HOUSING AGENCY SYSTEM (HAS): MULTI-CRITERIA SATISFICING & MASS-CUSTOMIZATION OF HOMES

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The field of architecture and houses demands a radical re-invention of methodology in order to scale design and regain agency in the design of dwellings. The design of houses has become a highly mechanized process with the most recently available data indicating a maximum of only 28% of houses have direct involvement with an architect or licensed design professional.[1] The vast majority of homes in the United States have been built using mass-production tract housing methods where similar home plans are copied, mirrored and rotated to create standardized communities. Architects have the ability to improve the quality of these environments but have been disempowered in the design of houses. There is no shortage of design talent; in 2010 there were as many unemployed architects[2] as all the homes built by the five largest home-builders in the United States.[3]
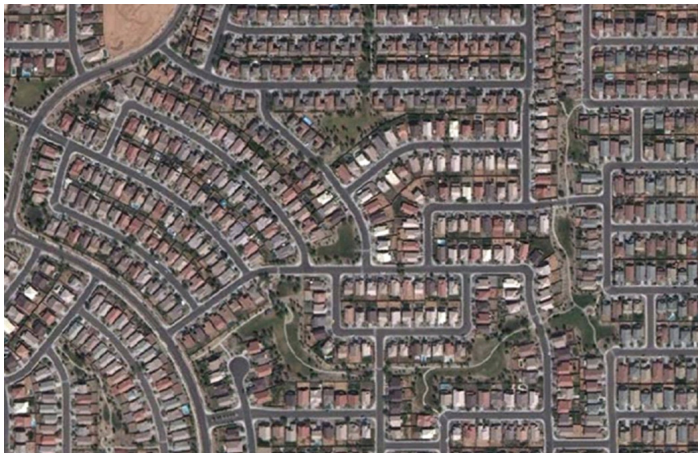

Figure 1. Tract Houses are often designed tabula rasa, without regard for natural features, and oriented based on minimal frontage and maximum profit. Satellite imagery, courtesy of Google Earth.

To ameliorate this unfortunate condition, The authors propose a design system called the Housing Agency System (HAS) that combines Multi-Objective Optimization algorithms with Building Information Modeling parametric software allowing for architects to loosely prescribe designs by establishing constraints and relationships algorithmically. These complex models are then customized to the unique needs of each individual family and site-specific climactic conditions using optimization technology. A search model built to explore a design space called the flexible parametric model (FPM) manipulates parameters either through a brute force method or using a search method such as genetic algorithm or simulated annealing to generate a candidate population of designs and find the most satisfactory solutions.

In this paper, the Housing Agency System design taxonomy is described, consisting of three main components – *Search Constructors*, flexible parametric models and relationships which describe a design space, *Simulations* which evaluate each iteration of that design space and *Goal Sets* which determine acceptable solutions and guide the system towards better results by weighting the results of simulations and queries.

The system as described promises at the least to increase the number of options available in the design of mass-customized housing and increase the viability of mass customization in the market. At the best it has the possibility to give agency back to designers and the general public and avoid the standardized blandness that has enveloped our suburbs and exurbs.

The HAS prototype is designed to allow design professionals to interface with clients who desire customizations to a home through a web and social networking interface. This connection is possible without adding the high costs to the project that prohibit developers from hiring architects in the existing system of housing production by allowing for an accretive library of algorithmic expertise.

Recent developments in design computation, offsite fabrication and simulation provide a fertile environment for generative routines that allow for rapid evaluation of thousands of potential home designs to assist design professionals in projects of multiplicity, where homogenization is the current standard. Rather than dispatching a small series of designs that are homogenized to address a huge variety of site and client relationships poorly, the HAS utilizes a

series of flexible parametric home models that are then customized to the unique conditions of each site and family.

VIABILITY & DEVELOPMENT

Multi-Objective Optimization has been utilized in home production in the past, although it has been in a closed-framework that does not identify the various stakeholders in the built environment (community members, inhabitants, architects, engineers, planners, etc.) as having significant importance. This is only a small improvement on the current system of production and has mainly been used to minimize cost and time of construction. In contrast, the HAS invites the various stakeholders to take part in a model that is analogous to the model of interaction enjoyed by the currently small number of clients who are able to work personally with design professionals to design a custom home.

The first step in developing such a system is to develop a taxonomic framework from which a series of tools and interaction methods are developed for integration with the larger design community. Every effort has been made in the HAS prototype to ensure a modular and accretive development process so that each project completed expands the scope and efficacy of the design system. This paper outlines the main components of that framework and its implementation through the prototype of the HAS.

