Utilization of Artificial Intelligence Concepts and Techniques for enriching the Quality of Architectural Design Artifacts

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Abstract

The process of architectural design aims to define a physical form that will achieve certain functional and behavioral objectives in a particular context. The use of computers as designing support tools has implications for the way designing is carried out. In architectural designing most of the current CAD systems can only be used at the very late stages of the design process after most of the major design decisions have been made and very few can be used during the conceptual stages of designing. The discipline of Information and Communication Technology (ICT) has developed over the last few decades into a major commercial industry. One of the primary contributions of ICT is the application of Artificial Intelligence. The utilization of Artificial Intelligence (AI) concepts and techniques can contribute significantly to the process of architectural design. This paper addresses the utilization of concepts and techniques of AI to support the design process and to enrich the quality of architectural design artifacts and the computational contribution that can be offered. This paper presents three examples of utilizing AI techniques for enriching the quality of architectural design artifacts including case-based architectural design, pattern recognition of architectural style learning and diversity and complexity in architecture utilizing artificial life.

Keywords: Architectural Design, Artificial Intelligence, Computer Aided Architectural Design, Case-Based Reasoning, Artificial Life, and Machine Learning.

1. Introduction

Unlike painting, music or literature, architecture is of the earth. It belongs to the ground as a container for the activities of mankind. A civilization can best be understood by its architecture because of the way buildings show the interests of a society, its organizational skills, affluence or poverty, the kind of climate and the attitude towards technology and the arts. In towns and cities the general structure of society can be understood through the medium of architecture, so it becomes the most pervasive mirror of man's presence [1].

The process of architectural design aims to define a physical form that will achieve certain functional and behavioral objectives in a particular context. It comprises three distinct, but highly interrelated, operations: (1) Definition of the desired objectives; (2) production of alternative design solutions; and (3) evaluation of the expected performances of the solutions and comparing them to the predefined objectives [2].

The process of architectural design requires a special attention. The most relevant issue in supporting architectural designing is its nature as an ill-defined problem in which neither design problems nor design solutions can completely predetermined in advance. Infrequently is there an evident and indisputable solution to a design problem, mainly because the definition of the problem itself contains many ambiguities or even discrepancies. The design problem is often revised and the final design suits the design problem not only because an optimal solution has been found but also because the design problem has been shaped while searching, developing and creating solutions.

The use of computers as designing support tools has implications for the way designing is carried out. During the last three decades of the twentieth century CAD systems provided support for calculation, documentation, animation and modeling of designs. In architectural designing most of the current CAD systems can only be used at the very late stages of the design process after most of the major design decisions have been made and very few can be used during the conceptual stages of designing. During the process of designing, solutions are fluid and emergent entities generated by dynamic and situated designing activities. The ability to provide useful designing support at the conceptual stages of designing to accommodate the situated and fluid nature of early schematic designing is important in designing.

The discipline of Information and Communication Technology (ICT) has developed over the last few decades into a major commercial industry. The application of this new technology has challenged almost every professional discipline, in commerce, engineering, construction, design, industry, service industries, medicine, education, humanities, etc. One of the primary contributions of ICT is the application of Artificial Intelligence. The utilization of Artificial Intelligence (AI) concepts and techniques can contribute significantly to the process of architectural design.

This paper addresses the utilization of concepts and techniques of AI to support the design process and to enrich the quality of architectural design artifacts and the computational contribution that can be offered.

2. Artificial Intelligence in Architectural Design

There are many activities that we refer to as Design. We normally consider it to be synthesis. However, a design task can involve much analysis. Design is an intelligent human information processing activity requiring many skills and much knowledge. Design problems can be solved by individuals or by teams. They may take minutes or years. Design occurs in a wide variety of domains, ranging from the design of a sky scrapper to that of a guard room, and from a computer to a ship. In this paper we refer mostly to architectural design. The general design process is often characterized as mapping needs to function to structure. It is carried out using many different types of reasoning and many different sources of knowledge. In general, design is the process of specifying a description of an artifact that satisfies a collection of constraints. These constraints may arise from a variety of sources. The constraints may be imposed by the problem, the designer, the manufacturer, the user, or by natural laws. They reflect the desired function of the artifact, the available resources, the physical limitations of the materials, the demands on the artifact from the environment in which it will be used, the manufacturing processes required, general design criteria and the design process itself [3].

