definition

The term 'creativity' is used to reflect a psychological view of creativity on a personal level in contrast to innovation as used in the world of business on an organisational level (Sternberg and Lubart 1999). Innovation traditionally focused on products and processes. Hargreaves (2000) suggests that 'you can have creativity without innovation, but you cannot have innovation without creativity'. Warr (2007) examines the work of a number of researchers and points out that there was no definite consensus regarding how creativity is defined. He finds that the creative process looks different to different researchers. There is general agreement among researchers that the act of creation does not occur as a fixed point in time, but that it manifests as a process that extends through time, varying in duration (Ford & Harris 1992). Rogers (1995) defines an innovation as "an idea, practice, or object that is perceived as new by an individual or other unit of adoption". Diffusion is "the process by which an innovation is communicated through certain channels over time among the members of a social system" (Rogers 1995).

Mumford (2003) defines creativity as the production of novel, useful products. In the fields of art and literature, originality is considered to be a sufficient condition for creativity, unlike other fields where both originality and appropriateness are necessary (Amabile 1998, Sullivan and Harper 2009). So can we define creative architectural projects as the production of novel, useful and original architectural projects? Such definition may look too general. Within the design studio context, the definition of creative architectural projects would be distinguished by the goals/objectives and outcomes of the design studio course. Gero & Maher (1993) argue that ground breaking designs are those which possess innovative and creative qualities, and provide solutions that were previously unknown (innovative design) or subsequently produce entirely new products (creative design). To find out the features of creative design within the design studio context, a small survey was undertaken by the first author in 2009 of the design studio tutors and students to find out the importance of a number of design features in considering an architectural project as innovative. The survey showed the important aspects - arranged from more to less important - are as follows (see table 1):

TABLE 1: The significance of a number of design aspects in considering an architectural project as innovative *(Note: scale: 1 not important, 5 extremely important. Number of students 48, number of tutors 15)*

The design feature/ aspect	**Student survey (Mean value)**	**Tutor survey (Mean value)**
A creative functional solution	3.79	4.40
A solution that is in harmony with the climate and environment	3.75	4.33
A design solution that effectively addresses building users' needs	3.54	4.33
Successful response to the site parameters	3.65	4.13
Aesthetic treatment of plans, elevations and form	3.70	4.07
A design solution that considers other design aspects such as user safety and security	3.32	4
A level of integration and harmony between the 3D components of the form	3.43	3.93
Unique structural solution	3.48	3.87
A design solution with a high economic value	3.69	3.87
Other aspects	2.56	3.5

- A creative functional solution
- A solution that is in harmony with the climate and environment
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- Aesthetic treatment of plans, elevations and form
- A design solution that considers other design aspects such as user safety and security
- A level of integration and harmony between the 3D components of the form
- Unique structural solution
- A design solution with a high economic value

The tutors, however, set more emphasis on all design aspects than students, and the difference in the importance weighting between students and tutors is not always the same. This may cause possible conflict between students and tutors as each party has his view regarding the creativity weighting of each design aspect. However, different outcomes would result if the same survey was conducted in other Colleges of Architecture around the world, so what is considered as the most creative design aspect here would not be considered to have the same creativity weighting elsewhere!

2.2 Creativity and the design precedents and communications

The development of the architectural project from initial concept to the end product is an interactive social and psychological process. Through this process, the designer negotiates various solutions to the design problem with oneself and communicates ideas with colleagues and instructors. The design process consists of a number of stages and these stages are linked with forward and reverse (backward) loops. Lawson (2006) points out that the design process is a simultaneous learning about the nature of the problem and the range of the possible solutions. The designer repeatedly evaluates and alters the design scheme and would return back to the previous stage or may be to the start stage to find out/ test a solution for the whole or a part of the design scheme. Lawson (2003) argues that experienced designers develop the ability, more than inexperienced designers, to see some kind of underlying pattern or theme and make connections in a design situation (between design aspects) and with some precedent in the episodic memory. Expert designers acquire knowledge about solutions rather than necessarily about problems (Lawson 2003). This design approach style would initiate creativity as: "*it is probably commonly accepted in design that creativity involves making use of solution ideas from apparently superficially different situations"* (ibid). Gennari and Reddy (2000) describe the design process as, '*human activity, involving communication and creative thought among a group of participants'*.