The flow of information in the HAS is described in Fig 2, The design process enabled by the HAS requires a flexible parametric model (FPM) defined by search constructors, that is mutated by a stochastic process which searches for satisfactory results based on data received from simulations and queries. The data from simulations is then evaluated by weighted goal sets that either discard the design iteration or accept it and guide the solver towards better results. What follows is a detailed overview of the main components and their interactions.

HAS TAXONOMIC FRAMEWORK

Within the HAS, there are three main levels of operation that allow the system to facilitate a generative and analytical feedback loop and provide viable design schemes to the client and/or design team.

Search Constructors

In the HAS, Search Constructors combine to create a robust "design space" that represents the range of possible design solutions to be analyzed by the solver. Computationally, each search constructor is described as sets of parametric constraints and relationships defined collectively by design stakeholders. These interact to form a FPM or Search Model. When implemented on a design project, each search model requires description at six architectural scales to be complete: Site Model, Planning Strategies, Formal Strategies, Construction Systems, Surface/Detail Systems and Building Components, described in detail below.
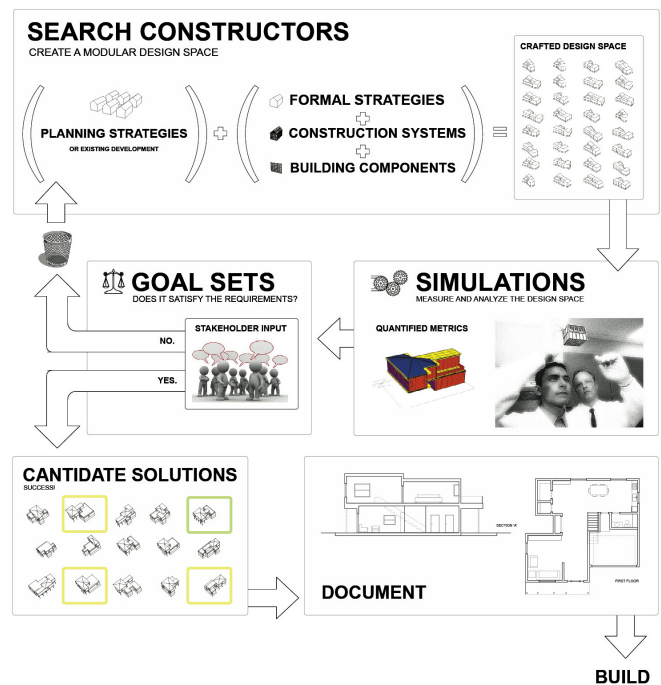

Figure 2. Flow diagram of the HAS system. Image by author.

Site Model: a comprehensive model of the physical site that contains properties and unique conditions of the site. Topography, obstructions and trees, market value of adjacent homes and location of utility inputs are examples of required information for the site model. View corridors and desire lines are required for some goal sets to help determine the position of windows and walls as manipulated by the solver to satisfy desired configurations.

Planning Strategies: include the planning for one or more houses simultaneously and account for interaction between the various units, and their impact on the larger community. The frequency of pedestrian pathways, parks setbacks and density standards can be included in Planning Strategies.

Formal Strategies: 3-dimensional massing organizations that include properties and constraints are customized based on defaults gathered from goal sets to limit the search space. The HAS toolkit enables the effective modeling of search spaces for architecture, as in Fig. 2, where a house with size variations that range 1200 to 2600 square feet and angled walls that respond to lighting and view orientations is described in a matrix showing 36 design possibilities from the design space. The level of flexibility in the formal strategy may be further constrained by designer or client goal sets.

