A 3D INTERFACE PROGRAM THAT COMBINES "EXPERT SYSTEM" PROCEDURES WITH SIMULATION PROGRAMS

João Mariz Graça[1], Luisa Brotas[1]

[1]INETI – Instituto Nacional de Engenharia, Tecnologia e Inovação, IP. Lisbon, Portugal

joao.mariz@ineti.pt; luisa.brotas@ineti.pt

ABSTRACT

An interface environment system is under development. The system is being designed with the aim of improving architect's work by helping them finding the most energy efficient solutions for their building projects in an easier and faster way.

The system provides a simple "3D CAD modeller" that allows the user to describe a geometrical definition of a building. It then generates the geometrical input for other programs, namely Energy Plus or Radiance. As these programs are very complex and may require a great effort to define their input, the main focus of this interface system is the generation of the geometrical definition of the building for these target programs.

INTRODUCTION

The main concern of this work is to help architects on building design tasks. They may perform quick evaluations during the design process and detailed analysis in later stages.

In fact, earlier design decisions that architects take, particularly when they are sketching their projects, are often quite important to the performance of the building in terms of its energy consumption. On the other hand, programs that provide detailed output, such as Energy Plus, are very time consuming in terms of their input definition.

If an architect wants to design climatic conscious buildings he should follow some rules of practice which, during the initial sketches, can be similar to the bioclimatic strategies defined by Baruc Givoni (Givoni, 1976). These strategies should be kept in mind in the design process, even in initial ideas before any sketch have been made.

In the initial sketch phase the architect tests different shapes for the building while also checks its aesthetics and functionality. It would be interesting if the architect could have feedback in terms of energy performance of the building during the design process.

Energy Plus and Radiance simulations are more appropriate for later phases of the architectural design, since they require a more detailed definition of the building's shape and its constructions.

Objectives and Motivation

Architectural design is a complex discipline, however two major kinds of reasonings can be identified:

- Analytical reasoning, which derive from the effort to understand things. These are the most common reasonings when designers try to fulfil performance requirements. Analytical models are very useful to inform design decisions.
- Critical reasoning, which derive from the ability to appreciate or react to things. These are the reasonings that leads to artistic aspects of buildings (Lansdown, 1998).

The architect's work can also be defined as a "synthetic task" since he has to design a shape which, after being constructed, gives a good response to every performance requirement identified for that particular building.

To perform the architectural design of a building a great number of different performance requirements can be identified. However, computer tools that use analytical models to simulate these requirements are often independent from each other. They are like islands. Quite often there is not very much communication between tools for simulating the energy performance of buildings, the energy embodied inside the construction elements, or the acoustic performance.

CAD programs have recently improved very much their capabilities, and 3D drawings are becoming more common. By using such tools the architect can perform his critical reasoning about artistic aspects of building shape. However, it is still difficult and time consuming to obtain information about the building performance at the same time as the shape is being designed.

The main objective of this work is to develop tools that can be as close as possible to common reasonings of architects and help them in the design of climatic responsive buildings. For that purpose:

- A 3D interface is very important since it allows the possibility of a critic evaluation of artistic issues;
- Expert systems that simulate reasonings of the type “how insulated should be the construction elements to comply with the regulations?” They are recommended in the evaluation of the building shapes, specially in the earlier phases of design;
- Analytical tools can be useful to refine building’s constructions and shape;
- A system with a common geometrical model guarantees consistency through out the different modules.
- Other reasoning and methodologies like generation of shape grammars informed by the feedback of previous simulation evaluations will be studied in the future.

STATE OF THE ART – OTHER AVAILABLE INTERFACE PROGRAMS

There are already several interface programs for the energy plus simulation program. However, they may not have features expected in this one. We group here only the software programs that allow the user to define the geometry first and then generate the input file to Energy Plus. We have excluded programs that need the Energy Plus geometrical definition input to generate 3D images. These programs only aim to check if the input file is correct. We have also excluded interfaces that don’t provide 3D images of geometrical definition of buildings. So the most important software programs available with the mentioned features are:

- **Design Builder** Interface Program that “has been specifically developed around Energy Plus allowing all of the Energy Plus fabric and glazing data to be input. Databases of building materials, constructions, window panes, window gas, glazing units and blinds are provided …Featuring an easy-to-use OpenGL solid modeller, which allows building models to be assembled by positioning 'blocks' in 3-D space and realistic 3-D elements providing visual feedback of actual element thickness and room areas and volumes”. (http://www.eere.energy.gov/buildings/energyplus/ep_interfaces.html);
- **EcoTech**. “Complete environmental design tool, which couples an intuitive 3D modelling interface with extensive solar, thermal, lighting, acoustic and cost analysis functions. ECOTECT is one of the few tools in which performance analysis is simple, accurate and most importantly, visually responsive.” (http://www.eere.energy.gov/buildings/tools_directory/software.cfm/ID=391/pagename=alpha_list).

There are also several available interface programs for the Radiance program.

- **Adeline** Program provides the scribe modeller, which can be used to generate rad files for later use with radiance program.
- A Radiance Interface program is under development by Francesco Anselmo to use inside the Blender CAD program.

These programs already provide interfaces to simulation programs like Energy Plus and Radiance, though few provide it for both. This gives the basis to one of our aims to develop a system, which can ensure that the geometrical definition is consistent with every simulation model generated.

EcoTech seems to be the most powerful program in terms of its compatibility with different types of performance requirements and physical modulation features, however it doesn’t answer to our particular aims:

- Check if initial sketches of the building under design are conformant with Portuguese regulations;
- Perform feedback in terms of shape grammars to be used in other buildings.

PREVIOUS WORKS

Different kind of tools have been developed in the past, with the following aims:

- Improving the design process;
- Give information about the design decisions while they are taken;
- Simplify simulation tasks.

The present work aims to put them together in one system.

An Interface between AutoCAD and DOE2.1C

Using the AutoCAD facility of adding user-defined commands through the AutoLISP language, a set of new commands has been developed to use inside AutoCAD environment (Graça, 1994). Those commands allow the user to define, inside a 3D drawing, the building’s geometry according to DOE2 needs. Every exterior wall, interior wall, building shape, window, and their correspondent overhangs or fins can be easily made through AutoCAD. Later on, another AutoLISP routine reads the database of the drawing and writes a new file according to the Building Description Language that DOE uses for the input.

The AutoLISP language was used because it is part of the AutoCAD program, which is a very popular program. Also because the routines developed could take use of the AutoCAD 3D environment.

This work was developed for earlier AutoCAD versions and was successfully test under version 14. It can be send free on request to the first author's e-mail.

An Expert System for the Portuguese Code of the thermal buildings behaviour

The Portuguese thermal regulation for buildings imposes that "the indoor thermal comfort must be achieved without too much energy waste" (Portuguese Law 40/90). To evaluate if a building complies with the regulation, a Solar Load Ratio (SLR) based method is imposed. What is "too much energy waste" is defined with four parameters, two for winter conditions (***Table 1***) and two for summer conditions (***Table 2***).

	Energy required to maintain the inside temperature above 18ºC.	
	Real building	Standard building
Winter Parameters	Nic	Ni
Performance requirement	$N_{ic} \leq N_i$	

Table 1 – Portuguese thermal Winter parameters

	Energy required to maintain the inside temperature below 24ºC.	
	Real building	Standard building
Summer Parameters	Nvc	Nv
Performance requirement	$N_{vc} \leq N_v$	

Table 2 – Portuguese thermal Summer parameters

A standard building is defined in the code in terms of recommended U-values and solar factors that vary accordingly to climatic regions in the country. Also the glazing area is restricted to a maximum of 15% of the floor area.

To help architects designing buildings according to this regulation an expert system was developed on PROLOG language. It is expected to adapt this expert system with typical parameters affecting the energy performance into the architectural design. A PROLOG routine was made to help architect when he is studying the shape and layout when he needs to evaluate the energetic consequences of his decisions (Graça, et. al., 1999).

This routine, for a defined shape, searches how much insulated should the walls and roofs be and how protected the solar radiation should the openings be to comply with the thermal regulation. Therefore the shape is evaluated in terms of thermal insulation and sun protection required.

The routine is composed of four main parts:

- A module to define geometry of the building;
- A module to execute calculations based on the algorithms of the regulation;
- A database of construction types;
- A group of heuristic rules that set how the search is performed.

A scheme of the PROLOG Routine is presented in *Figure 1*.