Since Design is an ill-structured activity requiring intelligence, it is a suitable topic of study for artificial intelligence. Simon [4] goes as far as to say that the proper study of mankind is the science of design. A fundamental hypothesis shared by most AI in Design researchers is that there are core reasoning skills, and types of knowledge, that are common across domains [5]. That is, although design problems in different domains require different domain knowledge, such as knowledge of components and analysis techniques, there are underlying similarities in the form of that knowledge and in the way that it is used. For instance, design in any domain requires selection. If we can describe the essential characteristics of this reasoning skill, including the knowledge used and the process, then this can be more easily implemented for any domain [6].

The increasing complexity of the artifacts being designed and the use of new technologies, materials and methodologies, all indicate the necessity for more computer support for design activity. This fuels the need for better understanding of the design process, of design representations, of software-based design tools, of designer-tool interactions, and of designer-designer interactions.

AI in design is concerned with using AI techniques to study design. This is done by making hypotheses about designing and producing models of design knowledge and activity. Using these hypotheses and models, computer programs (i.e., design systems) are built to assist designers. Thus hypotheses about design are tested and refined using design systems. Design systems can range from autonomous design tools that when given requirements will produce designs, to design assistants that interact with a human designer (or designers) to support their design activity.

Computers have contributed to architectural design for quite a while by providing analysis tools, data-bases (e.g., of drawings and components) and computer-aided drafting and drawing tools. Geometric Modeling allowed designers to consider objects on the screen as real. They were able to concentrate on decisions about objects rather than about drawings. This is much closer to Computer Aided Design, as opposed to Computer Aided Drafting. Since its inception, CAD has gradually been concerned with representing increasing amounts about the objects being manipulated. Geometric information has moved from 2D to 3D, and from planar to curved surfaces. Information about surface finish and color has been added. Geometric and Topological models specify the structural relationships between components. Descriptions of form features can be included. Application-specific information, such as material properties or manufacturing requirements is also useful. Thus CAD representations have gradually been moving closer to being a Knowledge Representation, to include all aspects of knowledge about the designed object [3]. With the development of research programs in computational design and design systems of CAD in architecture, a new term “CAAD” has emerged; that is Computer Aided Architectural Design.

3. Scenarios of utilizing AI in CAAD

There are various scenarios of utilizing AI in CAAD: (a) a computer can assist the designer using CAD systems, pattern recognition, learning systems and expert systems; (b) a computer extends the designer’s ability of exploration and discovery through collaborative design and virtual reality; and (c) a computer automates the design process via autonomous design agents. Within theses scenarios lies a set of possibilities that includes:

- The architect suggests and the computer design agent executes,
- Architects collaborate around the globe over virtual environments,
- Architects show the design agents how to do what is needed to be done,
- Computers become critics of architectural design,
- Architects set the way for design agents to follow and learn autonomously how to proceed afterwards, and finally
- Computers may autonomously design via situated design agents.

The focus of this paper is on the utilization of AI concepts and techniques to assist architects for achieving a better design performance and enriching the quality of architectural design artifacts.

4. Types of Architectural design

There are different types of architectural design that range from conceptual, preliminary, routine, innovative, creative, parametric, to non-routine. By Conceptual design it is meant that the kind of things being decided at that point in the design process are abstract (i.e., conceptual). For example, that the design requirements can be satisfied by an object providing a particular function. By Parametric design it is meant that the things being decided are values for a pre-specified set of attributes. Another way of classifying design problems is to divide them into those that have subtask ordering decided a priori, those that know the dependencies in advance, but order them during the design, and those for which the dependencies between subtasks are both discovered and ordered during the design [7].

In routine design both the knowledge sources and the problem-solving strategies are known in advance. In innovative design, only the knowledge sources are known in advance. While in creative design neither are known. For Routine design, everything about the design process, including the knowledge needed, must be known in advance. This does not mean that either the specific design solution or the pattern of use of the knowledge (i.e., the design trace) is completely known in advance. The underlying thesis is that design tasks become routine due to learning brought about by repetition of similar problem-solving.