Formal Subdivision Strategies, a subset of formal strategies, respond to typical conditions found in formal strategies and allow for division of the spaces while maintaining desired program and circulation clearances, defined as part of the algorithm.
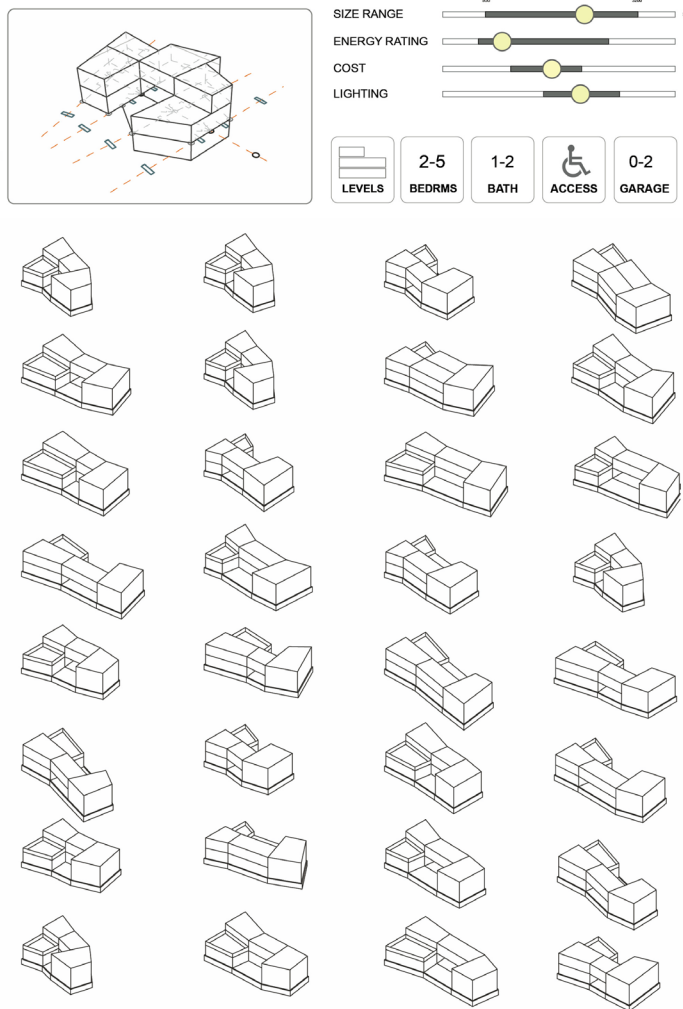
LEVELS	2-5 BEDRMS	1-2 BATH	ACCESS	0-2 GARAGE

Figure 3. A sample of candidate solutions from a flexible parametric model (FPM). Image by author.

Construction Systems: rationalize the construction of formal strategies by defining the process algorithmically. The HAS prototype provides for the application of Light Frame, Heavy Timber, Light Gauge Steel construction systems. Custom systems can be developed, see *Contractor Interaction*.

Surface / Detail Systems: are construction details that are defined algorithmically. The surface or detail systems interact with construction systems and affect their assembly. A surface or detail system may allow a construction system to be adaptable for varying climates, seismic conditions and weather events. Rain screens, hurricane clips and siding options are examples.

Building Components: pre-fabricated or manufactured elements that alter the construction system. Windows, Doors, Stairs and Mechanical Equipment are a few of the many examples of building components. Building Components interact with construction systems and may affect the structural behavior and cost of the design. Building Components may be custom elements or chosen from a database of com-

mercially available products and typologies. The position of building components may be manipulated by the solver within a range defined as part of a formal strategy.

Defining these nested parametric model elements allows Search Constructors to quickly develop a constrained parametric model for the optimization process. Crafting these elements with established standards for simulation engines allows the building model to be analyzed and evaluated by goal sets.

Simulations

In the HAS, Simulations play the role of quantitative evaluations that help narrow defined search spaces and inform the definition of goal sets. Simulations allow stakeholders to evaluate existing design iterations and set performance metrics to which these iterations must comply. Computationally, each simulation is described as a procedural query performed on design iterations that returns evaluative information as a decision assistant to guide a solver towards a desired result.

Structural Simulations: evaluate geometrical configurations in combination with construction systems to determine if the configurations meet minimal requirements for gravity, wind and seismic loading. The HAS prototype includes tributary area, shear wall and member optimization tools.

Cost and Schedule Simulations: Cost simulations evaluate the first and approximate lifecycle costs of a building. The material can be evaluated as well as labor costs associated with a process. Construction Systems that specify their processes by contractors with historical data or verified resources may also include a time linked phasing parameter to generate schedules.

Energy Simulation: The Energy Plus system has been integrated into the HAS design environment[4]

Solar and Light Simulation: Using third party simulation software[5], physically accurate radiation results and solar energy calculations are made available as information to use within goal sets and as decision assistants within the design interface.

View and Sound Simulations: As a component of the site model, sensors dispatched to a specific site as well as feedback from human agents can be used to determine the Sound Transmission Coefficient (STC) rating of a wall assembly or the placement of axes or glazing to reinforce or exclude a specific view or sound.

Flood, Fire and Code Simulations: includes algorithms which analyze the risk of flood and fire in addition to tests for code violations from the International Building Code and Americans with Disabilities Act. The queries provide feedback for reducing risk and improving life safety. Insurance providers may provide custom algorithms of this type using the HAS toolkit.

