COMPUTER AIDED DESIGN AND ARTIFICIAL INTELLIGENCE IN URBAN AND ARCHITECTURAL DESIGN

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A CASE STUDY

ARTIFICIAL INTELLIGENCE AS A SUPPORT SYSTEM IN ARCHITECTURAL AND URBAN DESIGN DECISION-MAKING.

In general, computer-aided design is still limited to a rather elementary use of the medium, as it is mainly used for the representation/simulation of a design idea w an electronic drawing-table. hich is not computer-generated. The procedures used to date have been basically been those of an electronic drawing-table.

At the first stage of development the objective was to find a different and better means of communication, to give form to an idea so as to show its quality. The procedures used were 2D design and 3D simulation models, usually used when the design was already defined.

The second stage is when solid 3D modelling is used to define the formal design at the conception stage, using virtual models instead of study models in wood, plastic, etc. At the same time in other connected fields the objective is to evaluate the feasibility of the formal idea by means of structural and technological analysis.

The third stage, in my opinion, should aim to develop procedures capable of contributing to both the generation of the formal idea and the simultaneous study of technical feasibility by means of a decision-making support system aided by an Artificial Intelligence procedure which will lead to what I would describe as the definition of the design in its totality.

The approach to architectural and urban design has been strongly influenced by the first two stages, though these have developed independently and with very specific objectives.

It is my belief that architectural design is now increasingly the result of a structured and complex process, not a simple act of pure artistic invention. Consequently, I feel that the way forward is a procedure able to virtually represent all the features of the object designed, not only in its definitive configuration but also and more importantly in the interactions which determine the design process as it develops.

Thus A.I. becomes the means of synthesis for models which are hierarchically subordinated which together determine the design object in its developmental process, supporting decision-making by applying processing criteria which generative modelling has already identified.

This trend is currently being experimented, giving rise to interesting results from process design in the field of industrial production.

Industrial design as a field of advanced experimentation

The direct application of computerized systems to industrial processes has enabled some progress to be made in this field by increasing the amount of A.I. in CAD/CAM procedures. In this field procedures such as design knowledge based, behavioral modelling, generative design, etc. are already commonplace and others are being developed which render problem-solving automatic and retrieve and distribute knowledge to support what can be defined as the **technical and creative process.**

The basic principles of industrial design can be summarised as follows:

- definition of design intention
- design constraints
- interactions between design features
- identification of relevant knowledge
- distribution of relevant knowledge
- identification of any design inconsistencies
- process synthesis.

By analogy an attempt can be made to apply the same procedures to architectural and urban design.

The city shaped as a field of exploration

The search for the application of support for decision-making procedures in the field of architectural and urban design must be based on the assumption that the approach to the study of architecture takes two fundamental principles into consideration: the study of the shaping of the city in respect of its morphology and the study of typology for the architectural composition of the buildings – both seen as the organization of empty spaces inter-related through the construction of enclosures which are hierarchically related and by their interaction create an architectural language. These principles are immediately applicable and are recognizable in the building fabrics which have been planned to a certain extent and can be reproduced.

Therefore, our work begins with the study of the shaping of the city, considering the analysis of urban morphology as the study of the relationship which exists between the shape of an urban plot and the building types present there.

The approach levels are thus defined hierarchically, and start with the morphological study based on the analysis of urban blocks, followed by the study of the building plot and finishing with the identification of the building types used.

The analytical criteria start with a preliminary level of understanding of the space and comprise both pure and functional spatial relations, which enable a study to be made of how the use of buildings and dwellings has changed over time.

Knowledge of the rules which define the building of the city, or part of it enables us to hypothesize an A.I. system at three specific stages: definition of the shape of the urban block, identification of the building plot in the urban context, application of the building typology to the plot. Using these rules the A.I. system facilitates evaluations, proposals and suggestions for architectural composition during the design process.

A DESIGN HYPOTHESIS

All the tectonic, technological and building knowledge – in addition to being an important element in defining which categories a particular model comes under – supports the decisions which the designer has to make during the design process. The appropriateness of a material, shape, building method, functional or spatial relationship, is analysed by the system using the models it has learnt to recognise and these enable the designer to evaluate the quality of the choices made more quickly and consciously.

Of course, none of this can replace the designer's creativity, which will always be the starting point, even for the most sophisticated and expert A.I. system in order that it can accomplish its objectives.

However, this method makes it possible for the system to explore the complexities typical of both architecture and the city so that the generative models of the (artificial) built environment can be decoded, thereby enabling us to fully understand unsolved problems and unexpressed potential, as if it were a kind of DNA of architectural and urban organisms.

This is the approach used by generative design, which is currently being explored by the visual arts and industrial design.

We have now arrived at the stage which I call **global architectural design**. This means a single design process comprising all the significant factors for the realization of the design, where the interrelations are evaluated and weighed up at the same time so that the design choices are made definitively and consciously.

