COMPUTING IN ARCHITECTURAL DESIGN: REFLECTIONS AND AN APPROACH TO NEW GENERATIONS OF CAAD

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SUMMARY: *This paper introduces a reflective perspective on the role of computing in architectural design over the previous generations of computer aided design. Paradigms of the design process and computational models of designing are discussed. The evolution of computer aided architectural design is investigated. Both deadly sins and arguable virtues of computing in architectural design and their implications are reviewed. Based on addressing recent emerged developments of computer aided architectural design (CAAD), this paper introduces an approach for the new generations of CAAD that has the potential to provide a better CAAD future for architectural researchers, educators and professionals. This approach envisages that in the new generations of CAAD architectural designing will be carried out collaboratively and synchronously within smart and real-time 3D virtual environments within which architects are designing with intelligent agents based on the view of situated digital architectural design.*

KEYWORDS*: CAAD, architectural design, future of CAAD, 3D real-time virtual design environments.*

1. INTRODUCTION

It is almost half a century since computers have been used in building design. Their first use was in structural analysis and construction planning. The use of computers in building design analysis has included extensive developments in the analysis of building structure, HVAC (heat, ventilation and air condition) and environmental performance of buildings. Recently, sophisticated analyses of environmental behaviour and the behaviour of building users have been developed and implemented. Computer graphics was developed initially in the 1960s and formed the basis of computer-aided drafting systems, termed as CAD systems. These systems are used during the development and documentation phases of building design. CAD systems have been developed beyond simply drafting to modelling the geometry of the building. Today's commercial CAD systems are used at various stages in the building design process and are integrated with analysis tools (Gero, 2002).

Computer Aided Architectural Design (CAAD) has been defined and redefined, many times, over the years as the role of the computer in architecture has been subject to many changes. It was first envisioned as a sophisticated simulation machine and then as a repository of accurate and comprehensive records of buildings. The late 80's and early 90's ushered in a different view of computers in architecture. First, the computer was not seen as a replacement for other things such as draftsmen, hard copy documents and organizations. Second, it became to be considered a "medium" no more no less, and thirdly as a collaborator in the design process in which the computer and the human complement each others' weaknesses (Akin and Anadol, 1993).

The objectives of this paper are: (a) to introduce a reflective perspective on the role of computing in architectural design over the previous generations of computer aided design; and (b) to develop an approach for the new generations of computer aided architectural design (CAAD) that has the potential to provide a better CAAD future for architectural researchers, educators and professionals. The remainder of this paper addresses the different paradigms of the design process including rational problem solving and reflection-in-action. Computational models of designing that involve viewing design as search, planning, exploration, reflection-in-action, emergence and situatedness are discussed. The evolution of computer aided architectural design is investigated during the first and second generations of CAAD including a review of both CAAD's deadly sins and arguable virtues and their implications. Recent emerged developments of CAAD including virtual collaboration, digital tectonics, 3D virtual design environments, intelligent agents in design, and situated digital design are addressed. Based on the recent emerged developments of CAAD an approach for the new generations of CAAD is proposed to envisage architectural designing to be carried out collaboratively and synchronously within smart and real-time 3D virtual environments within which architects are designing with intelligent agents based on the view of situated digital architectural design.

2. PARADIGMS OF THE DESIGN PROCESS

In the digital age, computing in architecture has posed new challenges since its early beginning; it has given better tools that changed the working methods in the architectural profession. However, it is important to realize the historical background of the science of designing while investigating the role of computing in aiding architectural designing. Design paradigms include: (a) *the plan is the process* in which the role of professional designer is to develop and make available the processes of design decision-making, rather than to produce solutions; (b) *the process is design-in-use* wherein design is a continuing activity and the processes of decision-making should be as relevant to building modification, adaptation, growth and management as to the generation of the original built form; and (c) *design-in-use* is participatory whereby design decision-making is the province of those affected by design decisions, therefore these processes should be usable by clients and users. While these paradigms might be valid over all fields of design, there are unique characteristics that distinguish architecture and building design. These characteristics include: (a) magnitude of the solution space, e.g. there are some 7 million ways of arranging 12 spatial units within a 3 x 2 x 2 unit envelope; (b) multi-variant nature of architectural design including the need to satisfy functional, environmental, aesthetical, financial, structural and cultural requirements; and (c) temporal variation of requirements over the life cycle of buildings. The inability to address the problems arising from these characteristics has led to a reduction of the solution space to a sub-set, a strict hierarchal ordering of design decisions, and a perverse commitment to a single concrete statement in terms of built environment (Maver, 1972).

Furthermore, many systems of describing design processes have been developed over the years. In the early 1960s methods of design methodology were influenced by theories of technical systems in which design has been viewed as a rational process. Interest in the fundamentals of design theory in view of logical form and status of design has been raised by the criticism of viewing design as a rational process. Problem solving theories introduced by Simon (1992) provided a framework of the paradigm of technical rationality. This view has dominant influence on shaping prescriptive and descriptive design methodology. The implications of viewing design as a rational problem solving process includes taking classical sciences such as physics to be the model for a science of design, and logical analysis and contemplation are the main ways of producing knowledge about the design. The problem solving approach means looking at design as a search process in which the scope of steps taken towards a solution is limited by the information processing capacity of the acting subject. The problem definition is suppose to be stable and defines the solution space that has to be surveyed.

