Optimization of building envelope shape in early design stages for low energy consumption

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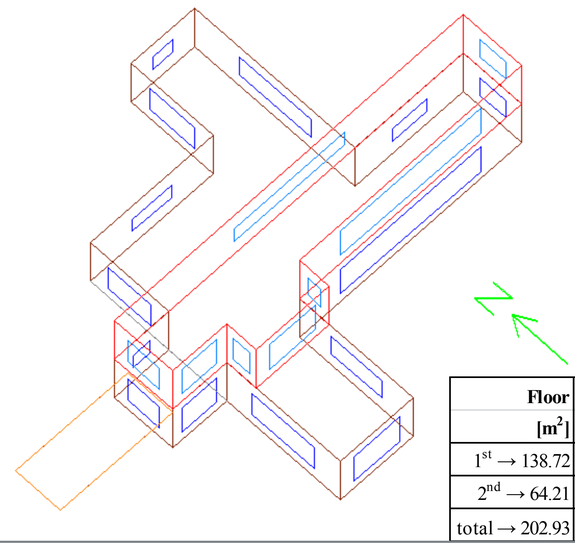
ABSTRACT

This research presents a methodology to assist design decisions regarding the building envelope shape taking into account its implications on the energy performance of the building. It involves a design system, to generate various envelope shape solutions, an integrated energy simulation process, to calculate the energy consumption values of each solution created, and an optimization algorithm. If the design system is perfectly crafted, in such way that every generated design is equally satisfying, optimization can be used to find the best energy efficient shape design.

Design systems encoded into shape grammars have the ability to guarantee stylistic coherence in their generated designs but the lack of a shape grammar interpreter shell makes them hard to implement. Parametric systems are easy to program but it is more difficult to guarantee stylistic coherence. This methodology converts a grammar into a parametric design system.

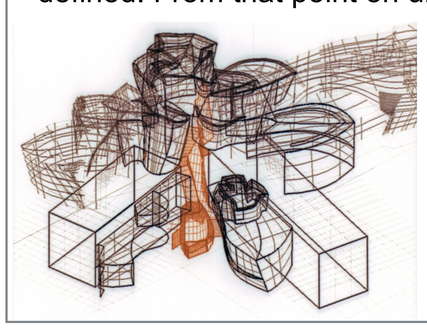
The illustrations below are from the application of the methodology to the grammar for Frank Lloyd Wright's prairie houses [1].

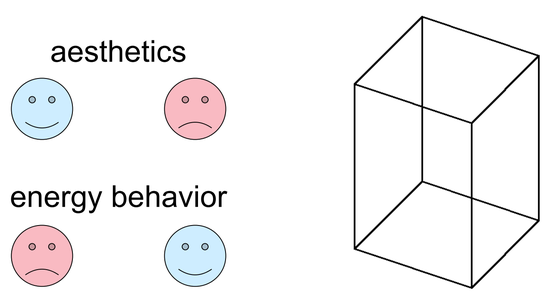


Floor [m^2]	Lights [kWh/y]	Heat [kWh/y]	Cool [kWh/y]	Total [kWh/y]
1st → 138.72	1594.9	1926.5	1428.4	4949.8
2nd → 64.21	738.3	1243.9	1888.2	3870.3
total → 202.93	2333.2	3170.3	3316.6	8820.1

Shape Design Decisions in Early Design Stages

The envelope shape of a building is probably its most salient characteristic and has great impact on its energy consumption, therefore it concerns to both architects and engineers. Although architecture is increasingly considering environmental issues in design, architects still prioritize aesthetics over energy behavior. On the other hand, engineers focus mainly on energy efficiency, often underestimating the value of architectural attributes in design. The discussion about the envelope shape happens in the early design stages, when this is defined. From that point on until the end of the project, it suffers little changes.

