Evolution Aided Architectural Design

A method for designing sustainable buildings

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Abstract: A design method is proposed that uses evolutionary software in order to evolve alternative design possibilities. This paper describes the overall design procedure specified by the proposed method. This description will focus on one of the key advantages of this method: the ability to create designs that are well adapted to the environment. Alternative designs are generated and evolved based on the predicted performance of each design. In order to assess this performance, each design is placed within a virtual environment and then its behavior within this environment is analyzed and simulated. Unlike human designers, the evolutionary software can assess the complex and long-term ramifications for large numbers of alternative designs.

1 INTRODUCTION

Evolution Aided Design is a design approach that relies on evolutionary software systems in order to aid in the process of designing. The evolutionary algorithms that such systems employ are loosely based on the neo-Darwinian model of evolution through natural selection. Such algorithms consist of a cyclical process whereby whole populations of representations are continuously being manipulated in order to ensure that the population as a whole gradually evolves and adapts. When evolutionary algorithms are used in a design context, the representations being manipulated describe possible designs. One of the principal aims of such systems is to evolve designs (or parts of designs) that are well adapted to a particular environment. Numerous evolutionary design systems have been developed in a variety of design fields (Frazer 1995, Bentley 1996, Bentley 1999, Bentley and Corne 2002).

This paper proposes a building design method that is based on the Evolution Aided Design approach. This method is referred to as the Evolution Aided Architectural Design method or EAAD method. This method relies on an evolutionary application — called the Model Evolution Application — to evolve alternative design possibilities. This application is described in more detail in (Janssen et. al. 2003). This paper will focus on the overall design method.

A design method explicitly describes a way of designing; it prescribes a semiformalized design procedure. Some design methods — such as those developed by the design methods movement in the 60s and 70s — are highly rational in nature and attempt to create a completely mechanistic design process. Others are highly personalized. For example, some methods use random and accidental techniques in order to generate new designs (Cross 1999), with some designers even resorting to 'random drawings' (McLachlan and Coyne 2001). The EAAD design method falls somewhere between these extremes; some parts of the design process are formalized and automated while others parts are left ambiguous and elusive.

Design methods are conjectures of a potentially useful design process. They are useful to the extent that their application will lead to end products that embody certain design qualities that are seen to be beneficial or desirable. For the EAAD method, one such beneficial or desirable quality may be highlighted as being important with respect to issues of sustainability: the creation of designs that are *well adapted* to their environment.

2 ENVIRONMENTAL ADAPTATION

Sustainable development ensures that the needs of the present are met without compromising the ability of future generations to meet their own needs (WCED 1990: 8). In order to make development within a particular environment (either Earth as a whole or some region of it) sustainable, the impact of humans on that environment must be kept within certain limits (sometimes described as the 'carrying capacity' of that environment). The environmental impact can be described by the following formula (Sylvan and Bennett 1994: 47):

$$\text{Environmental Impact} = \text{Population} \times \text{Consumption} \times \text{Technology}$$

In other words, in order to reduce the environmental impact, either the size of the human population must be reduced, or the consumption per member of the population must be reduced, or improvements in technology must reduce the impact of consumption. The EAAD method can help with the second of these: reduction in consumption per member of the population. An important part of this consumption is the production, use, renovation, and demolition of buildings. By creating designs that are appropriately adapted to the environment, the method can help to reduce the consumption per member of the population.

2.1 Identifiable character

The EAAD method consists of two phases. In the first phase, a design team develops the identifiable character that will be common to a family of designs. This character is then encoded in a computer readable form. In the second phase, the Model Evolution Application is used in order to evolve alternative design possibilities based on the character defined in the first phase.

The concept of identifiable character already exists in traditional design processes. In general, a designer's body of work does not consist of a disparate set of unrelated designs. Instead, the individual designs tend to be related to each other, and can be seen to reflect specific ideas relating to style, aesthetics, structure, materiality, construction and buildability. The individual designs may often be seen as part of a personal process of exploration and development. The designs may form a stylistic group or a chronological sequence, or parts of one design may be found within another design.

John Frazer (2002) describes this methodology as both personal in the sense that it is particular to one designer, and generic in the sense that this designer will use it within multiple projects. Frazer describes it as a working method that "characterises their 'style' ". He identifies this approach within a variety of design fields, including art, fashion and jewelry design, where in each case a recognizable style can often be found. In the field of architecture, it is also common for buildings to be immediately recognizable. However, Frazer emphasizes the fact that this 'style' may also be the result of a more abstract procedure that underlies the design process of a particular designer.

As a result of the identifiable character, each design becomes recognizable as being part of the designer's body of work. This body of work may be seen as a family of designs that share the same characteristics, where these characteristics may include issues of style, aesthetics, structure, materiality, construction and buildability. In most cases, the identifiable character is not explicitly defined, but is instead an emergent phenomena embedded within a personalized design process. Within the EAAD method, the identifiable character is developed and encoded in an explicit manner.