In general, design activity can start at any level of abstraction and finish at any more specific level. Usually, the larger the gap between the level of the specification and the desired level for the design, the harder the design process is. Dixon and Others [8] state that conceptual design is often used to describe moving from the Function level to the Embodiment level. He considers preliminary design to be an extension of conceptual design to another level of specificity, i.e., to Artifact Type. Parametric design goes from Artifact Type level to the Artifact Instance level. As we move along the Conceptual - Parametric axis less structure needs to be decided during the design process.

5. AI Techniques in Design

There are enormous AI techniques that could be utilized for enriching the quality of architectural design artifacts. We have selected in this paper, due to space, only three AI techniques that are most tangible and might be used to implement functions that play roles in the building of design systems in architecture.

5.1 Case-based Reasoning (CBR) and Analogy

This approach to design is based on a representation of previous design experiences as case studies. The direct or analogical use of previous designs or design plans can reduce search and improve quality by taking advantage of stored experience [9, 10].

5.2 Learning

Automatic generation of design tools has utilized a learning mechanism with a simple search to learn problem decompositions, or with generate and test to improve the generator by moving knowledge from the test back into the generator. Other work on learning in design includes: the learning apprentice, LEAP, which learns design "refinement rules" by generalizing the user's input [11]; the Designer-Soar system that learns to design algorithms [12]; Bridger, which learns to classify designs for reuse [13] and learning shape patterns as parts of style knowledge [14].

5.3 Artificial Life

Numerous concepts in the field of Artificial Life (ALife) [15, 16] are advantageously applicable to an architectural design process that emphasizes system-level and constituent understanding. In ALife every component of a system, including elements of the environment, is conceptualized as being capable of agency. Agency between components implies that their interactions create a level of dynamics and organization. Organizations that dynamically define themselves on one level can themselves exhibit agency and, thus, a new level of organization can form as a result of a lower level of dynamics. Levels are not necessarily hierarchically organized. They may, in fact, be recognizable by a particular perspective from which the entire system is viewed.

For example, an office building can have a level in which the components are moveable and semi-fixed relative to movement patterns and more stable space defining elements or infrastructures. Different local organizations (workgroups) emerge in response to changing organizational structures and projects. Contemporary non-hierarchical work environments when studied closely may be effectively conceptualized as living systems with a myriad of interdependencies between their components and with numerous levels of interdependent organizations.

Both ALife and Architecture find it necessary to consider the influence of non-determinism in the outcome of complicated system behavior. ALife simulations can be used by architects to model non-determinism. The systems can be defined so that certain behavior has only a probability of occurring. Then different runs of the system will show the result of such non-determinism. In addition, both ALife and Architecture are very aware of how an outcome is sensitive to details of initial conditions. ALife simulations can be defined with parameterized initial conditions and run with different parameter values for the initial conditions. They allow architects to study the impact of initial conditions. For example, a designer may want to investigate the implication of a spatial constraint. How does plan morphology and volumetric form interact with distribution of program requirements, height restrictions, circulation area, and day lighting? Or how will a limited set of forms interact with a given site boundary? ALife simulations facilitate the interactive investigation of many possible spatial outcomes. While ALife models abstract the physical into visualization, the computer is extremely fast and flexible in exploring and modeling a vast design space. These tools can be employed in parallel with more traditional visualization tools or used directly to produce physical models for evaluation via CAD/CAM technology [17].

6. Examples of Utilizing AI Techniques in Architectural Design

6.1 Case-based architectural design

Architectural design distinguishes itself from other engineering design activities by the fact that it is very strongly based on precedent cases. In Artificial Intelligence, the paradigm of case-based reasoning corresponds closely to this form of reasoning. However, an important difference is the fact that case-based reasoning deals mostly with indexing of large case bases, whereas the most important task for architects is to adapt previous designs to new environments.