3. THE RESEARCH METHODOLOGY

The literature review has highlighted the degree of complexity of the creative design process, communications and characteristics of the design studio's environment. It illustrated the importance of a number of possible factors, i.e., the use of design precedents, the need for incorporating the design negotiations in the design scheme. This paper argues that the design negotiations and innovative precedents can be efficiently utilized if they are incorporated into an intelligent CAAD system.

However, to find out social factors that would affect the end design product, a field survey was conducted. It aims to find out what the most significant factors are, and how they are linked together and influenced innovation in the architectural design studio. This was achieved by testing the possible impact of social factors on innovation in the design studios of the College of Architecture, UoD. Therefore, the objectives of the research were:

• to explore the social hindrances and initiators for innovation in the design studio;

• to find out communication routes and techniques that students use to obtain innovative ideas and feedback; and

• to make recommendations how to incorporate these factors in the intelligent CAAD system.

First, the questionnaire survey was conducted to ascertain the level of general agreement of students on various topics. Thus the interviews were made to explore the hidden causes behind the issues under study, to validate the questionnaires results, and to clarify ambiguous points. There was a use of mixed methods i.e., quantitative and

qualitative research methods. This was in order to have the findings relate to each method and be used to complement one another, as well as enhance theoretical or substantive completeness (Morse 1991, Ausubel 1968).

A sample was chosen from third to fifth year students-one hundred and ninety four males from the Architecture and Building Technology Departments. The first two academic years were excluded as they provide basic design architectural education. Participants were asked about the tools, systems and conditions that would help in producing innovative design projects. Forty eight students replied. This constituted 25% of the total number of third to fifth year students. Two software programs were used to analyse the quantitative data: SPSS 16 and AMOS. The following statistical tools were used to analyse the data: mean calculation, percentage, and path co-efficient. Only co-efficient path relations that have significance value ($P < 0.05$) are reported here.

Only the fifth year students, who participated in the questionnaire survey, were then invited for a subsequent interview. The reason for choosing solely fifth year students was because they were more experienced with regard to the social interaction problems of the design studio. Nine students accepted the invitation, and were interviewed using unstructured interviews. The use of this type of interviews was used because it provides a relaxed environment which would aid the researcher in obtaining valuable information from the interviewees.

4. THE FIELD SURVEY RESULTS

4.1 The questionnaire survey results

Respondents consider the following tools as the most helpful in producing innovative projects and these are ranked according to their helpfulness (from more to less):

- the use of advanced rendering programs
- walkthroughs generated by the computer
- computer simulation of building behaviour, (e.g. thermal, environmental, users movement)
- partial 3D free hand sketching of the project or building
- smart White Board that is used for presentation and discussions
- standalone virtual reality
- full 3D sketching of the project or building
- web-based virtual reality
- Immersive Virtual reality. Students have little knowledge about these systems as these are not available at the College of Architecture so they assume that these tools are not very helpful.

Respondents consider the following information resources as the most useful resources that help in producing innovative projects and these are ranked according to their usefulness (from more to less useful): instructor's feedback and advice; discussions with their colleagues in the same year; and in higher levels in the course the projects student's. Whereas they state that the following information resources are the least useful: projects of the same year students, the hard copy references and the electronic references at the University library (see figure 1).

The most frequent student activities and exchanges of communications in the design studio during the term time are the followings:

- the generation of many sketches before making up mind when working on a design problem
- Participating in interactive and useful dialogue with instructors on how to reach to a creative design solution
- capturing innovative ideas of colleagues in the higher academic level from other departments
- not taking many risks because of the fear of failure

Whereas the least frequent activities and communications of students are:

- seeking the students' and staff advice from different departments to help in solving specific design problems;
- capturing innovative ideas of colleagues in the same academic year from different departments; and
- capturing innovative ideas from other departments' tutors

It seems that the design studio is governed mainly by two types of activities/ behaviours. One of these seems positive which is the student's frequent use and integration of different communications activities and techniques to initiate creativity and innovation and the other seems negative which is the instructor dominance on the design process. Students said that instructors mostly encourage them to:

- do many attempts to develop the design solution;
- follow various design approaches to reach to an innovative solution; and
- present a creative design solution

However, around one third of students state that strategies to motivate and initiate innovation are rarely applied in design studio and conflicts are hardily handled through constructive dialogue. The most frequent support that students get from the instructors is regarding the following cumbersome situations (arranged from more to less):

- the attempt to change the whole design solution during the design process;
- confusion over the nature and context of the design process;
- the attempt to change of the approach to the design solution during design process; and
- misunderstanding of some project requirements