Geometrical Queries: Information such as the volume, area or dimensions of a space and relational factors, such as proximity or overlap, wayfinding[6] and adjacency are implemented within the library.

Simulations play a key role in the generative cycle of the system: simulation results are gathered from the analysis of a defined Search Model and then evaluated by Goal Sets. The HAS then determines the action to be taken in order to manipulate the Search Model to better satisfy the various Goal Sets.

The simulations described above represent a comprehensive list of those that have been successfully integrated to the HAS. Building scientists, engineers, contractors or other qualified stakeholders may contribute additional simulations in the future.

Goal Sets

In the HAS, Goal Sets quantify stakeholder values. They are described as specific numeric targets, ranges or benchmarks that determine the degree of success that a particular manipulation of the model has produced from the point of view of a given client, site or design team. Goal Sets often conflict, for example, a planner may have a benchmark that conflicts with the opinion of the homeowner and architect. This productive tension creates dynamic environments that avoid the strict homogeneity of traditional zoned developments and more accurately represents the negotiation of values typical in the custom home design process.

Designer Goal Sets: Designers declare the importance of characteristics of projects through Goal Sets. Third party systems for evaluation such as the International Building Code or the LEED system are defined by algorithm and are considered Goal Sets. Performance data from simulations, proximities, ratios of space and types of materials are examples of the many conditions that can be specified through goal sets.

Community Goal Sets: A locality may allow a collective goal set to be created to facilitate collaborative design. These goal sets are typically linked to the *Planning Strategy* search constructor and define collective opinion through voting.

Client Goal Sets: Clients provide goal sets based on surveys or interviews with architects to determine the specific needs of future homeowners. The number and type of rooms in a home as well as the lighting, sound and cost requirements are examples of parameters that may be modified within the Client Goal Set. See *Client Interaction*.

Goal sets are analogous to fitness functions that guide a solver in a genetic algorithm system. The HAS allows for weighting of the various objectives within a goal set to mediate any conflicting goals of the various stakeholders.

STAKEHOLDER INTERACTION

Within the HAS, each stakeholder interacts with the system in a different way to take advantage of their unique specialties, needs and interests.

Designer Interaction: Architects and designers are able to create flexible parametric models, which address a wide variety of design problems pertaining to homes. The parametric models use the HAS toolkit to create search spaces. Additionally, designers create goal sets representing their opinion of how a project should perform and function. These values are combined with client and community goal sets to obtain satisfactory design solutions.

Contractor Interaction: Contractors are able to develop algorithmically defined workflows that rationalize the construction of formal strategies. A contractor may develop a new type of construction assembly based on simulation results and geometry. These definitions may accommodate a wide variety of conditions including windows, doors and load bearing capacities of construction systems. Additionally, the HAS toolkit provides cost estimation algorithms and makes possible a marketplace where developers may bid on projects that are ready to be constructed.
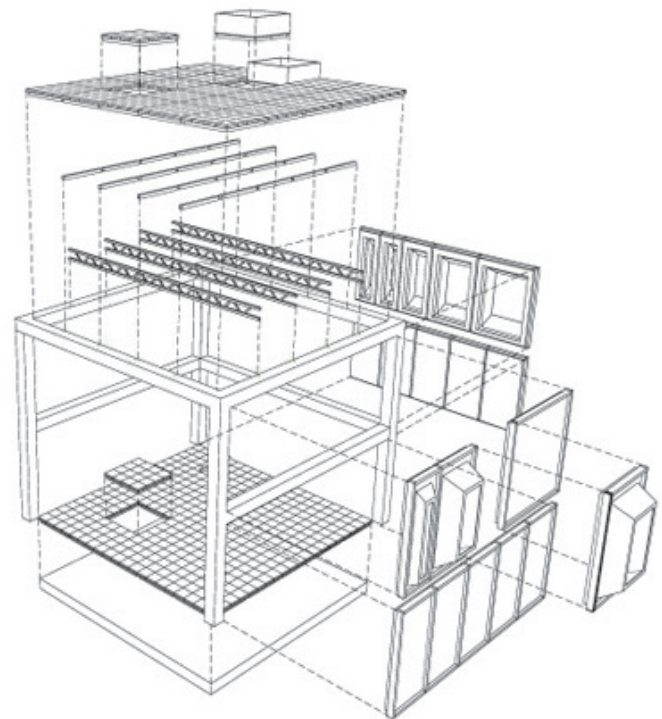

Figure 4. Visual Representation of modular and dis-assemblable algorithmic construction system. Image by author.