On the other hand, Schön (1983) has proposed a radically different paradigm to the technical rationally one describing design as a process of reflection-in-action in which any design problem is unique and a core skill of designers' lies in determining how every single problem should be tackled. Design is seen as a reflective conversation with the situation. Problems are actively set or framed by designers, who take actions and make moves to improve the current situation. The link this paradigm provides between design process and the content of the design problem is most valuable. But the treatment of design as a reflective conversation lacks the clarity and rigor achieved by the rational problem solving paradigm (Dorst and Dijkhuis, 1995). Viewing design as a rational problem solving process is particularly appropriate in situations where the problem is well defined and the designer has strategies to follow while solving them. On the other hand, describing design as a reflection-in-action fits more in the conceptual design stages wherein strategies to be followed to provide solution are fairly undetermined. A comparison between both rational problem solving and reflection-in-action paradigms is illustrated in Fig. 1 (modified after Dorst and Dijkhuis, 1995). The factors of comparison include the designer, problem, process, knowledge, and model.

3. COMPUTATIONAL MODELS OF DESIGNING

Designing has been modelled computationally based on the design paradigms addressed in the earlier section and concepts of artificial intelligence and cognitive science. Most dominant computational models of designing are shown in Fig. 2. The computational models of designing include modelling design as search, planning, exploration, emergence, reflection-in-action, and situatedness. The computational process of search underlies the use of artificial intelligence techniques in design including knowledge-based systems (Coyne et al, 1990). The basic assumption in modelling designing as search is that the state space of possible designs is defined in advance which demotes the model to detail or routine design. The advantages of modelling designing as search include the ability to search spaces described symbolically rather than numerically. Modelling designing as planning is extracted from its artificial intelligence conception as the determination of the sequence of actions required to achieve a goal state from a starting state. Planning has been used to model design (Coyne et al, 1990, Hauser and Scherer, 1997).

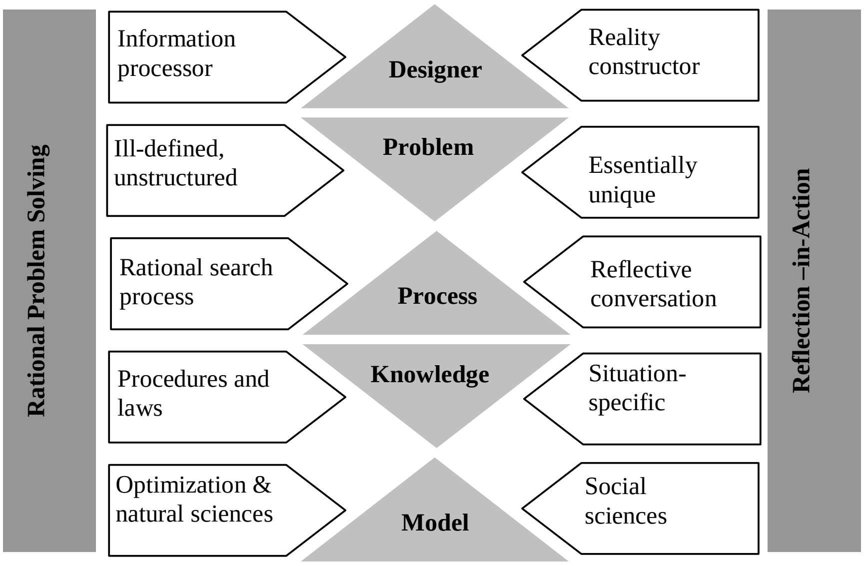

FIG. 1: A comparison between the rational problem solving paradigm and reflection-in-action paradigm.

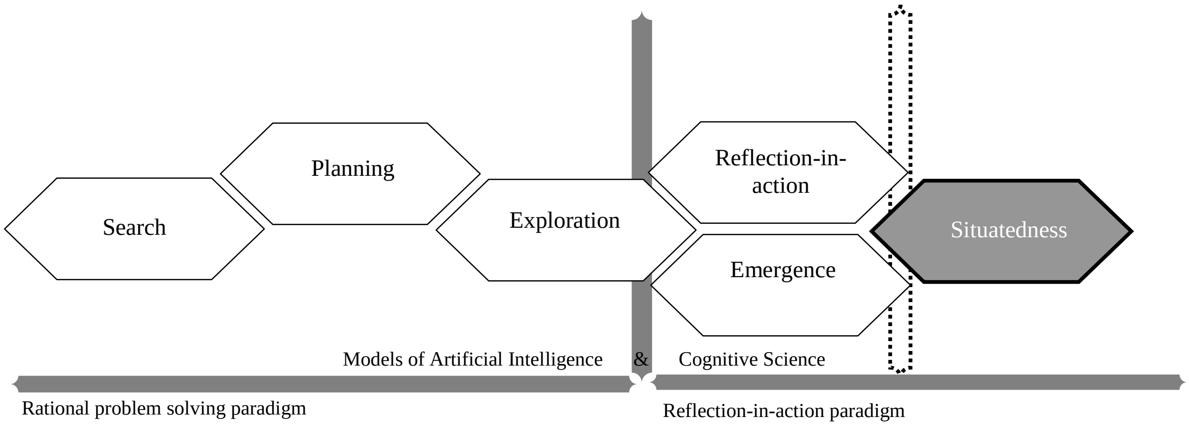

FIG. 2: Computational models of designing from search to situatedness.