The least frequent support that students get from the instructors is regarding the following cumbersome situations:

- low level of knowledge of students regarding one of the design aspects
- misapplication of one of the design requirements

The co-efficient path results show that when the frequency of tutor's support regarding some cumbersome design situations of the tutor increases, the student's performance (represented by the final grade) of the student improves. The results show that when the instructors encourage the student to follow various approaches to reach to an innovative solution more frequently, the student would be more able to proceed from one design stage to another smoothly and to make radical changes to the design solution. Also, when students do more interactive dialogue with their instructors on how to reach to a creative design solution and attempt – more frequently- to capture innovative ideas from colleagues in the same and higher academic level, they would be more able to: quickly understand the design problem, do quick analysis of the design problem, set quick conceptual design solution and to do fast appraisal of a design solution and their grades. Students who seek students and staff's help and capture innovative ideas of colleagues of the same academic level from different departments more frequently, would be more able to make radical changes to a design solution. Eventually, when design studio environment is govern with forgiving culture, patient with failure and trustful more frequently, the student would be able more to do quick analysis of the design problem, fast appraisal of a design solution, and proceed from one design stage to another design stage smoothly. On the other hand, the co-efficient path results revealed some odd results. For example, more frequent support from the tutor regarding the student's uncertainty about a design aspect and misapplication of a design concept affect negatively the student's ability to do a fast appraisal of a design solution thus lowering his design grades. Further investigation was undertaken to clarify the questionnaire results.

4.2 Summary of the interviews' results

The interviews were used to clarify some ambiguous points of the questionnaire's survey and provide deeper understanding to the possible factors that would impact innovation. These factors are grouped as the following:

a. design resources

Design precedents are necessary though they are useless without proper analysis of their negative/ positive features and innovative aspects

b. the student's communications

- Students have little knowledge on how to design some architectural aspects of a project
- Some students are unwilling to collaborate with their tutors and have little trust of the tutor's design abilities
- Some students have Communication problems with their tutors as they do not know how to communicate with them; and

- During development of the design scheme, it appears that each party i.e. the tutor and the student have different imagination/ idea of what the final/ possible design solution/ outcome would be

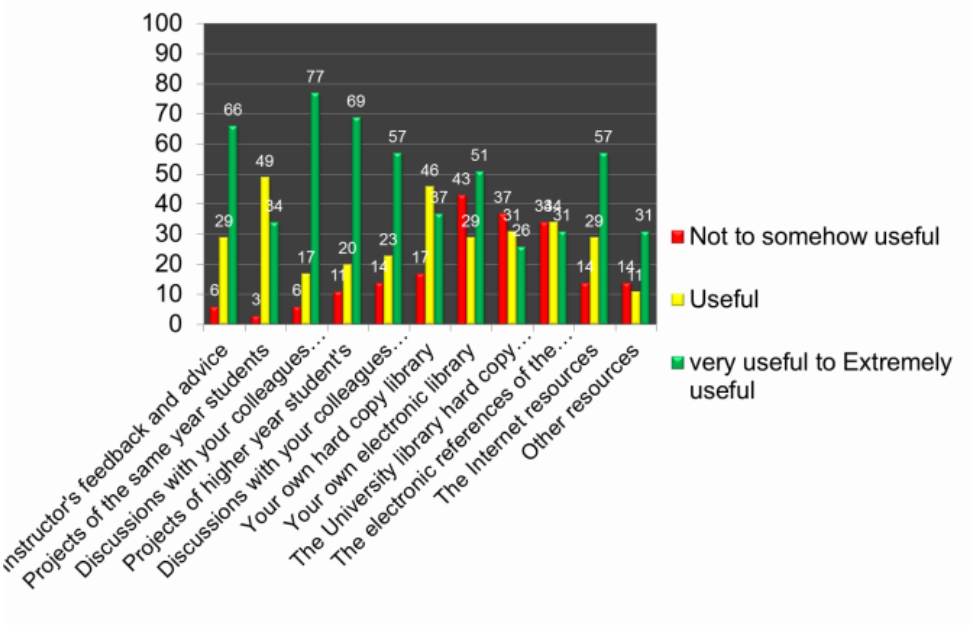

FIG. 1: The usefulness of a number of external and internal resources of information in producing an innovative project. (Note: the Y axis represents the percent of students)

5. BRIEF DISCUSSION OF THE FIELD SURVEY RESULTS

This study -supported by the previous research- shows the role that CAAD systems play at present in initiating innovation and production of innovative projects at College of Architecture, UD. It also highlights the importance of design communications and design precedents in initiating innovation. The study found some negative factors that hinder innovation and these are related to the student's knowledge, communication abilities and communication problems with the tutor. This study argues that CAAD systems should be designed in a way that improves the students' knowledge and skills. The next section discusses the proposed design of a CAAD prototype.