A prototype system [CADRE] [18] has been developed and tested on examples of realistic complexity. CADRE formulates cases as instances of particular buildings along with a set of constraints which restrict the possible modifications which can be made to them. CADRE distinguishes two forms of adaptation: (a) dimensional adaptation, where only dimensions of the case are changed, and (b) topological adaptation, where the arrangement and number of spaces and walls are also modified. Figures 1 and 2 show an example of an adaptation of a layout carried out by the CADRE program. The user has specified the combination of the non-shaded parts of the two shown cases. The case on the left in Figure 1 is called the host case, meaning that it dominates in case of conflicts, and the case on the right is a guest case which is adapted to fit the host case. One of the solutions proposed by CADRE using both dimensional and topological modifications is shown in Figure2.

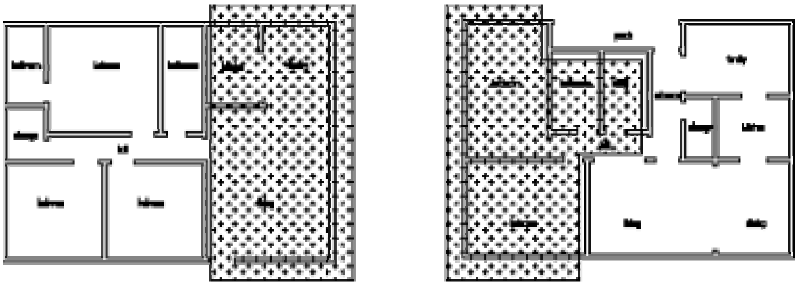


Figure 1. Case fragments to be combined and adapted by CADRE [18].

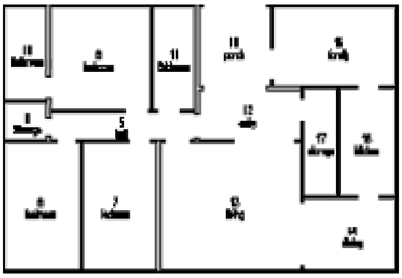
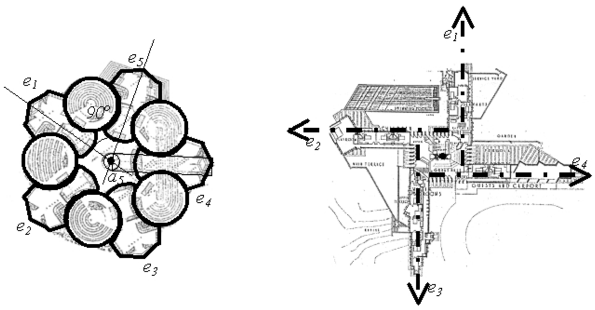


Figure 2. Result of adaptation [18].

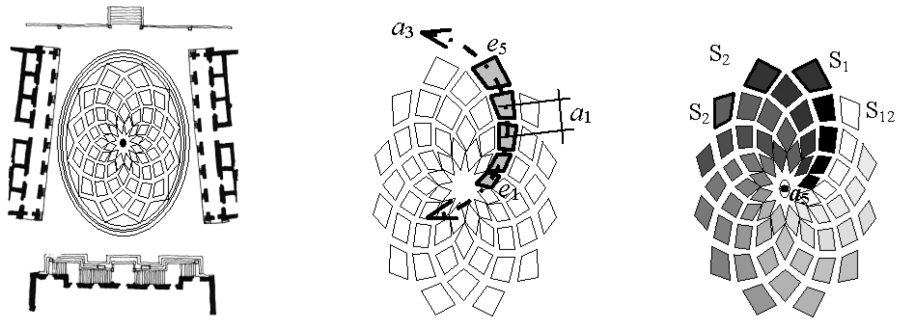
6.2 Pattern Recognition of Architectural Style learning

Shape pattern is a spatial relationship between repeated shape elements that could be physical shapes, spatial relationships or sub-patterns. Most CAD systems and computation models use numerical representations for drawings. These representations place limitations on designers and computers, and thus are useful only for drawing platforms which are not helpful at a more conceptual level of design. Cha [14] proposed a shape pattern representation designed to work at an abstract level, endowing a CAD system with conceptual reasoning. Among shape relationships, isometric transformation relationships are mainly employed on describing shape patterns. Based on this shape pattern representation methods of applications in design computation have been developed, such as shape pattern recognition, style learning and shape complexity measurement. Style is identified by commonalities appearing in a set of architectural designs from individuals, regions, and periods. Commonalities between architectural drawings can be identified using shape or shape pattern similarity. The identified similar shapes and patterns are generalized from categorization using inductive generalization rules. Generalized shapes and pattern descriptions are learned style from a set of shape objects. Examples of various patterns in architectural drawings are shown in Figures 3, 4 and 5.