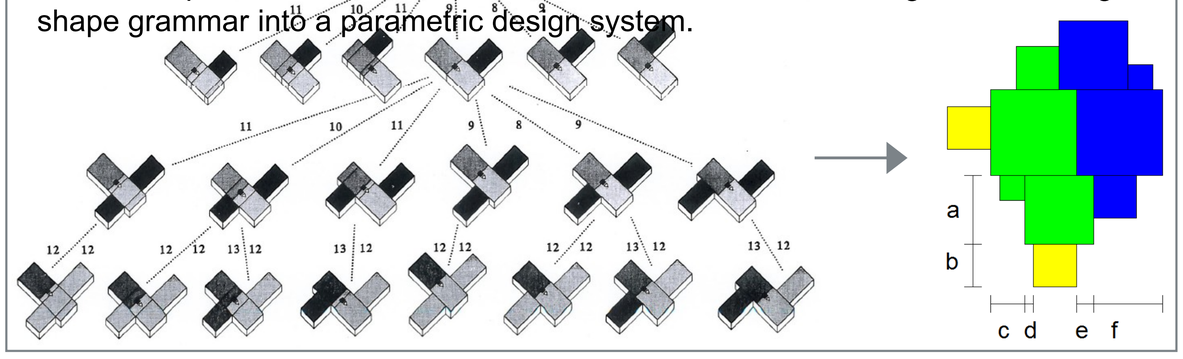




Flexible Shape Design with Architectural Attributes

In order to improve envelope shape design regarding energy efficiency, the design has to comprise flexibility, suggesting the use of a design system. A design system is defined as a set of computational rules that apply to generate alternative building designs.

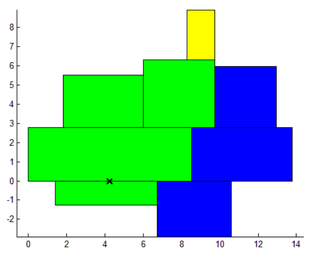
Design systems encoded into shape grammars [2] are more adequate for the architecture field, given their ability to guarantee stylistic coherence, but they are hard to implement. The solution to overcome this shortcoming is converting a shape grammar into a parametric design system.

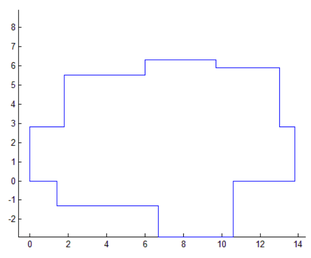


Integrated Energy Simulation

Opposing common perception, there is not a clear rule to define building form for better energy efficiency [3]. Therefore, values from energy simulation have to be available in early design stages to assist design decisions. Since modeling for energy simulation is a time-consuming task, and therefore frequently overlooked, the solution is to integrate energy simulation in the design system.

To reduce the simulation time and due to the low level of design detail in the early stages, simpler models (without the interior details, such as partitions) are used to calculate only the magnitude of the energy consumption.





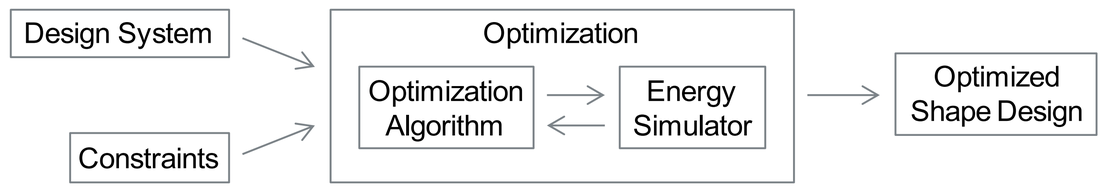
Floor [m^2]	Lights [kWh/y]	Heat [kWh/y]	Cool [kWh/y]	Total [kWh/y]
1st → 91.36	1050.4	1309.0	1010.2	3369.7

Floor [m^2]	Lights/m^2 [kWh/(m^2y)]	Heat/m^2 [kWh/(m^2y)]	Cool/m^2 [kWh/(m^2y)]	Total/m^2 [kWh/(m^2y)]
1st → 91.36	11.50	14.33	11.06	36.88

Optimization

If the rules of the design system are perfectly crafted, in such way that every generated design is equally satisfying from the architectural viewpoint, the existence of energy information for every generated design creates the opportunity for implementing optimization techniques to find the envelope shape design (for a certain context) which minimizes energy consumption.