6. THE PROPOSED INTELLIGENT PROTOTYPE

This research findings supported by the previous research highlighted the shortages of the present CAAD systems. It pointed out the need to provide an intelligent and analytical archival knowledge based system.

This paper suggests that some factors which initiate the production of innovative design projects such as the design negotiations and design precedents should be incorporated as a module within an intelligent CAAD system. This module can be built on the concept of BIM, and is IFC (i.e. The Industry Foundation Classes) based. A BIM is a computer model database of building design information, which may also contain information about the building's design, construction, maintenance etc (GRAPHISOFT, 2003). This database is constructed with intelligent 'objects' which represent building elements. From this central database, different views of the information can be generated automatically; views that correspond to traditional design documents such as plans, sections, elevations, schedules etc. As the documents are derived from the same central database, they are all coordinated and accurate - any design changes made in the central model will be automatically reflected in the resultant drawings, ensuring a complete and consistent set of documentation (GRAPHISOFT, 2003). This module can be used to incorporate innovative design precedents and design negotiations into the design scheme. It would include the following (see figure 2):

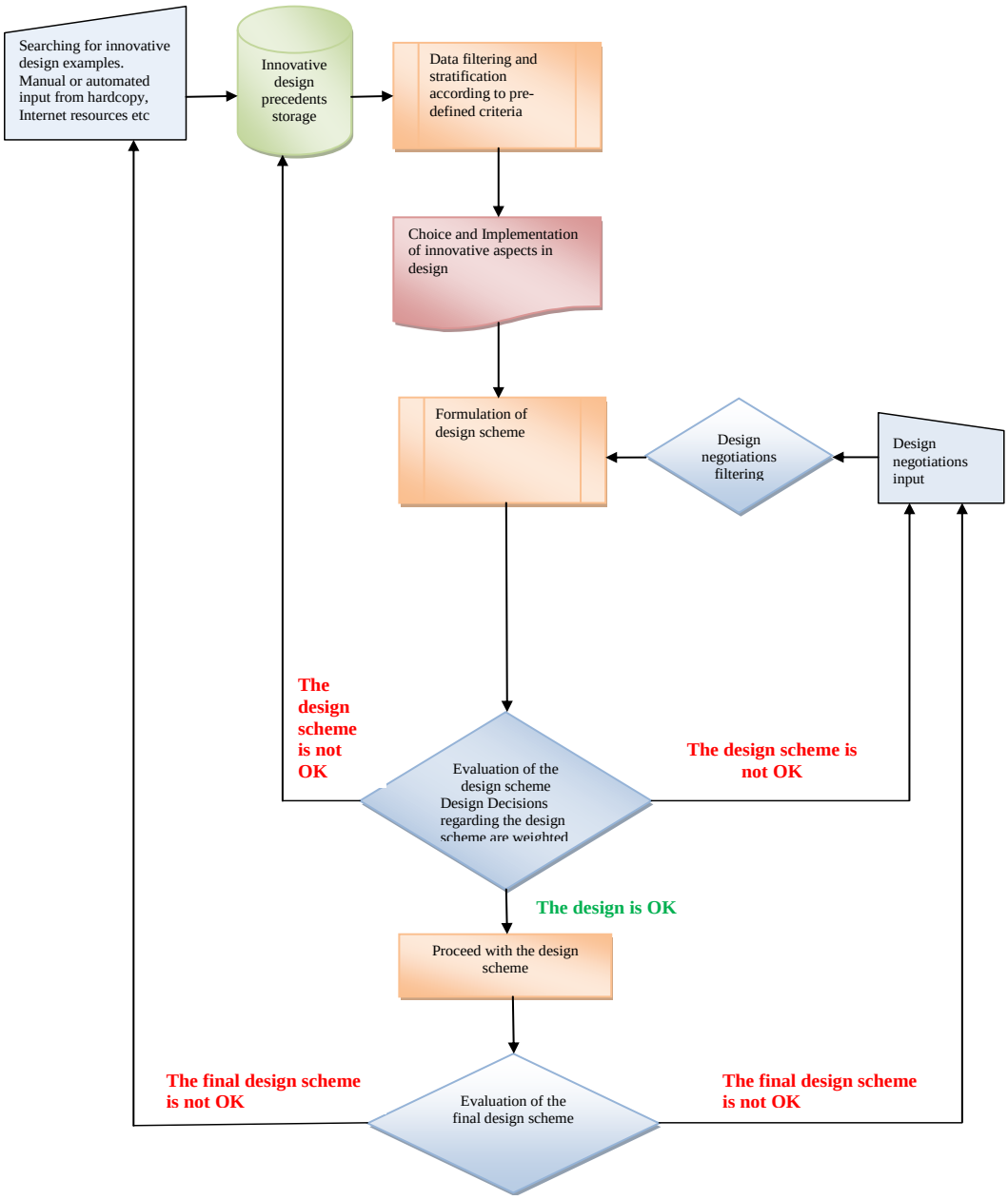

FIG. 2: A flow chart that shows the components of knowledge based system that should be incorporated in CAAD systems to support the production of innovative design projects

- multi-dimensional knowledge base: a platform that stores innovative design examples from real life projects as well as from higher years' projects. It contains a Filter/ processor that analyse innovative precedents according to programmed innovative design criteria that would analyse how these precedents are designed, the design ideology, concept and methodology, what the innovative aspects are, how the design responds in an creative way to design constraints/ requirements and how they are linked to a specific design aspect i.e. form, function, order, aesthetics, structure etc. Also, the system would use similar system to BIM "clash detection" to scan architectural precedents and highlight the area of match with the innovative design criteria. The system would compare the present criteria of the design scheme with the cases that are available in the knowledge base and evaluate how far one or more of the innovative components or the whole design can be used in the present design scheme. This

would provide the student with an intelligent tool that would enable him/ her to choose and evaluate innovative design precedents thus implement it in the design scheme;

- digital storage and analysis centre that stores and analyse self-communications, Video-audio Communications or/and input from verbal communications with tutors and colleagues. This centre documents design negotiations; analyses and capture innovative bits/ ideas. Thus it would verify how far these ideas are relevant to the design scheme criteria;