Modelling designing as exploration stemmed from recognizing designing as a wicked problem (Rittel and Webber, 1973) and assumes that the state space of possible designs to be searched is not necessarily available at the outset of the design process. Exploration can be viewed either as meta-search in which the designer searches for state spaces amongst the set of possible predefined state spaces or as a form of construction where each state space bears some connection to the previously constructed state spaces. The concepts of viewing designing as reflection-in-action and emergence provide the seeds for the notion of modelling design as a situated activity or as a sequence of situated acts (Gero, 1998). Emergence is a related concept to reflection which is a way of seeing what was not intentionally represented. Situatedness is concerned with relating knowledge to its locus and application and locating knowledge in a context so that the decisions that are taken are functions of both the situation and the way in which the situation is constructed or interpreted (Clancy, 1997, Reffat 2000). The concept of situatedness provides the bases for modelling designing for conceptual or non-routine design. Adding the notion of situatedness to framework of Function-Behaviour-Structure (Gero, 1990) provides a model of situated function-behaviour-structure framework (Gero and Kannengiesser, 2004).

4. EVOLUTION OF COMPUTER AIDED ARCHITECTURAL DESIGN IN THE DIGITAL AGE

Since the beginning of digital age, new technologies have influenced people in different ways in which life is not anymore as before, the world is different and people become more open and knowledge worldwide become more accessible. However, there are continuously more perspectives and opportunities, people are encountering problems never existed before the digital age. The digital age has posed new challenges and given people tools with which the working methods have changed. Architecture is still searching for its own position with the use of computers in designing. The evolution of computer aided architectural design (CAAD) can be viewed through the generations of CAAD. In the first generation of CAAD, analysing designing commenced from the view of systems method that divides reality into a small number of subsystems with specific and clear influences. In accordance with the theory of general systems, each system acts in relation to others on the basis of direct and linear coupling within a deterministic approach of association. The assumptions of the General Systems Theory have become the methodological basis for the developed methods of aiding design. Systematic designing methods can be divided into two groups: strategic and tactical methods. Strategies derived from scientific research methodology include: (a) analysis-synthesis-evaluation, (b) divergence-analysis-transformation; while synthesis-convergence–evaluation represents the idealistic creative approach. Tactical methods include that of spatial distribution at both urban and architectural scales (Asanowicz, 1999).

The efforts to present the designing process as logically formal and internally cohesive from a mathematical point of view were not that successful; however the architectural thought is supported by abstract logic. Abstract logic means to signify a meditative exploration that arrives at a crystallization of the complexity and richness of the world, rather than a reduction of its reality through diminishing its concreteness. At the core of architectural creation is the transformation of the concreteness of the real through transparent logic into spatial order (Ando, 1991). Therefore, the first generation methods had many drawbacks including: deterministic and linear approach of the design process, limited scope to solve functional problems, and a lack of graphical interfaces for communication between users and the computer. The second generation of CAD facilitates designer’s communication with the computer whereby software packages were released to enable one to draw on the computer screen without having to know any programming languages. Since then, designers are using computers as a digital board to be an alternative to the conventional drawing board. CAD systems are used to produce technical drawings and 3D computer models. The typical use of CAD systems at subsequent stages of designing can be illustrated as shown in Fig. 3. Little computer support has been provided for both concept and exploration of various useful alternatives. The primary computer aided support is basically for developing design documents, construction and working drawings and generating presentation drawings in 3D and multimedia formats including animations and movies. Extensive computing support has been given to the design analysis including structure, lighting, acoustic, mechanical, space syntax, etc. In the second generation of CAAD systems, there was no real difference that can be identified from the conventional design support apart from replacing the drawing tools of pencil, drawing board and brush with efficient and powerful digital replacements. The computer is transformed into a drafting machine and CAAD meant more Computer Aided Architectural Drafting than Designing. It is arguable that these systems provided the architect with more time to spend on the creative stages of the design process. However, it is not questionable that such systems have enhanced the acceleration and development of the technical documentation of designs and generating architectural free forms that diverted away from the canon of right angles and straight lines. On the other hand, the Ronchamp Chapel and the TWA airport terminal in New York, designed by Le Corbusier and Saarinen respectively, are just examples of magnificent architectural forms created without the use of computer (Asanowicz, 1999).