2.2 Two phases of the EAAD method

During the first phase of the EAAD method, the character is captured as a generic design that is referred to as the *design schema*. This design schema is then transcribed into a set of rules and data structures encoded in a computer readable form. These rules and data structures define a set of evolutionary transformations that the Model Evolution Application requires in order to evolve alternative designs. The encoded design schema is called the *evolution schema*.

During the second phase, the Model Evolution Application is used to evolve alternative design proposals. In order to start the evolutionary process, this application requires two sets of data: the *evolution schema* and the *virtual environment*. The evolution schema has already been described; it is developed during the first phase and consists of an encoded design schema. The virtual environment is an encoded version of the design environment for the project in question. This environment will include data relating to both the *criteria* that any designs must fulfill, and a *context* within which the design will exist. For example, the criteria might include required spatial dimensions and typical indoor performance targets, while the context might include site dimensions and weather conditions.

These two sets of data — the evolution schema and the virtual environment — allow the Model Evolution Application to evolve designs alternatives that are adapted to the environment specific to a particular project. These design alternatives are not fully detailed design proposals, but are instead models — referred to as *skeletal models* — that define the overall organization and configuration of the design. When the evolutionary process is complete, the most appropriate skeletal model is selected and this model is then further developed into a detailed design proposal.

The first phase of the method focuses on developing the design in the absence of any specific design environment. Only when this first phase has been completed is the design environment actually allowed to play a role in shaping the design. However, the design schema is not created in the absence of any reference to the environment, but is instead developed with a certain type of environment in mind. This type of environment is called the *environmental niche* for the design schema, and will describe a generic type of context and a generic type of criteria.

For example, for the first phase, the environmental niche might have a generic context that describes local climate, and generic criteria that includes typical indoor performance targets. The design team can then develop a schema that takes such generic environmental conditions into account. For the second phase, the design environment might have a specific context that includes neighboring buildings that overshadow the site, and specific criteria that include a detailed list of room dimensions and areas. The Model Evolution Application can then use the design schema in order to evolve a design proposal that is adapted to these specific environmental conditions.

The method therefore embodies an approach towards adaptation that makes a distinction between two different types of environment. The first phase creates a design schema that is adapted to the environmental niche (a generic environment), whereas the second phase creates a design proposal that is adapted to the design environment (a specific environment). The environmental niche is loosely defined, and may even be largely implicit. On the other hand, the design environment needs to be explicitly defined and encoded as the virtual environment.

The design environment is specific to a particular project, and therefore for every new project, a new virtual environment will need to be specified. However, this is not the case for the evolution schema. The evolution schema can be reused within any project whose design environment matches the environmental niche for which the schema was developed. This possibility opens up a range of new opportunities for the design process. Traditional design approaches only develop a design schema in a very loose way, and as a result this schema must be re-examined with each new project. The EAAD method on the other hand allows the design schema and the associated evolution schema to be reused without modification in multiple projects.

As a result, projects where a certain building type is repeated are likely to benefit most from using this method. Housing projects, where variants of a certain house type are repeated many times, are therefore particularly appropriate for the EAAD method.

2.3 Design evolution

The EAAD method relies on Model Evolution Application in order to aid in the process of designing. A three-dimensional model is created for each design alternative to be explored. Each model is placed within the virtual environment and is then subjected to a set of simulations and analyses, the results of which are used to create an overall assessment of how suitable that particular alternative is. The process of simulating and analyzing the skeletal model may include a variety of environmental simulations and analyses such as energy consumption, CO^2 emissions, daylight and sunlight simulation, and so forth.

The Model Evolution Application does not simply randomly generate alternative models, but instead uses the most suitable models as a basis for creating new models. The software manages these alternatives as a dynamically changing population. Design models that have a low assessment are removed from the population while those that have a high assessment are used to create more new designs that are added to the population. Gradually, as more and more design alternatives are explored, the emergent evolutionary process will ensure that the population of models will gradually adapt to the virtual environment within which they are being generated and assessed.

The ability of the human designer to foresee the future consequences of the numerous and interrelated design decisions made during the design process is limited, particularly when considering design decisions made early on in the design process. The complexity of the design task is typically so great that the designer will need to rely on the ‘rule of thumb’ and their ‘gut feeling’ when it comes to making early design decisions. The consequences of these decisions will only become clear much later in the design process when it may already be too late to explore alternative avenues. Even if further time and resources are available, only a small number of alternatives could ever be feasibly explored.