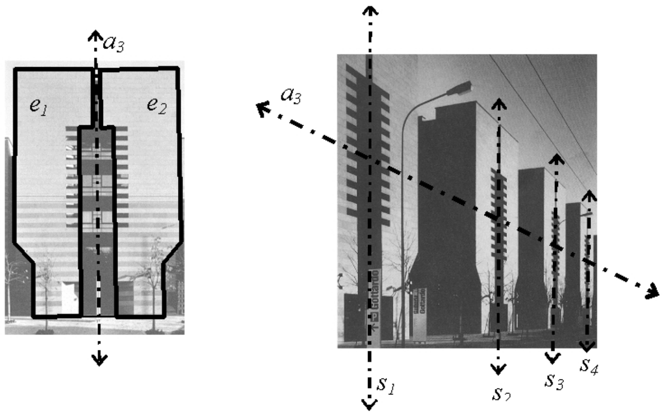
(a) (b)

Figure 3. Rotation patterns appearing in Wright's designs: (a) dihedral rotation pattern in the Daphne Mortuary plan, (b) pinwheel rotation pattern in the Johnson House, Wisconsin [14].



(a) (b) (c)

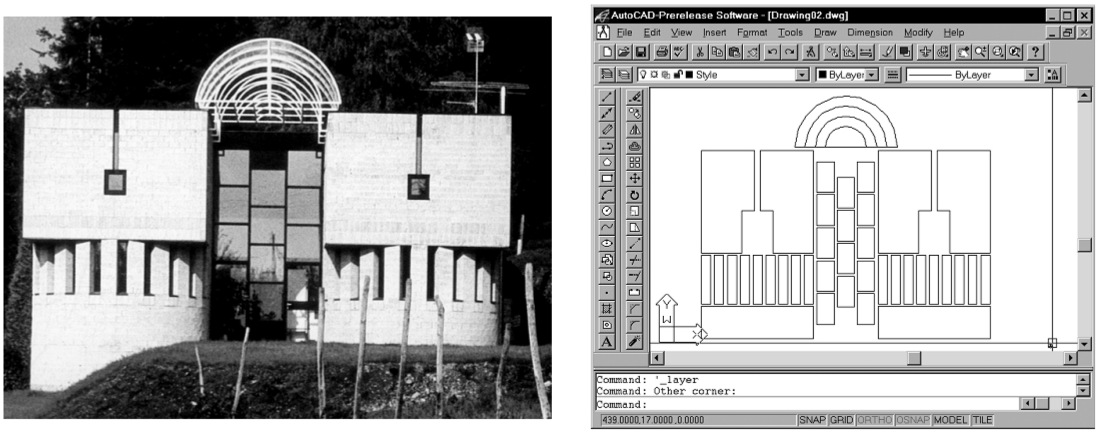
Figure 4. Rotation of complex patterns: (a) the Campidoglio (Michelangelo), (b) complex pattern by scale, translation and rotation, (c) rotated patterns [14].



(a) (b)

Figure 5. Gothard Bank in Lugano (Mario Botta): (a) reflection pattern, (b) translation of reflection pattern [14].

The shape pattern representation has been utilized in developing a shape pattern recognition system that reads input shape data, identifies shape congruency and pattern congruency, and produces shape pattern descriptions. The system is an integrated system of both shape pattern representation model and a congruency identification model. The shape pattern recognition system is able to recognize pattern knowledge in shape drawings and describe it with symbols and numbers as shown in Figures 6 and 7. The computer can read and learn shape patterns as parts of style knowledge from a set of shape objects. Two types of style knowledge, prototype and family style, can be learned by different generalisation processes. The integration of prototype and family style can produce various shape objects that are regarded as members of a class to which a previous shape belonged. Learned style descriptions provide important design knowledge for generation processes, such as instantiation, parametric design, analogical design, metaphor design, generative shape grammar and genetic algorithms.