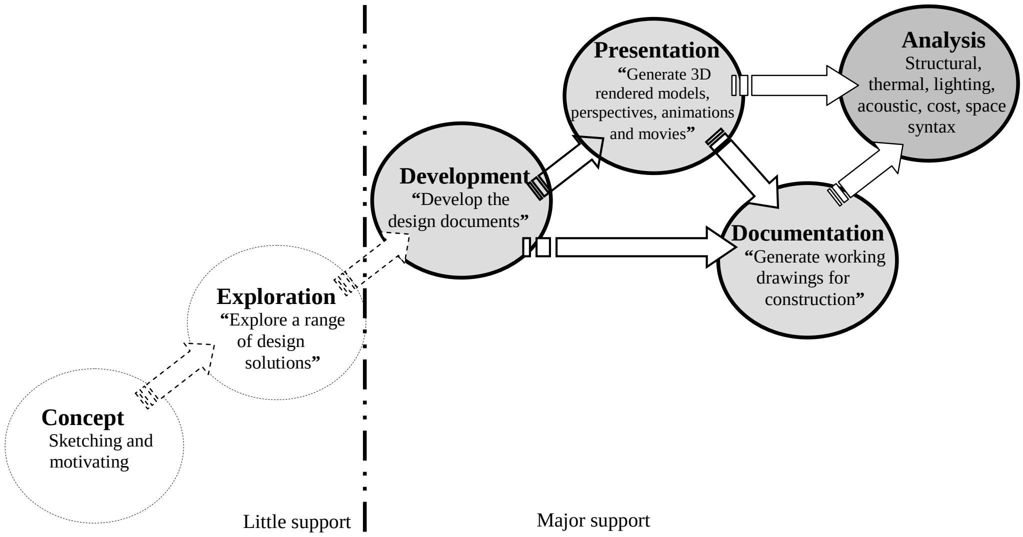

FIG. 3: Computer aided support to various stages of the design process in the second generation of CAAD.

5. COMPUTER AIDED ARCHITECTURAL DESIGN BETWEEN DEADLY SINS AND ARGUABLE VIRTUES

Akin and Anadol (1993) addressed "what is wrong with CAAD" and noted that Computer Aided Architectural Design (CAAD) is far from fulfilling its expected role (as assistants to the designer, providing a medium and set of tools for the designer), in the professional or the academic context in all aspects of the design activity. Akin argued that CAAD development should be directed towards greater impact on practice by means of principles that are related to the steps used to construct CAAD tools for conception, defining the goal, developing the product, fitting out the product, and discarding. Maver (1995) has provided a critical view of the direction of research and development in computer aided architectural design. His criticism was set out as seven deadly sins including macro-myopic, déjà vu, xenophilia, un-sustainability, failure to validate, failure to evaluate and failure to criticize. The seven deadly sins of CAAD are elaborated in Table 1. CAAD researchers and educators should not be disheartened by Maver's (1995) critical view on the direction or research and development of CAAD, but on the contrary it is as important to the future role of computing in architecture as enumerating the advantages and virtues of CAAD as Maver (1998) later remarked. Kvan (2004) has endeavoured to illustrate the inevitability of sinning the "macro-myopic". Distinguishing between wasteful repetition and productive re-exploration is a skill since reworking is an essential activity in discovery that is recognized more readily in art than in science. Therefore, it becomes an important research activity to revisit problems. Therefore, sinning in Maver's definitions might be a necessary condition of progress, at least in a field of endeavour such as CAAD wherein the link between practice and research in CAAD is weak. It seems to be a necessary condition of CAAD that one struggles between the holistic experiential goal of architecture and the reductive nature of science (Kvan, 2004). Furthermore, it is essential to note some of the benefits of importing concepts and procedures from other disciplines to architecture, for instance, artificial intelligence research brought a better understanding of design activities and opened the field for new support methods; geometric modelling and geometric reasoning research formed the foundation for CAAD programs that dominate the instrumentation of architects worldwide; design methods research brought much needed knowledge into the nature of design (Schmitt, 2004).

Maver (1998) and Gero (2002) noted the prospects of CAAD and the advances of information technology in building design respectively. Maver (1998) reviewed with reasonable detail a variety of CAAD systems developed since 1965 for the first program that generates a single floor plan layout which minimized the pedestrian travel within the building as the origin, energy efficiency systems, integrated appraisal systems, design decision support systems, simulation of form, photorealism and animation, and the virtual and augmented reality systems. Maver (1998) noted that "it is difficult, perhaps unreasonable, however, to maintain a critical and pessimistic view of the CAAD world in face of such a wealth of innovative, relevant and enjoyable developments". Gero (2002) remarked the advances of using computers in the building industry commenced with research into automating structural analysis through the development of the matrix method of frame analysis, developments of environmental analysis of buildings and developments in construction project management. Most recently Koutamanis (2004) questioned the validity of CAAD deadly sins by Maver (1995) and in contrast has attempted to adapt the seven arguable virtues to CAAD as represented in Table 2. Some of the virtues argued by Koutamanis (2004) have been renamed by the Author and old terms are placed between parentheses. The primary reason of renaming is to make them more tangible to CAAD development.

TABLE 1: The seven deadly sins of computer aided architectural design.

Deadly sins of computer aided architectural design	
macro-myopic	**Overestimating the short term impact but underestimating the longer term impacts**. Unfortunately it is still rife in today's CAAD community. Most of Ph.D. theses claim anything less than "all-singing, all-dancing, fully integrated, multi-disciplinary decision support system".
déjà vu	Current CAAD efforts **do not build on what went before.** This is observed with the emergence of new ideas, with increasing frequency, in the CAAD filed that have striking similarities with early abandoned and almost forgotten work.
xenophilia	**Absence of core research discipline.** Obsession with importing concepts and procedures from other disciplines, from language through to artificial intelligence seem to have diverted intellectual effort from the central task of identifying and understanding the substance and true nature of architectural designing.
un-sustainability	**Research and development are focusing on architects more than on architectural design products.** Efforts are devoted to facilitating the practice of architecture with less attention to achieving design solutions with improved quality to building clients and users. Nevertheless, attention to form rather than function, style rather than substance has been dominant on the expense of fitness-for-purpose, cost-effectiveness and environmental sustainability.
failure to validate	**Generating a plethora of exotic unsubstantiated claims with prototype implementation or rudimentary testing.**
failure to evaluate	**Little recorded evidence of investigation** (including credible user feedback), of the usability and functionality generated prototypes software in the architectural teaching and practice.
failure to criticize	**Not exercising our critical faculties** on the research and development carried out by us and our peers in recent years.