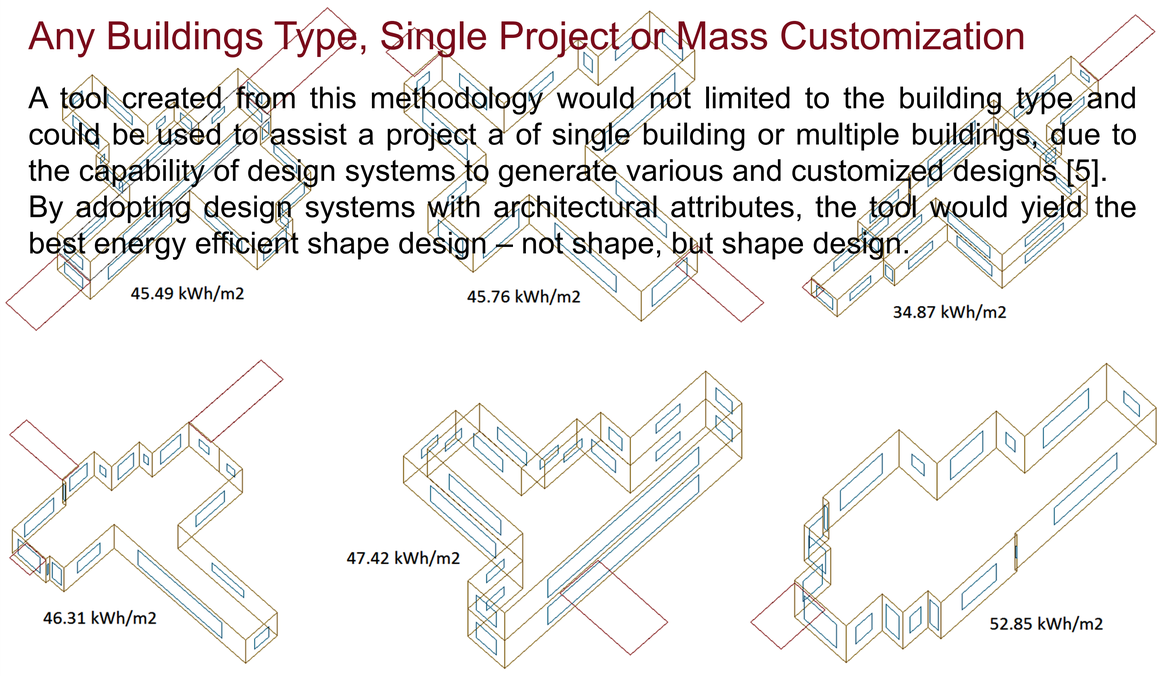
This type of methodology for the development of sustainable building design tools is part of the research strategy of the Energy Department of AIT, not only concerning the shape but also other design components of the building [4].



Any Buildings Type, Single Project or Mass Customization

A tool created from this methodology would not limited to the building type and could be used to assist a project a of single building or multiple buildings, due to the capability of design systems to generate various and customized designs [5].

By adopting design systems with architectural attributes, the tool would yield the best energy efficient shape design – not shape, but shape design.



Future Developments to Increase Market Size

The following described developments will turn the methodology into a marketable design tool and expand its market size.

– Extend the optimization to building materials.

– Consider the embodied energy of materials in the calculations, adopting a life cycle approach to the design optimization.

– Extend the program to the neighborhood level (one more level of optimization), including the effect of the shadow from adjacent buildings.

– Add an interface to parameterize and modify the design systems.

– Include the option to export the designs in an *ifc* format (Industry Foundation Classes), to use in Building Information Modeling software.

With the involvement of a software development company, the expected time-to-market is 3 years.

REFERENCES

[1] H. Koning and J. Eizenberg, “The language of the prairie: Frank Lloyd Wright’s prairie houses,” *Environment and Planning B: Planning and Design*, vol. 8, no. 3, p. 295 – 323, 1981.

[2] G. Stiny, “Introduction to shape and shape grammars,” *Environment and Planning B: Planning and Design*, vol. 7, no. 3, p. 343 – 351, 1980.

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[5] J. P. Duarte, “Customizing Mass Housing: A Discursive Grammar for Siza’s Malagueira Houses,” Ph.D. in Architecture, Massachusetts Institute of Technology, 2001.

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