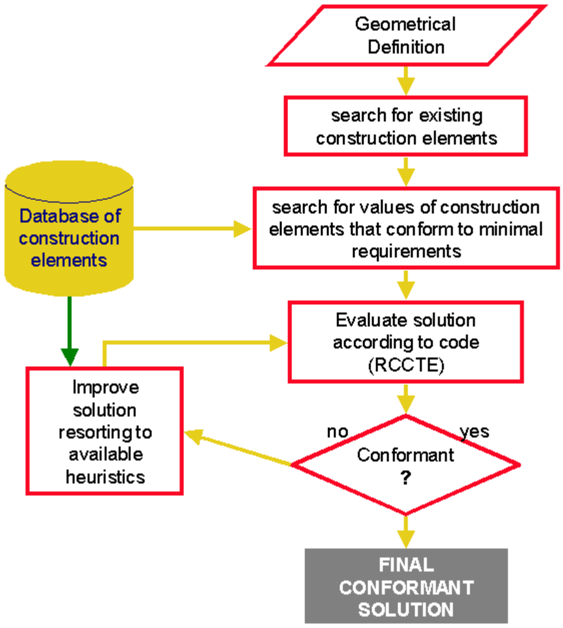

Figure 1- Searching Algorithm of the Expert System for the Portuguese Thermal Regulation

The expert system gives information to architects in terms of constructive solutions. The energy consumption of a building may be difficult to analyse by architects particularly in the initial phases of design. This system uses some heuristic rules to improve the energetic characteristics of the constructive solution and to define the characteristics of the conformant solution. The heuristic rules are based on the most common practices and building technologies existent in Portugal.

Figure 2 shows some of these heuristic rules. The system follows the order presented for trying each improvement. A more adaptive heuristic is under development so that the system checks the areas of the elements (walls, roof, or floors) before deciding upon which is the more effective improvement.

1) Improve thermal behaviour of exterior walls until insulation material is needed.
2) Improve thermal behaviour of exterior roofs until 4 cm thickness of insulation material is needed.
3) Improve thermal behaviour of exterior floors until 4 cm thickness of insulation material is needed.
4) Improve thermal behaviour of exterior walls until 4 cm thickness insulation material is needed.
5) Improve thermal behaviour of exterior roofs until 6 cm thickness of insulation material is needed.
6) Improve thermal behaviour of exterior floors until 6 cm thickness of insulation material is needed.
7) Improve thermal behaviour of exterior walls until the most energy efficient construction wall type in the database.
8) Improve thermal behaviour of vertical exterior windows until double-glazing is needed.
9) Improve thermal behaviour of horizontal exterior windows until double-glazing is needed.
10) Improve thermal behaviour of interior floors until 6 cm thickness of insulation material is needed.
11) Improve thermal behaviour of interior walls until the most energy efficient construction wall type in the database.
12) Improve thermal behaviour of interior roofs until 6 cm thickness of insulation material is needed until the most energy efficient.

Figure 2 – Some of the heuristic rules for improving construction.

This part of the system only applies for Portugal and the main reasons are:

- The climatic data available and the SLR method were developed and apply for Portuguese conditions;
- The constructive solutions that the system selects are based on typical Portuguese building practices.

The European Energy Buildings Performance Directive (EBPD) imposes different requirements and the Portuguese Thermal regulation is under revision so that it can be conformant to the EBPD. Although the Directive requires a common methodology it is left with the country members the adaptation to their climate conditions. For that reason, different models are needed to different countries. EcoTech for instance provides routines to check “Part L” regulation in the UK.

The use of PROLOG is justified since “conceptually this language is a data base program with the addition of rules, which make it possible to satisfy a query or not, just by looking it up in the database, but also by inferring it from other known facts” (Graham, 1994).

The AutoLISP program and the Expert system are independent from each other, but they have common features. The main motivation for both is to get closer to architects reasoning when designing buildings.

The main reasons for focusing in the interface PROLOG system are:

- It is independent of AutoCAD which is a program not always available in energy consultant offices;
- Architects also use different CAD programs;
- The PROLOG interpreter used is platform independent.
- The PROLOG language was considered more suitable for the type of operations required.

WHY XPCE/SWI-PROLOG

The PROLOG language is specially designed to develop Artificial Intelligence applications, like Expert Systems. As they are needed for the development the work the PROLOG language was considered very useful.

Although the “XPCE Architecture is not PROLOG, it is linked to PROLOG and provides a very complete set of libraries for (graphical) user interfacing (GUI). It also provides object oriented (OO) techniques, which are very well suited to handle the complexity of GUI components” (Wielemaker, et al., 2002).

“XPCE is an object-oriented library for building Graphical User Interfaces for symbolic languages. XPCE provides all semantic elements that can be found in many object oriented programming languages: classes, objects, methods, instance-variables, inheritance, statements, conditions, iteration, etc.” (Wielemaker, et. al., 2002).

Since we are dealing with buildings and architectural shapes, GUI libraries were found very useful to implement the 3D routines. They can provide friendly 3D images where the user can check the progress of the work.

Other facilities are expected to be added in the future to this system. Namely checking if adjacent spaces or zones are not overlaid and constraining adjacent spaces/zones so that they can only be modified under certain rules. These rules can be very easily implemented with PROLOG language.

EXPERIMENT

Using the interface modeller

The system provides a 3D environment were the user can model geometrically the building and check visually if he is doing the correct definitions.

After the definition of the building, the system can generate part of the input file needed for other simulation programs like Radiance or Energy Plus.

Figure 3 to *Figure 7* present several steps of the available dialogs of this system.

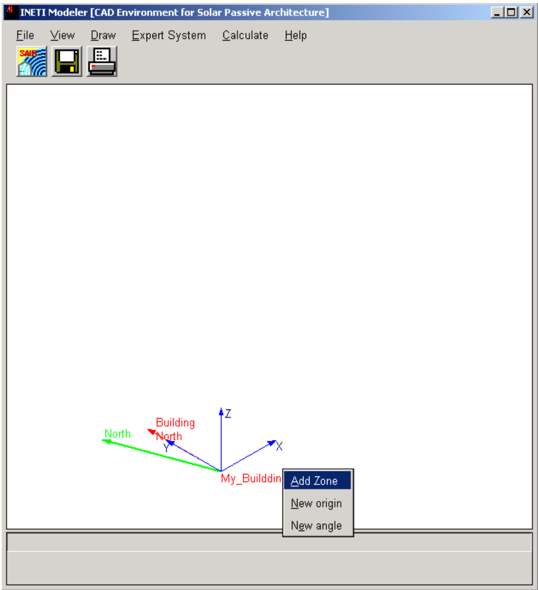

Figure 3- 3D Axis and relative position the North.

Once the object building is defined the environment shows an image of the coordinated system (3D Axis and its relative position to the North – *Figure 3*).

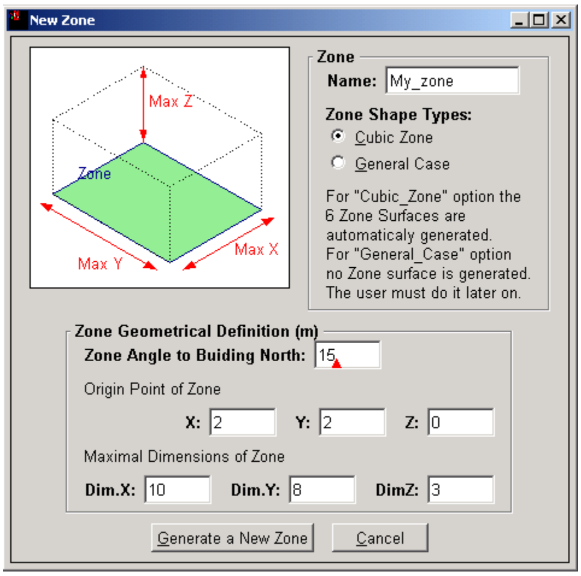

Figure 4- Dialog for Zone Definition.

By right clicking over the image, a new dialog is presented to the user. Now he can define a cubic shaped zone with the variables showed in *Figure 4*. After clicking the appropriate button the surfaces are automatically generated.

The result is shown in *Figure 5*. By clicking over a surface object a set of options appear in a menu. When the user selects the "Insert Window" option a new window is added to the selected surface. *Figure 6* shows an image of the dialog for inserting a new window within an existing surface.

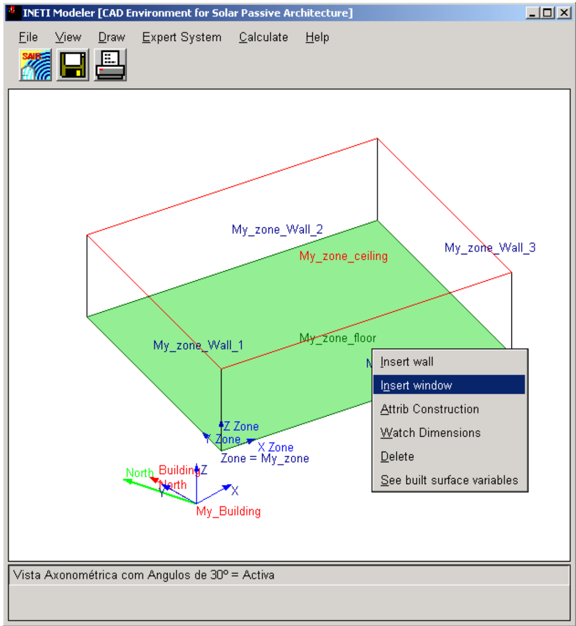

Figure 5 – A zone defined

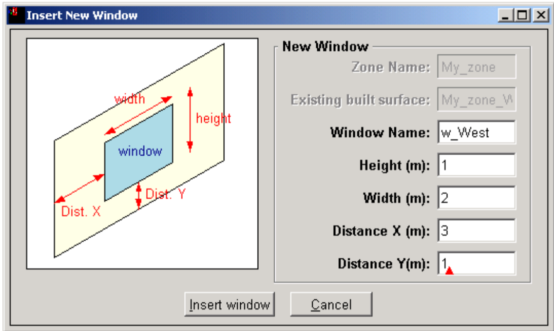

Figure 6 – Dialog for insertion of the window.

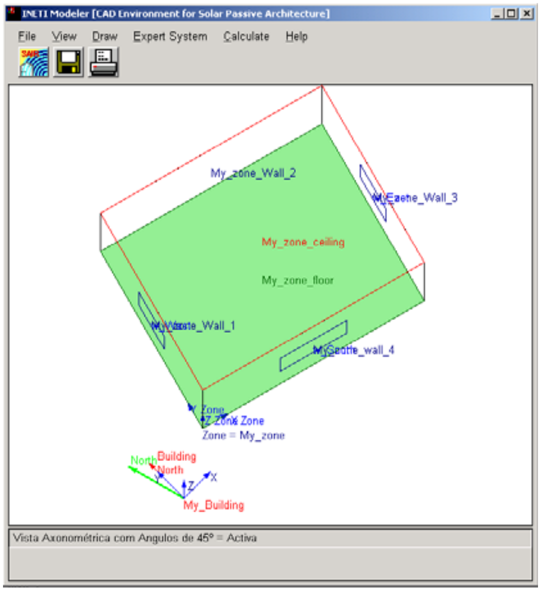

Figure 7 – Final Result: A 1 Zone Building.

Figure 7 shows the final result of a simple building modelled with the Interface Modeller.

DISCUSSION AND RESULT ANALYSIS

Once the geometry of the building is defined the system can provide information concerning a solution that complies with the Portuguese thermal behaviour of buildings code. In this case the program output the following results (*Figure 8*).

An Expert System simulation was performed for the city of Lisbon, and it gave the following results:

Walls should have a maximal U-value of 1.4W/m^2.K;

Roofs should have a maximal U-Value of 1.25W/m^2.K;

Windows can have a maximal U-value of 5.8W/m^2.K and must be shaded in Summer with blinds with a solar factor of 0,56 or less.

Figure 8 – The Expert System Result.

```
Surface:HeatTransfer,
 W SOUTH,                  !-
 Wall,                     !-
 parede de betao,          !-
 My Zone,                  !-
 ExteriorEnvironment,      !-
 ,                         !-
 SunExposed,               !-
 WindExposed,              !-
 0.5,     !-
 4,         !-
 0,         !- Vertex 1 X-coord
 0,         !- Vertex 1 Y-coord
 3,         !- Vertex 1 Z-coord
 10,         !- Vertex 2 X-coord
 0,         !- Vertex 2 Y-coord
 3,         !- Vertex 2 Z-coord
 10,         !- Vertex 3 X-coord
 0,         !- Vertex 3 Y-coord
 0,         !- Vertex 3 Z-coord
 0,         !- Vertex 4 X-coord
 0,         !- Vertex 4 Y-coord
 0;         !- Vertex 4 Z-coord
```