TABLE 2: Arguable virtues of computer aided architectural design in contrast to the deadly sins.

Deadly sins	**Arguable virtues**	
macro-myopic	**Prudence**	Careful consideration to the requirements and potentials of architectural computerization while establishing an appropriate pace of development. Neutral position to all external influences and false promises.
déjà vu	**Trust** (Faith)	Development of coherent, comprehensive, consistent and relevant theories by careful consideration of CAAD and appropriate choice of the constituents and backgrounds of CAAD theory with conviction, transparency and founded arguments.
xenophilia	**Originality** (Charity)	Establishing a core research discipline based on the substance and true nature of architectural designing.
un-sustainability	**Temperance**	Balanced emphasis on building behaviour and performance with design approaches and generative systems in CAAD. Focus on Computational design analysis and utilization of computer's analytical power to complement human creativity in an unobtrusive, constructive manner while addressing universal issues in the built environment.
failure to validate	**Promise** (Hope)	Research should be based on well-founded and well-defined expectations with the formulation of assumptions and validation approaches.
failure to evaluate	**Effectiveness** (Fortitude)	Developing rigorous and consistent evaluation.
failure to criticize	**Sound Judgment** (Justice)	Developing a sense and structure of impartial and fair criticism. Comprehensive precedent research instead of customary propagation of expectations to establish solid foundations for existing and further research.

6. RECENT EMERGED DEVELOPMENTS OF CAAD

There have been various recent emerged developments of CAAD. It is beyond the scope of this paper to thoroughly investigate and/or compare them. However, it is critical to address the most important developments pertaining to shaping the future of CAAD and that will also provide a logical bridge to the proposed approach of the new generations of CAAD as outlined in the following section. These important emerged developments of CAAD are illustrated graphically in Fig. 4 and include virtual collaboration and communication in design, digital tectonics and fabrication, 3D virtual design environments, intelligent agents in design, and situated digital design.

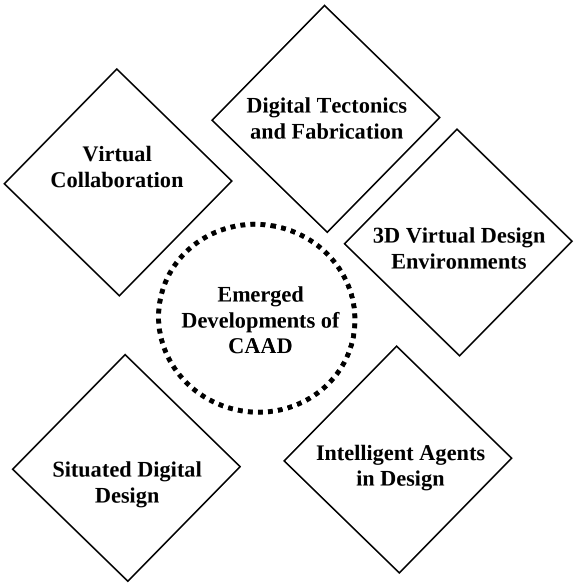

FIG. 4: Recent emerged developments of CAAD pertaining to shaping the future of CAAD.

6.1 Virtual Collaboration and Communication in Design

Initially, the mode of working with digital tools assigned a user to a machine wherein tasks were formulated as singular activities of preparing data and submitting them for processing. The complexities of design, therefore, were reduced to individual activities of groups of participants. Using digital tools for modelling, rendering and representation solely in a single user context fail to apply digital media in a manner that effectively supports design. Architects work in teams and collaborate on projects. The medium needs to address these creative and communicative roles of the designer. Studying the activities of designers and comparing co-located and distal activities has led to discover that designers working together on tasks in different environments engaged with the task in very different ways and that the assumption that high bandwidth social interaction was essential in supporting design was not necessarily the case (Kvan et al, 1998). Furthermore, it was found that the limited channel of a chat line, where 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.

6.2 Digital Tectonics and Fabrication

Digital tectonics is an evolving methodology that integrates the use of design software with traditional construction (Beesley and Seebohm, 2000). A breakthrough came in the early 1990s, when Frank Gehry and the technical team in the Gehry office began seriously to explore the use of digital tectonics and fabrication technologies on complex projects. The goal was to support efficient design and construction of buildings with curved surfaces and generally complex, non-repetitive forms. Gehry used Catia (a system that had been developed primarily for use in manufacturing industry) that offered a high degree of integration of design and CAD/CAM (Computer Aided Manufacturing) fabrication capabilities. This allowed developing complex and non-repetitive buildings but entailed more explicit decisions per square meter than repetitive buildings. Furthermore, detailed three-dimensional modelling of buildings is generally more time consuming and costly than two-dimensional drafting of plans, elevations, and sections (Mitchell, 2006). Models of design capable of consistent, continual and dynamic transformation are replacing the static norms of conventional processes. The predictable relationships between the design and representations are abandoned in favour of computationally generated complexities. Digital architectures are profoundly changing the processes of design and construction. By integrating design, analysis, manufacturing and assembly of buildings around digital technologies, architects, engineers, and builders have the opportunity to reinvent the role of a “master-builder” and reintegrate the currently separate disciplines of architecture, engineering and construction into a relatively seamless digital collaborative enterprise (Kolarevic, 2001).