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Command: '_layer
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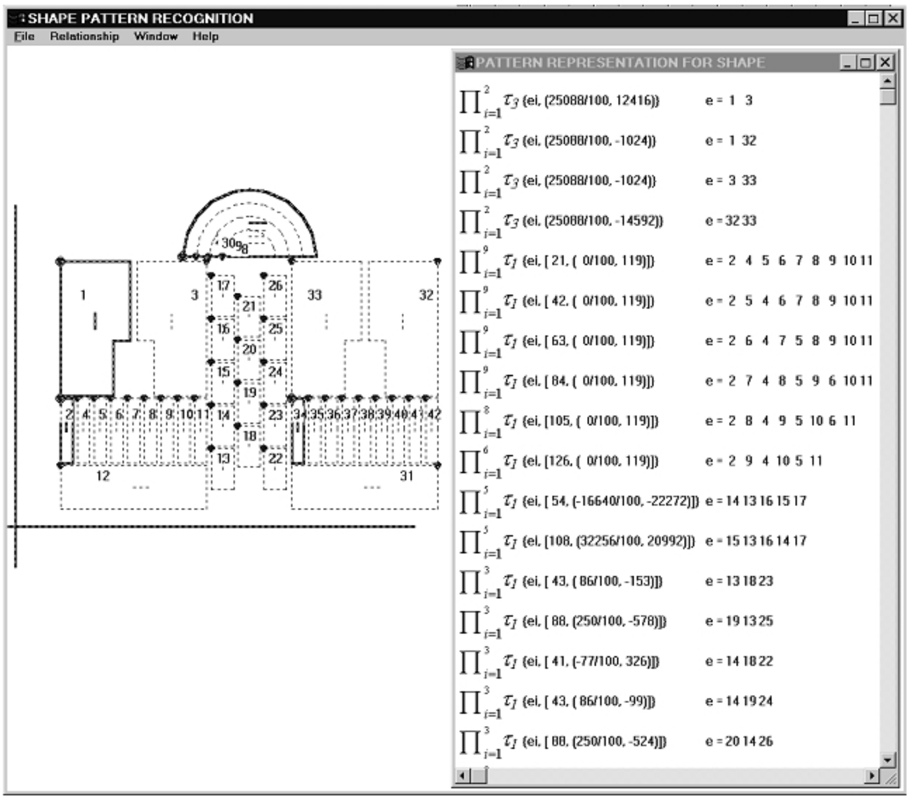
(a) (b)

Figure 6. (a) The picture of Mario Botta's house in Origlio, (b) the polyline drawing of Mario Botta's house using Autocad [14].



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$\prod_{i=1}^{2} \tau_3$ {ei, (25088/100, -14592)} e = 32 33

$\prod_{i=1}^{9} \tau_1$ {ei, [21, (0/100, 119)]} e = 2 4 5 6 7 8 9 10 11

$\prod_{i=1}^{9} \tau_1$ {ei, [42, (0/100, 119)]} e = 2 5 4 6 7 8 9 10 11

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$\prod_{i=1}^{8} \tau_1$ {ei, [105, (0/100, 119)]} e = 2 8 4 9 5 10 6 11

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$\prod_{i=1}^{5} \tau_1$ {ei, [54, (-16640/100, -22272)]} e = 14 13 16 15 17

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$\prod_{i=1}^{3} \tau_1$ {ei, [43, (86/100, -99)]} e = 14 19 24

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Figure 7. Low-level shape patterns recognised and represented from shapes [14].