In the context of professional work, this can:

- reduce design leadtimes;
- integrate suggestions and stimuli which relate to the design as it is being developed;
- monitor work plans while at the architectural design stage;
- monitor budgets stage by stage;
- improve the overall standard of the design;
- certify that the design meets the standards of clarity and low cost laid down by ISO 9000, etc.;

For teaching purposes it can:

- aid comprehension and interpretation of the **genius loci** of a design site;
- integrate suggestions and stimuli which relate to the design as it is being developed;
- illustrate the complexity of the architectural and urban design more effectively;
- aid comprehension of students on distance learning courses, as they can receive input from their tutor but also from the A.I. system;
- enable all the elements identified by the tutor as important for the design being studied to be monitored at the same time by the A.I. system.

Of course, the more precise the models which are input into the A.I. system, the greater the variety of possible results will be.

In addition to facilitating management of the development of the architectural design process in its compositional, tectonic, technological and structural complexity, this procedure makes it possible to realize designs which are all different but are recognisable as belonging to the same matrix.

A procedural MODEL

To apply the principles of A.I. to the realization of an expert system capable of supporting decision-making in architectural and urban design, first of all two stages of the process must be defined: learning and application.

Learning requires the organisation of the various fields which play a part, and determine hierarchies of application at the interpretation stage.

This learning process takes place through the application of a series of previously defined rules which determine univocally the responses supplied by A.I. or by means of a learning process of the A.I. system, obtained by analysing the reference models. In the first case the motivations for the choices made by the A.I. system can be explained analytically by a specific documented motivation or sum of motivations (strong A.I.). In the second case the choices made by the system cannot be explained by a reasoning which is a sum of exclusions/inclusions, as they belong to a process of synthesis which cannot be reproduced analytically - in short, the system is not able to specify the reasons why it supplies some responses rather than others (weak A.I.).

For the purposes of our interpretation the weak A.I. is more appropriate.

The interpretation models for the site of application can thus be classified in five categories: **Ur-**

ban Models – where the urban morphology (forma urbis) is given by the urban blocks; **Typological Models** – where the building type is given by the types existing in individual plots; **Tectonic Models**, depending on the type of structure used; **Technological Models**, which provide the general and specific technical features; **and Building Models**, defined by the materials and building methods used. (fig.1)

The system will also process other models relating to different disciplines which are relevant to the design. The first of these are: **Distributional/ Functional Models**, which contain the relations and minimum surface areas necessary for each function; **Structural Models**, which contain the different structural typologies with their geometric and dimensional rules; **Technological Models**, which contain general and specific technical details; and **Building Models**, which contain the materials and building methods.

After the expert system has learnt the basic models it has to analyse a representation of the **sites of application**, processed using criteria explained further on, which can be used to extract the **principles of urban growth** in the part analysed. The relations linking the various components of the analysis are synthesized at this stage autonomously by the expert system.

After completion of the learning process, at the application stage the system manages a general application area and at the same time carries out the design process starting with the **design idea**. By comparing the design idea with the **principles of urban growth**, the **Distributional/Functional Models, Structural Models, Technological** and **Building Models** a feedback process is initiated which creates the **generative evaluation** of the actual design. (fig.2)

Once this system has been set up it is easy to see how the same principles used in evaluation could be used by the A.I. as a generative code for an infinity of designs, all different but meeting the same criterion of inter-relating the various parts and the surrounding environment, to produce a proper system.

The application of a system of representation for the application site of the a.i. system

The starting point for instructing an expert system how to understand a model is the definition of the structure to be analysed. In order to describe the structure to the system a relational graph is used with attributes which simulate an urban plan.

Each graph is composed of "nodes" and "arcs", and each node generates a number of arcs. The node represents a single architectural feature irrespective of both the size and architectural scale. The arc, on the other hand, represents the relation between the nodes, in other words, the relation between two or more architectural features (fig. 4). Associated with the nodes and arcs there may be some attributes which enable representations to be made of the features considered, such as sizes, rotations, building features, categories and so on.

To instruct the expert system about how **urban morphology** should be dealt with we used the following procedure: we considered each urban plot as a "node", and all the nodes were connected with the respective "arcs", which had as an attribute the size of the type of road axis.

In the same way, each of the **building types** were described using the same number of graphs significantly reduced in size in a search process of subgraphs within the main graph which describes the whole plan. These subgraphs were input in a very precise manner, by breaking down into individual constructional/descriptive components the parts which make up the cell plan. In order to identify the dwelling cell univocally it is necessary to locate and mark the entrance to the cell in question, and this is the first node which is given the property of **Ist level entrance**.

The first node was connected to two arcs terminating in a further two nodes, the second nodes representing the line of the wall where the entrance had been inserted. Having input this data the expert system was informed that there was a cell (node/wall – arc – node/Ist level entrance – arc – node/wall) (fig.5). The wall thus structured is connected by another two arcs to the respective two nodes of the two walls (or to parts of it if there is an opening) which close the space of an environment. The two arcs can be assigned the attribute of a rotation, expressed in degrees to the entrance wall.