6.3 Virtual Design Environments

The concept of virtual environments has emerged from advances in computer networking, image processing, modelling, simulation, and multimedia representation (Simoff and Maher, 1997). Virtual environments that mimic the spatial arrangements of the physical world have changed the role of 3D CAD systems from drafting to producing blocks of the new 3D virtual environments. Virtual Environments (VEs) are attractive platforms for learning in which they can provide opportunities for new kinds of experience to enable users to interact with objects and navigate in 3D space in ways not possible in the physical world. The key property of VEs is their ability to captivate. Immersion in 3D environments is highly motivating, inducing users to spend more time on a given activity. Furthermore, virtual environments encourage people to be more active in the way they interact with external representations, through having to continuously choose their position and viewing perspective when moving through the virtual environment. Utilizing virtual environments in architectural design advances the concept of designing with computers (e.g. in a paperless design studio), to a multi user real-time 3D virtual environment for achieving collaborative designing (Reffat, 2003b).

6.4 Intelligent Agents in Design

An intelligent agent is an autonomous system situated within an environment, it senses its environment, maintains some knowledge and learns upon obtaining new data and, finally, it acts in pursuit of its own agenda to achieve its goals, possibly influencing the environment. Agents in Design still in early evolution stages whereas multi-agent systems is a relatively new area within artificial intelligence. Multi-agent systems provide means to model distributed computational process, and as such computational design agents. Computational intelligent agents enjoy the following properties: autonomy, reactivity and pro-activeness whereby they do not simply act in response to their environment, they are able to exhibit goal-directed behaviour by taking the initiative (Wooldridge and Jennings, 1995). Intelligent agents are expected to influence and change the environment within which they function. Users of world-wide-web inadvertently make use of agents during their web searches.

Designing with computational agents is at the cutting edge of current design computing research. This agent approach is derived from recent developments in cognitively-based design agents, where design is considered as a situated act. A design agent might have five kinds of reasoning: sensation, perception, conception, hypothesizer, and action (Gero, 2002). For instance, Saunders (2001) developed a computational model of curiosity based on a process of novelty detection. A curious design agent is an agent that uses the search for novel designs to guide its design actions. Computational models of curiosity provide general-purpose, knowledge-lean heuristics to guide the search for potentially interesting, and possibly even creative, designs. Determining interestingness depends upon the knowledge of the agent and their computational abilities; things are boring if either too much or too little is known about them. Hence situations that are similar-yet-different to previously experienced situations are the most interesting and this is what we mean when we say that something is novel. A novel situation is one that is similar enough to previous experiences to be recognized as a member of a class but different enough from the other members of that class to require significant learning. Furthermore, Reffat (2003a) developed a system of intelligent design agents that supports design exploration and creativity within the domain of architectural shapes. Creativity in architectural design compositions is viewed as an emergence of new forms and shapes or relationships between forms and shapes from which new concepts are discovered.

6.5 Situated Digital Design in Architecture

Empirically-based research uses the experimental paradigm in which experiments are set up and then data is collected and analysed to produce a set of results. These results are then used as the basis of either the development of a hypothesis or the confirmation of a hypothesis about designing. The experiments are typically developed to provide evidence for a particular theory or cognitive model of designing. Typical approaches to empirically-based design research include direct observation of the results of designing, surveys of designers' perceptions, and protocol studies of individual and collaborating designers. New protocol analysis methods have been developed and are being applied to produce novel results concerning the behaviour of designers as they are designing which has significance for the development of computational tools for designers. Empirically-based research produces results by which a greater understanding on how human designers design is acquired. Such knowledge have implications for both how information technology can be interfaced with human designers and, perhaps more importantly, provide new conjectures for design computing research in architecture to explore in order to provide the foundation for more useful tools for designers.

The evolution of digital design as a unique field of design endeavour, motivated by its own body of theoretical sources, and a culture of discourse, is beginning to evolve unique methodologies. Rather than the employment of digital technologies, it is these emerging conceptual structures that strongly influence the logic of architecture and its design methods (Oxman, 2006). Computational models of designing have largely been founded on fixed views of the world, often derived using artificial intelligence models focused on modelling and representing designed objects. These models were based on a paradigm of computing that assumes that the underlying programs are unchanged by their use and are not affected by where or how they are used as a one of the foundations of objective knowledge. These models have been useful but have proven to be inadequate to describe much of the detailed behaviour of designers observed in protocol studies (Schön and Wiggins, 1992). Such behaviour can be more modelled using the notion of situated computing and forms the basis of situated design computing; that is the inclusion of situated concepts into design computing. Situated computing makes use of concepts from situated cognition (Clancey 1997). The fundamental difference is between encoding all knowledge prior to its use and allowing the knowledge to be developed and grounded in the interaction between the tool and its environment. The effect of this is to provide a computational system with experience based on its interaction with its environment. That experience is then used to guide its future actions. The effect of this grounded experience is to provide the tool with the capability to respond differently when exposed to the same environment again depending on the experiences it had in between the two exposures. The objective knowledge within the tool is unchanged, only the knowledge that is the result of the interaction of the tool with its environment is changed. Situated design computing has the capacity to be the basis of computational models of designing that more closely account for the observed behaviour of designers. With situated computing tools that learn from their experiences and apply what was learnt within both like and new situations can be produced (Gero, 2002). A computational system of Situated Learning in Design (SLiDe) (Reffat, 2000) was developed to elucidate how design knowledge is learned in relation to its situation, how design situations are constructed and altered over time in response to changes taking place in the design environment. Situated learning is based on the notion that knowledge is more useful when it is learned in relation to its immediate and active context, i.e. its situation, and less useful when it is learned out of context. The usefulness of design knowledge is in its operational significance based upon where it was used and applied.

7. AN APPROACH TO NEW GENERATIONS OF CAAD: WAYS TO A BETTER CAAD FUTURE

Based on the recent emerged developments of CAAD, one should expect that the real support to architectural designing requires using computers effectively at the early stages of the design process by transforming the computer into an intelligent and creative medium. A medium that is creative by autonomously discovering new ideas as the designer moves and acts within it. The creative nature of the architectural designing encourages that role from CAAD systems. The computer can be used as a “metaphoric machine” (Asanowicz, 1999), means of mediation techniques (Van Berkel, 1999) and direct design using virtual environments. Computers can be useful as a “metaphoric machine” and can serve a superior role in the process of creation, taking the role of the generator of chances. The most important architectural potentials of the new mediation techniques include: expansion of spatial imagination, radical break with a hierarchical design approaches, and introduction of different disciplines into the design process, relating the design to its final execution. Furthermore is the use of computers for direct design within 3D virtual environments. Architects are often engage with the present, manipulate existing means and act in real time. Architectural designing in virtual environments has the potential of achieving direct manipulation with created forms and objects.

The proposed approach to new generations of CAAD aims to provide a better CAAD future for architectural researchers, educators and professional demands the elaboration of new methods of using the computer at the early stages of the design process. Using computers in architectural design should not be limited to generating variants of functional solutions and should be transformed from a tool into an intelligent medium. Fig. 5 graphically illustrates the proposed approach to the new generations of CAAD. This approach envisages that in the new generations of CAAD, architectural designing will be carried out collaboratively and synchronously within smart and real-time 3D virtual environments within which architects are designing with intelligent agents based on the view of situated digital design. The new generations of CAAD operating within smart 3D virtual design environments will be supported by a language of CAAD that matches the language of architecture in which it will be convenient for architects to design on their own terms. The implication of this includes developing a virtual design environment with an intelligent set of architectural elements that map to concepts of architectural designing.

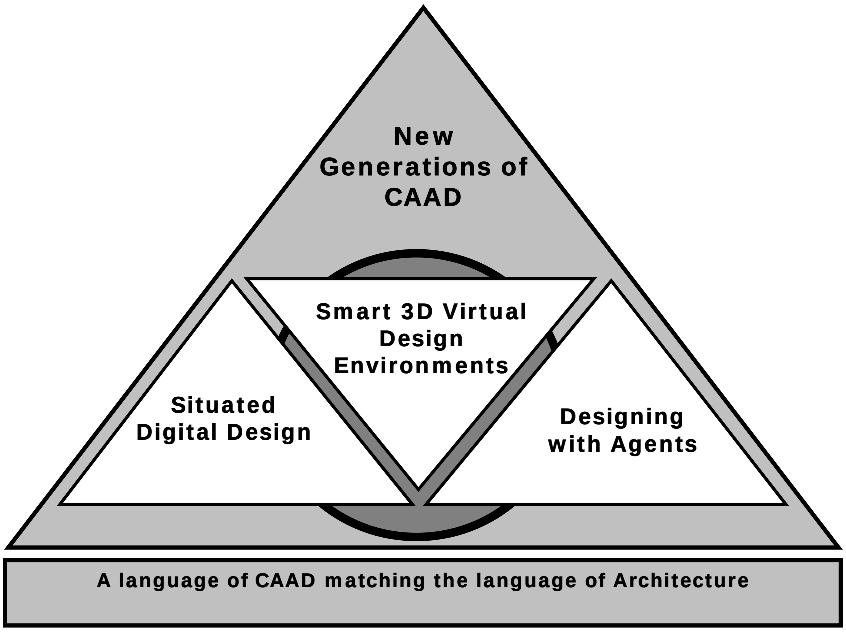

FIG. 5: A proposed approach to the new generations of CAAD.

In the proposed approach, architects will design interactively, test the consequences of actions, and explore different ways of solution refinement that are crucial in design and architecture. Smart 3D virtual design environments will be the medium that provides such capabilities to benefit the experienced designers and strengthen the novice designer's ability to gain depth in designing. The smart 3D virtual design environments will have two purposes: a simulation of physical architecture and a functional virtual place. The simulation of physical architecture is the most common purpose of virtual environments and is increasingly being used to visualize, understand, and present architectural designs. The advantages of simulating physical architecture into virtual environments include allowing architects, designers, and clients to collaborate synchronously, without being co-located. Virtual design environments offer functionality beyond CAD modelling in that all documents are treated as objects. The second purpose of using virtual environments involves the design and creation of virtual places in terms of their functional organization and electronic representation. Architects design buildings to provide places for people to live, work, play, and learn. Such places are embodied as buildings with internal spaces called rooms, halls, theatres, etc. An emerging concept for designed virtual places is to provide an electronic location for people to socialize, work, and learn with the potential for virtual places to be designed by architects and then constructed by programmers. Furthermore, opposite to Virtual Reality (immersion when dealing with a computer), is the Real Virtuality as the materialization in the real world of something that comes from a computer. Real virtuality might be more interesting in that it promises to augment our everyday reality in hopefully interesting and useful ways.