6.3 Diversity and complexity in architecture using artificial life

Soddu and Colabella [19, 20] have introduced a design system (BASILICA) as a generative design system for diversity and complexity in architecture. BASILICA can be looked at as an artificial DNA to generate a multiplicity of artificial possible events. BASILICA is a generative system that is able to generate an endless sequence of architectural events and instances that are different but all belonging to the same class of ideas. The logical and operative structure of the simulation system of BASILICA is based on the use of a main cycle, with auto-organization capability, and a set of increasing secondary cycles that are bound together. Each cycle represents a complete structure in simulating decision choices and it operates the transformation of answers into possible shapes. In the design process every choice is a moment of formalization. The sequence of formalization cycles draws a dynamic evolution of possible shapes and architectural scenarios. This evolution is directly connected with the capability of generation and degree of complexity. The number of possible alternatives and scenarios provides a measure of the resources of designed environment that relates to possible needs. BASILICA shows the multiplicity of possible scenarios that can be generated for a design composition in a given situation. The results are presented in a form of 3D scenarios as a projection of single composition idea. BASILICA has been used to emulate the procedures of producing diversity and complexity of a chair design as shown in Figure 8. The procedures are activated by codes that emulate the evolution of design as dynamic chaotic system. Hence, it is highly sensitive to the starting stage of design and its related inputs. Each chair is unrepeatable, as in all scenarios produced by dynamic chaotic systems.

Figure 8. Using BASILICA to achieve diverity and complexity in chair design [20].

BASILICA can also be used for the management of architectural and environmental design. The designer can build his own paradigm, change the structure of the relationship between possible events, change the geometry and arrange multiple possible geometries within the paradigm, define the quantity of possible exceptional events and the relationship between these events and the normal structure of the architecture. The designer may choose the time of evolution for simulation. With BASILICA it is possible to design an artificial DNA that is able to generate a set of ever changing, unpredictable and individually characterized artificial events. Every scenario, that is a 3D computerized virtual model of architecture, is recognizable as an individual of the same species. BASILICA has been used in professional experiences, designing the succeeding scenarios of town environments and new architecture. The DNA of the Italian Medieval towns has been designed. The result as shown in Figure 9 is a sequence of views of different 3D models generated directly with BASILICA.

Figure 10 shows an architectural project in Taiwan that has been done using BASILICA for achieving a high level of complexity in building design.