Client Interaction: Through client goal sets, the client is presented with a multitude of ways to contribute to the design of their home. The interaction takes on a variety of methods that facilitate complex

results that are unique to each client. A simple bubble diagram interface (Fig. 5) allows clients to determine relationships between spaces without having extensive design education. For instance, the client may determine that they want to see the back yard where children play, from their office. The rule is then implemented within the generative routine.
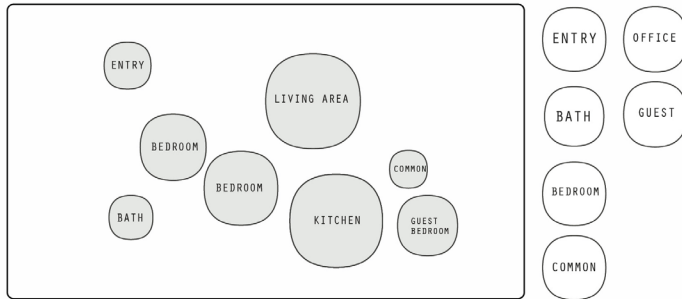

Figure 5 – A prototype interface allows clients to drag-and-drop programmatic elements into the home, size them relatively and provide rules. Image by author.

Manufacturer Interaction: Through the production of 'family' elements that can be input directly into the modeling environment, manufacturers can advertise their products through the HAS. Clients and Designers will have the opportunity to simulate the performance of products and learn their effect on energy use, durability, environmental impact and other outputs.

Policy Maker Interaction: National, State and Local codes must also be applied in order to create valid solutions. Components of the International Building Code and Americans with Disabilities Act have been implemented into the query library. By linking to a social network, communities may contribute to the development of their local codes.

Computer Engineers and *Amateur Programmer*s: May develop their own methods or applications via a programming interface within the HAS.

Through the interaction of various stakeholders in an open-framework and accretive framework, the efficacy of the system progresses over time as more simulations, search constructors and goal sets are created, tested and manipulated within the HAS.

IMPLEMENTATION & CONCLUSION

Creating an algorithmic taxonomy for a process as complex as building a home is not a simple task. This paper delivers an outline of the taxonomy and examples of algorithmic design methods. The system as described is a broad overview of the HAS prototype which stems from analysis of various architect designed custom home projects and developer home building methods.

Implementation of such a system is dependent on a methodology for describing and modeling the process and design that is consistent

for a modular algorithm method to work efficiently. Various platforms have been tested in the prototype including the Rhino/Grasshopper and Autodesk Revit/Vasari BIM modeling environment.

The terms 'optimization' used in this paper interchangeably with 'satisficing'. As described by Nicholas Negroponte in *Soft Architecture Machines*[7], optimization is often sought in the design of architecture but is extremely difficult or impossible to achieve due to the many thousands of objectives and dependencies. The nomenclature that is utilized by most design software still frequently uses the term optimization.

The HAS responds to a variety of recent trends in social networking, simplified mobile computing, public interest in design, increased industry collaboration through BIM/IPD[8] and elastic cloud computing. The applicability of the system for healthcare clinics and retail spaces is currently being evaluated.

Architects tend to be wary of design assistants such as the HAS. A claim is often made that they threaten the agency of the architect within the design process. The HAS is focused in a segment of architectural production that has been nearly eliminated from the influence of licensed design professionals. A interface that informs the general public of the value that architects add to the design of homes and provides a venue for interaction and advertisement can help architects regain a large percentage of this lost market.

ENDNOTES

1   LaBarre, Suzanne. "Truth in Numbers" *Metropolis Magazine*, 15, October 2008. Web. 21 Apr. 2012.
2   Clark, C. J. "Exactly How Many Architects in the U.S. Are Unemployed?" *Architecture Design for Architects.* Architectural Record, 10 Oct. 2010. Web. 21 Apr. 2012.
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4   Energy Plus is implemented using the DIVA plug-in for Rhinoceros and Grasshopper.
5   Autodesk Ecotect Analysis and the Geco plug-in developed by UTO are used.
6   The wayfinding algorithm is implemented using the Shortest Path method and utilizes the A* algorithm.
7   Negroponte, Nicholas. *Soft Architecture Machines.* Cambridge, MA: MIT, 1975. 120. Print.
8   Holzer, D. and Downing, S. (2010), Optioneering: A New Basis for Engagement Between Architects and Their Collaborators. Architectural Design, 80: 60–63. doi: