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The Ideal House - multicriterial optimization of a Single Family House

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Introduction (300 words)

Architectural design is particularly difficult, because it must combine multicriterial engineering optimization with other types of challenges, such as aesthetic and psychological which are usually ill-defined and arbitrary.

Single-family house (SFH) is an archetypal architectural problem. Not only because it deals with creating of a habitat for the basic social cell, but also in a nutshell represents the entire spectrum of issues prevailing to architecture. That is environmental, both natural and artificial conditions.

Since the scale of this classic problem is relatively small, it is usually manageable by a single architect. Nevertheless, the design conditions (natural and symbolical) are relatively diverse which inspire architects' imagination. This makes SFH probably the most favorable and pleasurable type of architectural design among the architects.

In this multicriterial optimization certain aspects are to be minimized (e.g. noise exposition, glare, overheating, etc.) and others to be maximized (e.g. functionality, privacy, etc.). Moreover, some aspects of design have discrete nature (e.g. the functional relationships among rooms), while other are continuous (insolation, etc.).

This paper presents preliminary results of the multicriterial architectural optimization of a SFH. A two-step algorithm has been applied: at first, a graph-theoretical combinatorial search produces a set of “good” architectural layouts, which are next evaluated against environmental conditions (noise, insolation and view exposition).

Methods (300 words)

Initially, the number of desired rooms and their preferred sizes and relative positions are given. Rooms are represented as cuboids, which depending on functions can be shorter (toilet, closet, pantry, etc.) or taller (living room). Due to the zoning regulations, the arrangement of rooms is vertically constrained to two stories, however, single story layout (with cellar) is preferred. Each of the “good” layouts are rotated on the site at few angles and evaluated against the following criteria:

1. Protection of particular rooms of the SFH interior from the noise, for example generated at the major road located approximately 2 km from the site. Since the source of noise is a relatively remote continuous TIR truck traffic, it has low frequency and long wavelengths. This type of noise is particularly difficult to mitigate.
2. Since the site is located a high-latitude country (Poland) the difference between lengths of day and night and corresponding average temperatures vary substantially throughout a year. As a result, during the winter time the direct sunlight exposition is desired, but at summertime – undesired.
3. Additionally, the layouts should provide “nice view” of the surroundings.

Results (300 words)

As mentioned above, SFH optimization is done in two distinct steps:

a) A complete set of all combinations of graphs representing a SFH (with given a number and type of rooms) is considered. From these graphs, completely unfit layouts are discarded. For a typical building, from the initial set of configurations, a fraction is eventually chosen for full environmental evaluation.

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b) The entire set of chosen, potentially functional graph configuration is then evaluated against environmental conditions. This is done by considering various geographic orientations, costs of terrain leveling, considering noise, sunlight and preference of localizing certain rooms towards directions with “nice view”. In order to speed up the process and make it practically useful, this step is done using a parallel program run o a GPU.

The exact numbers of potentially useful configuration and time of their environmental evaluation obviously depends on details regarding the expected structure and the environment in which it will be designed. Important part of the optimization is connected with defining the objective function. The SFH architect should decide about giving appropriate weights which reflect inhabitant preferences. The objective function quantifies preference of sunlight, avoidance of noise pollution, all connected with necessary costs of land, ground leveling, etc.

The case study presened in the paper consider a typical SFH in hilly terrain. The building is expected to contain 5-8 rooms, 1 kitchen, 1 living room, etc. This gives an astronomical number of all possible layouts, however, by intelligent use of constraints, the number of potential layouts can be reduced to thousands, from which approximately 10% is chosen for full evaluation. The latter is done by drawing a particular configuration of the building in a GPU card memory, placing it with various orientations and locations. Costs of leveling, noise, sunlight, etc. are all represented as 2D matrices overlapping with the terrain at which the building is expected to be located.

Conclusions and Contributions (300 words)

Due to difficulties of quantifying of the architectural process of SFH design, this branch of research is still rather unexplored. In this paper we propose a method of evaluation of SFH layouts with taking into account many preferences of future habitants. The process is divided into to steps: a) discarding useless layouts from the full set of graphs representing SFH b) brute-force like evaluation of the remaining layouts on a GPU. The entire process is demonstrated with a typical case study. This case study shows that there are large variations (up to 90%) of the assumed objective function stressing importance of the step (b).

Using the proposed GPU approach, each layout can be fully evaluated in the order of 1s (the exact time depends on factors like building graph size and rendering resolution).

It should be also noted that the SFH architect, at the end of optimization procedure, is presented with a number of candidate solutions ranked with the stated objectivity function. From this set, a final preferred layout and location should be chosen.

Keywords: architectural optimization, brute-force, GPU, multicriterial

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