A Parametric Design Strategy for 4,000 Bus Stops

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Abstract. This paper introduces an integrated parametric design strategy for 4,000 bus stops in Honolulu. According to various site conditions, the design of each bus stop is customized. The proposed strategy employs a simulation-based modeling in order to produce various bus stop design outcomes that fit into physical and environmental characteristics of the given sites in which they are installed.

1. Introduction

In Hawaii, "TheBus" has been a main transportation system since 1971. "TheBus" serves about 905,266 residents in Honolulu and approximately 100,000 daily users. Considering the high cost of living in Hawaii and the absence of a rail system, the use of "TheBus" has been an instrumental vein of the city life in Honolulu with rhythmical pauses at 4,000 bus stops in Honolulu. The current bus stops have been designed for the simplification and generalization of design developments in a linear process in order to maximize the economy of mass-production. When a designer is faced with the design of a large development like 4,000 bus stops, the common design solution is to design a limited number of bus stop prototypes, and then to repeat them with changing their sizes according to the physical dimensions of the sites. One of the reasons to apply this process of mass-production in the bus stop design comes from the fact that the designer is not capable of designing each bus stop individually due the large amount of information that would be required to process. The other is that the repetition of bus stop design with varying the scale of the prototype satisfies the requirements of traditional manufacturing techniques so that it lowers the production considerably. The envisaged process aims at overcoming such limitations by introducing a parametric design strategy for mass-customization.

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Mass-customization allows for the creation and production of unique or similar buildings and building components, differentiated through digitally controlled variation [4]. The employment of a computational mass-customization in architectural design extends the boundary of design solutions to the satisfaction of multi-objective requirements and unlimited freedom to search alternative solutions. The purpose of mass-customization is to maximize the quality of design at an affordable cost with satisfying various constraints [1, 2]. The current development of mass-customization in architectural design has been made with the rapid growth of parametric modeling applications that provide high level of geometric flexibility. The parametric applications allow a user to link various constraints or inputs to the geometric properties. It provides simulation-based design solutions to continuous non-linear problems such as energy efficiency architecture design [1], shape and partitions in buildings [3], and layout design [5]. In this research, a simulation-based parametric design strategy in the design of 4,000 bus stops is introduced as an initial process for generating various design alternatives of mass-customization before its assembly and construction process. Unlike the mass-produced bus stops commonly seen in most cities today, the proposed computational process allows the bus stop design proposals to be customized for satisfying physical and environmental requirements given from individual bus stop site. The variety and flexibility of the design alternatives provide an opportunity for a bus stop to be a "landmark & gateway" with highlighting the identity of each given site context.

2. 4,000 bus stops

The development of the integrated process starts from analyzing existing bus stop sites according to 1) configuration of the site, 2) size of the site, 3) sun direction, 4) site context (downtown, waterfront, or rural), 5) the usage of each bus stop and so on. This process is to ensure that the factors guiding the design will be site-specific, and provide substantiated design parameters of the bus stop. More than 300 bus stops in five routes were selected and analyzed for understanding various site conditions and current usage of the bus stops in Honolulu. The bus stops were organized by 1) physical site conditions, 2) contextual conditions, 3) climatic conditions, and 4) existing amenities.

Table 1. Bus stop conditions and design variables.

CONDITIONS	VARIABLES
PHYSICAL	Site categories, plot area (length and depth), possible expansion area, expansion direction, sidewalk with, distance from road, topographic slope
CONTEXTUAL	Site context (downtown, suburban, rural, tourist), usage (Low, Medium, High), accessibility type (terminal, shelter, node, linear), traffic (L, M, H), vandalism (L, M, H)
CLIMATIC	Precipitation, wind speed, axis orientation, sun direction/path, sun exposure (L,M,H)
EXISTING AMENITIES	Seating (# seats), roof overhang, columns, sheds, wind braces, lights, bike rack

From the analysis, the bus stops in Honolulu were categorized into 5 different types such as 1) wooden-post beam structure, 2) masonry foundation and wooden roof, 3) steel structure and skylight, 4) seating without shelter, and 5) bus stop sign as below.

Fig. 1. Five different types of existing bus stops.