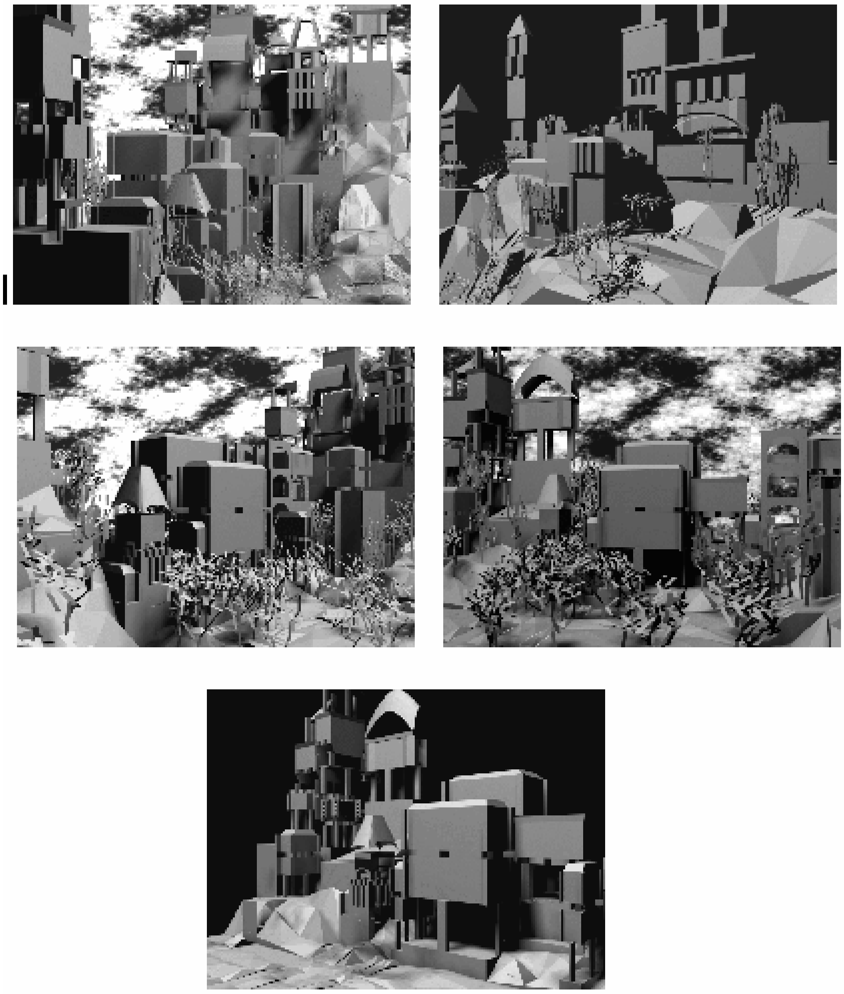

Figure 9. Using BASILICA for designing Italian Medieval towns [20].

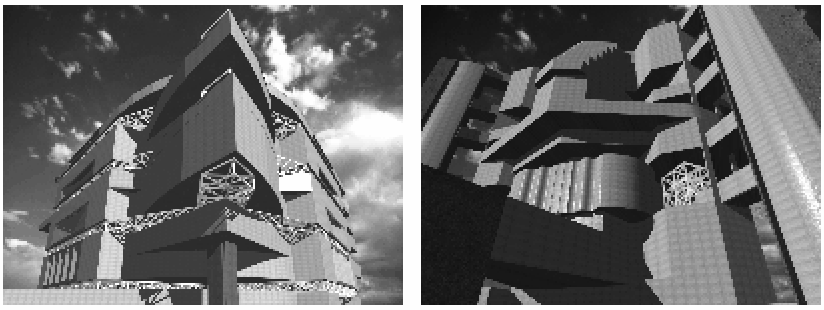

Figure 10. Using BASILICA for achieving a high level of complexity in building design [20].

7. Discussion

Today's commercial CAD software is the product of years of research that began in the 1960's and 1970's. These applications have found widespread use in the architectural marketplace; nevertheless they represent only the first fruits of research in computer aided architectural design.

Ever since the early 1980s, when computer-aided design programs began luring architects from their hallowed T-squares and meadow-size drafting boards to design and draft buildings on computer screens, there are some fascinating speculation about the way CAAD might change the world in which we live. Architectural firms still use computers for visualization purposes and generate astonishing images of their designs, but the use of AI techniques in architectural profession is still in its infancy. This is despite more than thirty years of research in design computing. Although, the aim of AI in architectural design is to bring to architecture precisely the kinds of tools that have been reasonably successful in research programs, little has been taken up by architects. Largely may be because many feel that they would be losing that their creativity when challenged by computers. However, that doesn't mean that there is not exciting work being done in the academic world, in preparation for the architects to awaken for the possibilities of AI in design.

The current computer-aided design tools such as AutoCAD, ArchiCAD, Microstation, 3D Studio, Form Z and Photoshop, although a remarkable departure from pencil and tracing paper, basswood and chipboard of the recent past, merely represent the commercialization of the first generation of CAD development. They represent the low-hanging fruit, the most obvious and easy applications of information technology in architectural design. The possibilities of information technology in architectural design have hardly been exhausted. Some of the most effective and exciting developments are yet to come. These mainstream CAD software products that now are standard tools in the design studio and architectural offices are the result of a ten to fifteen year research and development cycle. It is important for the schools of architecture to understand this cycle in order to anticipate future changes and to recognize where their own technology efforts best fit [21].

This may seem obvious to those who have witnessed the development of today's Computer Aided Design tools. However, many students who grew up in the age of computing take these products for granted and assume that CAD tools just come from the software store. They do not realize the ten to fifteen year research and development cycle.

8. Conclusion

This paper has argued that research in artificial intelligence can be fruitfully applied to architectural design to the point where they have the potential to significantly enhance and enrich architectural design artifacts. This paper has presented three examples for the utilization of AI techniques for enriching the quality of architectural design artifacts including case-based architectural design, pattern recognition of architectural style learning and diversity and complexity in architecture utilizing artificial life.

By exploring new information technologies especially artificial intelligence with an eye to how they can best be integrated into the architectural design process, and by rethinking architectural design with an eye to how information technology might improve it, researchers at the schools of architecture can find the fulcrum in this balance between research, development, and design.

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