For example, the sizing and positioning of the openings will affect numerous factors including construction costs, interior daylight levels, and levels of solar gain. Each of these factors are related in complex ways. For example, on the one hand, larger openings may increase solar gain, possibly leading to increased air conditioning load. On the other hand, larger openings will also increase daylight levels within the spaces, which may result in a reduction in artificial lighting. As a result, predicting whether the larger openings will lead to an increase or decrease in the yearly electricity bill is not straightforward. Human limitations mean that only a small number of these long term consequences can ever be thoroughly analyzed during the design process. These human limitations have been described as ‘design fixation’ and as ‘limitations of conventional wisdom’ (Purcell and Gero 1996).

The schema based design approach uses evolution software rather than human designer to explore these different alternatives. Such evolutionary software is inherently parallel in its mode of operation and is therefore able to explore very large numbers of possible alternative design approaches. Furthermore, the evolutionary process will ensure that the population of skeletal models will gradually adapt to the environment within which they are being generated and assessed. The resulting designs may be described as being *well adapted* in that they are adapted to their environment in a multitude of different ways. Designs that are well adapted are common in nature where biological organisms are adapted to their environment in intricate ways.

It should be pointed out however, that adaptation to a particular design environment can also be taken too far. All designs need to be able to cope with changes in the environment and the most straightforward method of coping with such change is to create designs that insulate themselves from this change. For example, consider a building that is adapted to a very specific type of weather pattern. The weather is typically very unpredictable, and such a building is likely to perform badly when the weather does not behave as predicted. Biological organisms also protect themselves from environmental change by using both static insulation and dynamic feedback. The relationship between the inside of a design or organism and the outside environment is discussed by (Simon1996: 8). Designs should be insulated from those aspects of the environment that are unstable, and should be adapted to those aspects of the environment that are stable.

2.4 Simulation and analysis software

The Model Evolution Application must continuously generate and assess alternative skeletal models. The assessment process is one of the most critical parts of the Model Evolution Application. The assessment process consists of first making a series of predictions that aim to forecast how the design would perform if built, and then combining these predictions to give an overall assessment of the skeletal model.

In order to be able to evolve skeletal models that are adapted to the design environment, the discrepancy between the assessment process and the real phenomena must remain small. In other words, there must be a reasonable level of correlation between the assessment of a skeletal model in its virtual environment and the quality of the design in reality. The skeletal models will evolve and adapt to satisfy the simulations and analyses rather than the to the real phenomena. Thus, if a large discrepancy exists, bizarre skeletal models may emerge that are in fact not well adapted to the environment.

One way to ensure that this discrepancy remains small is to use existing third-party simulation and analysis software applications. Numerous applications already exist that are able to perform a wide range of simulations and analyses. Such an approach would allow the Model Evolution Application to link to a wide variety of existing applications to make predictions that would forecast how suitable a particular skeletal model might be.

Recent advances in interoperability between software applications in the building industry will have a very important impact on the feasibility of such an approach. Interoperability between software is based on the idea of a Building Information Model or BIM (sometimes described as virtual building model or building product model). A BIM is a term used to describe a type of data model developed specifically for describing objects and relationships specific to buildings. This model is a comprehensive information model that describes not just the geometry of the building but also the semantics of this geometry. For example, rather than containing lines, surfaces and solids, BIMs contain walls, doors and spaces. BIMs allow analysis and simulation programs to extract the necessary information directly from the BIM. For example, the structural analysis program may require information about connectivity between building components, while the thermal simulation program may require information about spaces. Previous CAD models did not contain this information. In his book *Building Product Models*, Charles Eastman (1999) gives a detailed overview of the key research work in building modeling.

The Model Evolution Application generates skeletal models of buildings that then need to be assessed. By generating these models as BIMs rather than geometry models, the application can link to any simulation and analysis software that uses the same BIM. The Industry Foundation Classes (IFC) building model by the International Alliance on Interoperability (IAI) represents the latest effort, jointly by research organizations and commercial vendors, to develop a BIM. The analysis and simulation applications now using the IFC model include thermal comfort applications, energy simulation applications, airflow simulation, structural analysis applications, and so forth. For example, EnergyPlus is a comprehensive building energy simulation program developed by the US Department of Energy for modeling building heating, cooling, lighting, ventilation, and other energy flows. A module has been developed that automatically acquires the geometry of spaces, walls, windows, doors, floors, and roofs from an IFC model, and generates an EnergyPlus input data file.

3 CONCLUSION

Buildings designed by the proposed EAAD method may have a number of desirable or beneficial qualities. This paper has highlighted one of these qualities: the ability to create designs that are well adapted to their environment. The method offers the possibility of allowing large numbers of well adapted buildings to be design in a semi-automated fashion.

By reducing the energy consumption of buildings, this design method may be able to contribute to creating sustainable developments. This possibility is an impetus for further research.

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