3. Corpus of design

A design of a bus stop prototype inquires into the applicable parametric changes possible within a selected variation of the prototype. The selected variation can produce many other generated design solutions by the means of simulated deformations and manual deformations. The deformation tools not only change the basic parameters of width, depth, length, but also influence the overall geometrical complexity and the optimization of the design outcome considering different sun directions. An integrated parametric design strategy proposed in this paper consists of 1) definition of a prototype, 2) parametric variation, 3) manual deformation, and 4) simulation-based deformation as below.

Fig. 2. An integrated paramteric design strategy.

3.1. Definition of prototype

The definition of a prototype is the development of a basic design to be transformed for satisfying various conditions given from a site.

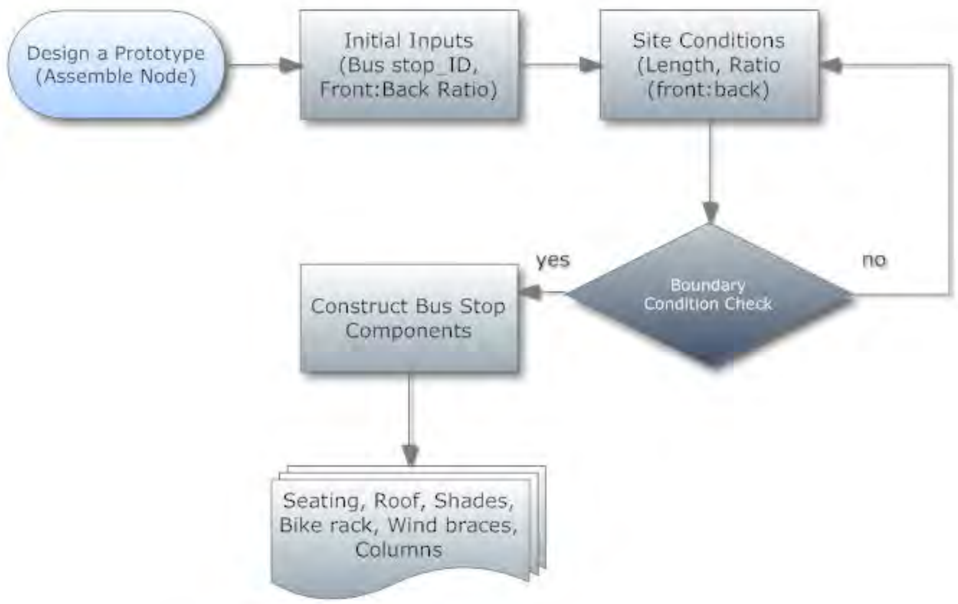


Fig. 3. Flowchart of generating a prototype.

In this paper, the bus stop prototype is developed from the analysis of more than 300 bus stops and the categorization of the existing bus stops according to their physical conditions, contextual conditions, climatic conditions, and existing amenities. Based upon the outcome of the analysis, the design variables of a bus stop prototype are defined with MEL (Maya Embedded Language) in order to allow its parametric variations according to user's inputs. The design variables guide the basic physical parameters for changing the physical configuration of the prototype according to a given site. From this, many possible design outcomes are generated as instances for further developments. The prototype consists of 1) seating, 2) roof, 3) shades, 4) bike rack, 5) wind braces, and 6) columns.