If there is a break in one of these two walls, it will become a node which will have the property of **"2nd level entrance"**, if it is completely permeable, otherwise **"window"** if it is semipermeable. Proceeding with this system the whole plan of the cell can be "designed". (fig.6).

So that the algorithym of the system does not distinguish adjacent environments rather those belonging to different cells, it is necessary to clearly define the hierarchy of the passages between one space and the next. Thus it was established that the reading of the perimeter of a cell should start from the **1st entrance level node** and, through the succession of arcs and nodes and the various 2^{nd} or 3^{rd} entrance levels etc., should complete the cycle and search for the next **1st entrance level**.

Having completed this stage, the system has stored all the necessary data to define a building type. It now knows all the features which make up the plan (nodes and respective properties) and the relations which exist between these (arcs and respective properties) so it is easy to deduce relations, for example, between surface areas and openings, between cell sizes and so on.

Having thus established the relations between the parts, the system also has at its disposal the classification of urban morphologies and building types, identifying in the node/arc relations the generative code which gives them their properties.

The databank formed by this process is now ready to be enhanced autonomously by the expert system every time it is provided with the reading of a new piece of the city. The graph matching algorithym will find the differences and the concordance with what it has "learnt" and if it does not find any correspondence or it cannot give any classification, it will be stored as "anonymous" while awaiting further input.

Input supplied to the system is basically a dense network of relations between elements. In order for these elements to be immediately recognised by the calculation algorithym, it is essential that the plan which is being read is supplied in a vectoral file format.

It is also important to note that this network of relations has an essentially bidimensional development, so the problem was posed in this system of the node which comunicates information about development in the third dimension. The need for a vectoral file derives from the fact that the elements stored in that file are representations of vectors, with two components, where bidimensional, and with three where tridimensional. Thus the "**scale" node** with the attribute of height (i.e. the height at which the level or connected levels are placed) has the task of informing the system at what depth the next levels are located compared with the current level.

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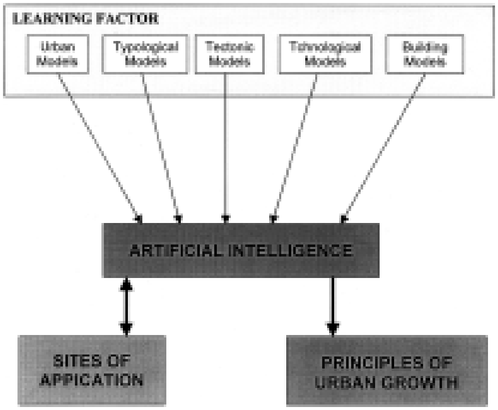
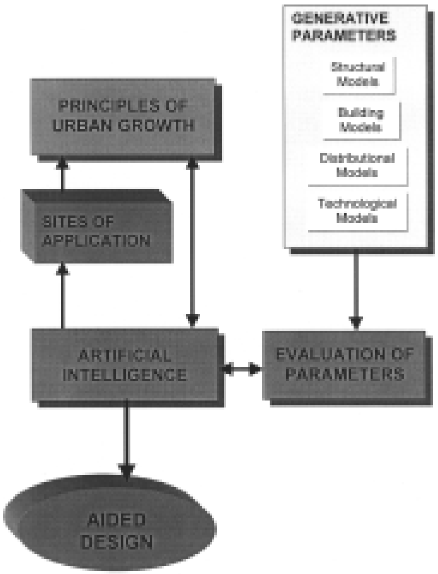


Figure 1
Flowchart for learning and making principles of urban growth



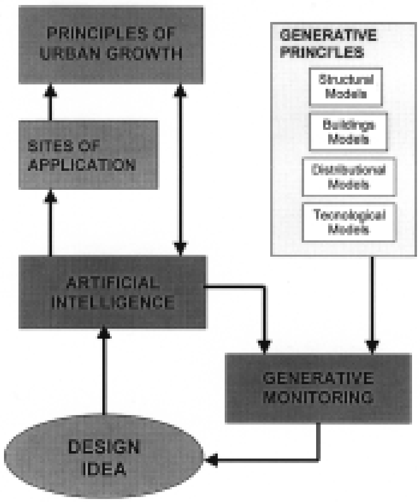


Figure 2 (left)
Flowchart for generative monitoring

Figure 3 (right)
Flowchart for Aided Design

Figures 4+5

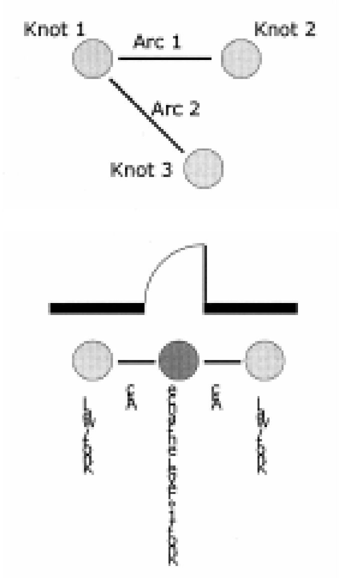


Figure 6