- innovative decision support tool: multi-criteria decision analysis (MCDA) that weight the completed design scheme regarding to the given design criteria and that assess how far the present design scheme is innovative. As innovation is a qualitative aspect, the evaluation of certain idea should be based on a qualitative measurement. The assessment of qualitative criteria would be through the use of Analytic Hierarchy Process (AHP); and
- The system should be flexible in terms of allowing decision loops that simulate the design backwards and forward loops.

Such system would help students to look for innovative architecture, explore the innovative aspects (i.e. aesthetics, technical, structural etc.) of the case studies, and to experiment several solutions and innovative ideas, making links between innovative design components and design ideas and feedback thus it may help in raising their awareness about innovative design products. Computer mediated communication would help students in getting wider feedback regarding the design scheme and would increase the student's knowledge about innovative solutions and how to incorporate it in the design scheme.

7. DISCUSSION AND CONCLUSION

The study has outlined the possible initiation and hindrances to innovation in the design studio. The utilization of innovative design precedents and design negotiations is essential to produce innovative design products. Students should be taught how to look for innovative architecture solutions, explore the innovative aspects of each case study, experiment with possible links between innovative design aspects/solutions and each dimension of the design problem, in line with expert designers' usual practice. Also, they should experiment with possible links with the ideas that they have obtained from the design negotiations. Tutors should not impose their own ideas on students but introduce them to students and encourage students to explore how the potential solutions can be integrated with the students' design ideas.

Keeping a record of the design negotiations and innovative design precedents would be useful as it may help the student to track the progress of the design, explore new links between design negotiations at the various stages of design, and the design problem.

However, with the increasing complexity of the design process and variables, it would rather difficult for students to master the design process. This paper suggests incorporating design negotiations and innovative design precedents in an intelligent CAAD system. Thus, it would be easier for students to document design communications and precedents, experiment possible links between these communications and precedents, and various aspects of their design scheme.

The paper has outlined the proposed intelligent knowledge-based system. The future research should explore the possible automation of the design process/ decision making process to initiate innovation. However, this CAAD prototype would not be capable to resolve all the troubled social issues in regards to the relationship of the student with the instructor. This needs further research that looks into the causes of this troubled relationship and find possible mechanisms to sort it out.

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