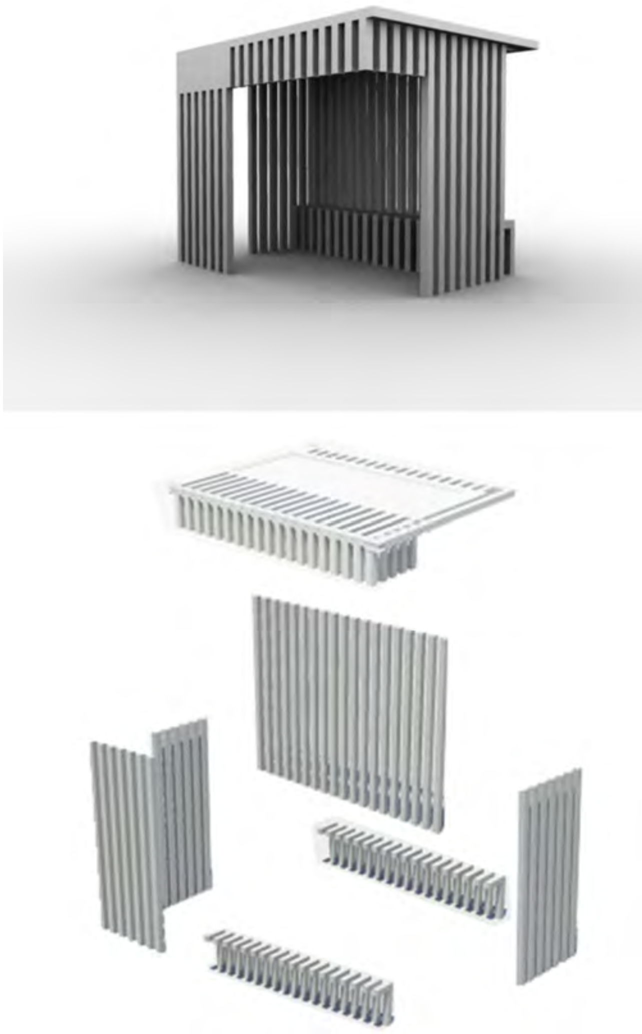


Fig. 4. A prototype and its basic component groups.

3.2. Parametric variation

Among the design variables defined from the analysis, length, depth, and the ratio between the front and the rear side of a bus stop are selected for generating a prototype and its parametric variations. The generation of the prototype variations are initiated by user inputs for defining the spatial volume of the prototype and the ratio between the front and rear side of the bus stop. The height is fixed to 120 inches. Each prototype is initiated with the definition of its bus stop id and the ratio like assembleNode (objectID, ratio value for the front, ratio value for the rear). Accordingly a user is asked to define the length and the depth of a given site as shown as below. The variations become the instances of manual deformations or simulation-based deformation for further design developments.

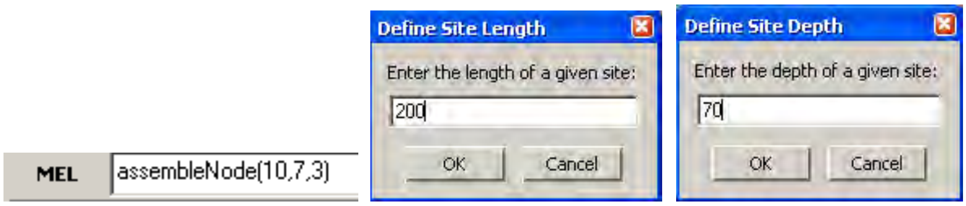


Fig. 5 (a). Initial user input for generating a prototype.

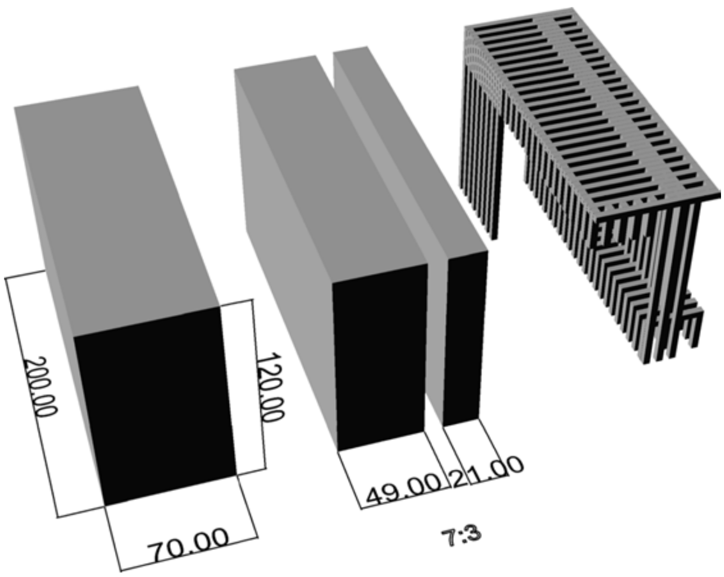


Fig. 5 (b). A prototype from the input.