The new generations of CAAD will transform its use in designing the built environment by conceiving the design process of the built environment to be an integration of technical and social processes. The technical dimension can be accomplished by developing an intelligent and interactive virtual design environment (VDE) for architectural design through providing interactive counterparts (virtual observers, e.g. intelligent design agents) to the designer to offer useful assistance in designing by supporting behaviour and semantic-based concepts within VDEs. The social dimension can be provided by offering a conduit between multiple human opinions and information sources to offer instructive and constructive design suggestions. This is reflected in the interactions within the VDE between the designers, clients, community and planners. The potential benefits of employing intelligent agents in virtual environments include empowering computers not only to support a much higher degree of visual realism but also with processes of intelligent behaviour. Research in the field of virtual environments is moving towards intelligent virtual environments in order to include specific options of functionality. A framework of an intelligent and collaborative design environment is introduced (Reffat 2003a and b; Reffat and Beilharz, 2004). Researchers in the field of artificial life have even more ambitious aims. These aims include the creation of virtual worlds containing digital life with new rules but not necessarily similar to those of real world. Some see distributed interactive virtual environments such as Activeworlds as a basis for the development of such virtual worlds allowing autonomous interaction between artificial life forms and virtual worlds. Mitchell (1995) addressed the necessity of developing virtual design studio (environment) in the architectural practice. Firstly, Practical design projects of any magnitude are almost invariably carried out by multidisciplinary, geographically distributed teams. Secondly, many design firms increasingly need to compete in international rather than local markets, therefore the need for effective ways to export their services is becoming essential. In addition, competitiveness increasingly depends on the ability to aggregate needed expertise in the most flexible and efficient way.

The agent approach to 3D virtual design environments provides new kinds of interaction among the elements of the virtual environment representation and between individuals and project teams with the components of the virtual environment that makes both the virtual environment and interactions with it more dynamic (Maher and Gero, 2002). Furthermore, Mitchell (1995) has early envisioned the potential roles of agents in virtual design environments. An architect working on a 3D building model within a virtual design environment wants to select and specify some ceiling tiles for a project under designing. The architect indicates the position of the tiles in the model, and invokes a software agent that crawls out on the Web. This agent visits servers, maintained by vendors, with product information about ceiling tiles. It finds a product to match the context and performance and price requirements, inserts the corresponding product information into the model, and generates an updated rendering showing how they will appear. If the architect indicates approval, the agent automatically places an order. There might be some of the negotiations and transactions involved in design and construction performed by an agent that operates in an open-ended network environment. However, this is yet to happen, it is a logical extension of the basic ideas inherent in the World Wide Web.

8. CONCLUSION

It is vitally important to reinforce the necessity of CAAD in architectural education and research to make significant inroads into design practice since CAAD will continue to play a crucial role in the future. Therefore, CAAD education is not a luxury, but an absolute necessity for the architects. CAAD will eventually become a natural partner in the design process when a broad population of architects and designers is familiar with all aspects of CAAD. CAAD opens the opportunity for the development of a new culture, in which the digital, the virtual and the physical coexist seamlessly and support each other to form a new whole. Teaching architecture might adopt a new digital language rather than a traditional discipline to enable communication between methods, knowledge and architecture, along with curriculum internal communication with history, technology, design and professional areas. CAAD research will become more significant than ever before whereby architects of this century will become creators of a digital design culture in education and research and participate in the development of information architecture (Schmitt, 2004). CAAD tools will eventually need to be extended to allow not only specification of geometry and association of material and cost properties with design elements and subsystems, but also the specification and association of intelligent behaviours. Simulation tools will need not only to render visual appearance, evaluate thermal performance but also to “run” and debug the design under various scenarios of external conditions and user demand much as in animation, video game, and robotics design tools (Mitchell, 2006).

This paper presented a reflective perspective on the role of computing in architectural design. The paper has spanned over the diversity of design paradigms and their impacts on directing the computational models of designing. The evolution of CAAD systems has been investigated in the first and second generations of CAAD. Both sides of CAAD impacts (as deadly sins and arguable virtues) on architectural research have been addressed and discussed. It is necessary to augment the potentials of CAAD by careful considerations of both sins and virtues.

The paper has introduced an approach to new generations of CAAD aiming to provide a better CAAD future of architectural research, education and profession within which CAAD will be play a role of intelligent medium and collaborative partner in the architectural design process. The proposed approach envisages architectural designing to be carried out collaboratively and synchronously within smart and real-time 3D virtual environments within which architects are designing with intelligent agents based on the view of situated digital design. Such a smart virtual design environment supports a language of CAAD that matches the language of architecture. This should not be seen simply as "all-singing, all-dancing, fully integrated, multi-disciplinary decision support system" but it is a visionary approach that might start to be witnessed in the future especially its components are grounded on current successful computational experiments and advances in information technologies that are currently taking place in both CAAD research and education.

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