Figure 9 – Part of the EnergyPlus generated file

Part of an input file for running Energy Plus program can also be delivered as shown in *Figure 9*. Only a part of that file is presented here.

```
# Surface 1 - W SOUTH
W SOUTH   polygon   Superf 1
0
0
30
        0    0    3
        0    0    0
        10    0    0
        10    0    3
        6.5    0    3
        6.5    0    1
        3.5    0    1
        3.5    0    2
        6.5    0    2
        6.5    0    3

# Surface 2 - W EAST
W EAST   polygon   Superf 2
0
0
30
        10    0    3
        10    0    0
        10    8    0
        10    8    3
        10    5    3
        10    5    1
        10    3    1
        10    3    2
        10    5    2
        10    5    3
```

Figure 10 – Part of the Radiance generated file.

Part of an input file for running Radiance program can also be delivered as shown in *Figure 10*. Only a part of that file is presented here.

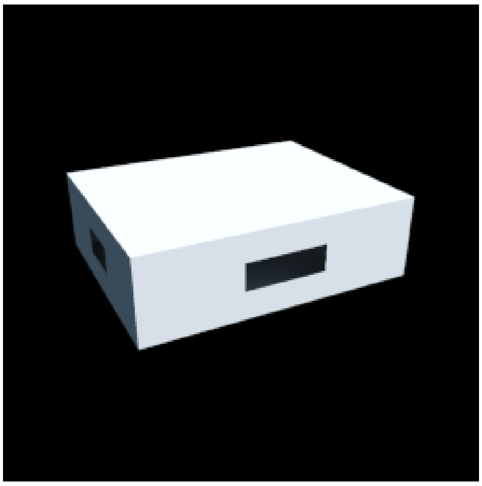

Figure 11 –Radiance image generated with the output file from the interface modeller.

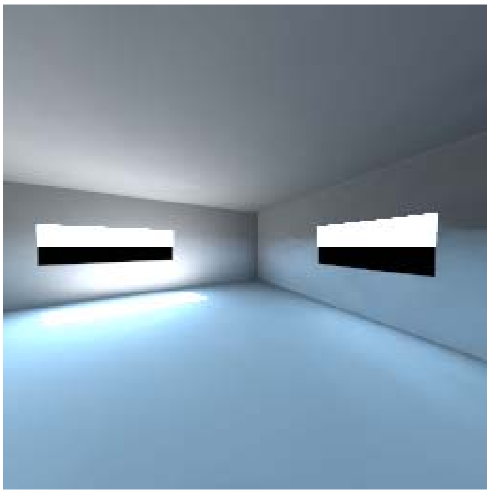

Figure 12 –Another Radiance image generated with the output file from the interface modeller.

CONCLUSION

The system under development can be helpful to building designers and architects. It allows the possibility of getting feedback in terms of the building energy performance during the design process. This can be of particular interest because earlier design decisions are often the most important ones for the future energy behaviour of the building.

The PROLOG Language and in particular the set of libraries that have been used, have proven to be quite suitable to the operations developed. As this language and libraries provide Graphic User Interface libraries and Object Oriented Techniques, they can link very well the 3D programming requirements and the expert system procedures.

In future phases of the development of this program other operations that take advantage of PROLOG facilities are expected to be added. Automatically checking of the adjacent walls and zones, or programming constraints to adjacent spaces and surfaces so they can only be modified under certain rules are examples of the potentialities that such system may achieve.

This program is not a CAD program. It is a simplified modeller to conceptualise architecture during the design process. Architects need information about several performance requirements of the shapes that are being adopted. The information that the program requires is restricted to the essential volumes and surfaces that are meaningful in terms of the simulations needs. The accurate drawing for architectural representation will be done in a posterior phase. However the facility of generating dxf files to export to CAD programs allows an easy implementation in future.

An important goal for future developments of this work is the implementation of shape grammars that can generate architectural shapes from a previous scheme. An example of such schemes is presented in *Figure 13*. We expect to develop Case-Based Design algorithms in order to inform grammars of previous performance of similar buildings.

Figure 13 – Example of future developments

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