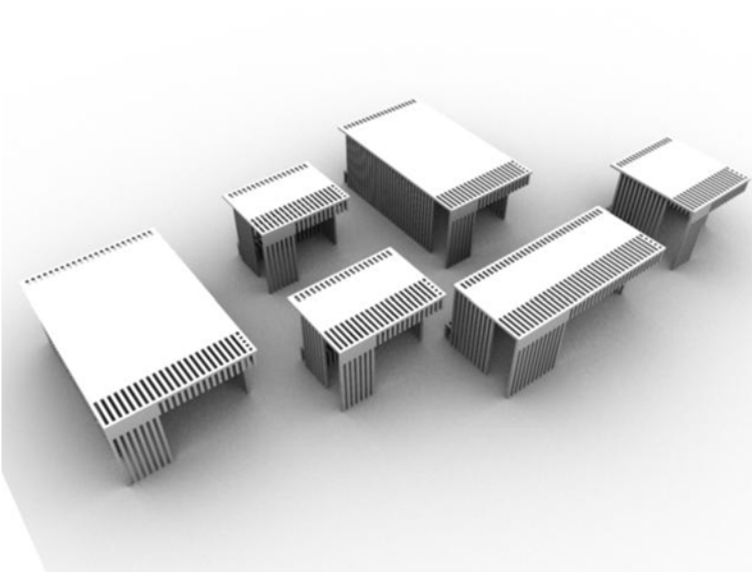


Fig. 5 (c). Parametric variations generated from the inputs.

3.3. Manual deformation

The process of manual deformation is where a designer employs his/her intuition to develop the selected parametric variation. The designer is compelled to think about the possible implication derived from formal variation. This optional process allows every design decision to have a creative solution from an individual designer with an incidental quality in aesthetics as shown in Figure 6.

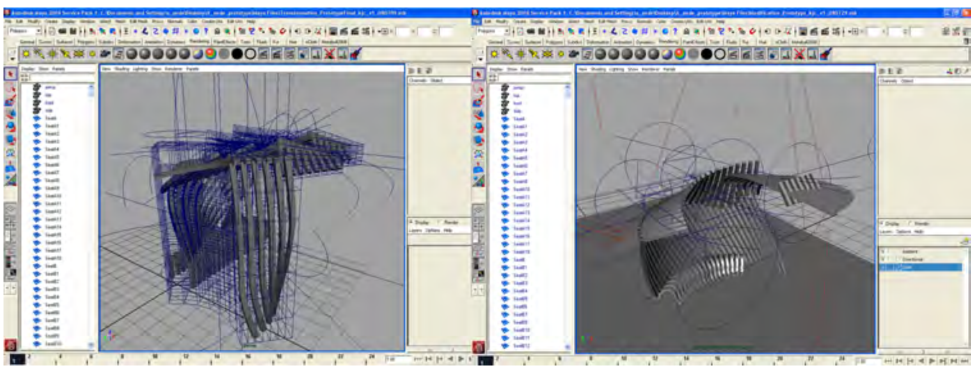
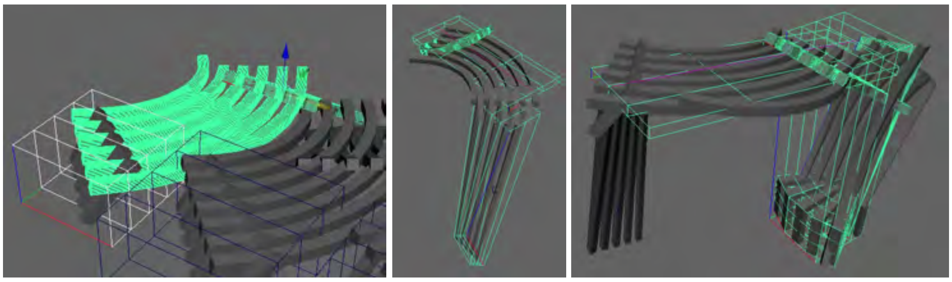


Fig. 6. Manual deformations.

From the initial parametric variations, deformation lattices are respectively assigned to the basic components of the prototype as a group. The deformation lattice is a constrained boundary that influences every object in the specified component group. It allows the manual deformation to be performed with maintaining the relationship among the same components. Furthermore, combined deformation lattices are applied to the different component groups for maintaining their interrelationship such as the contiguous connections as shown in Figure 7.



a) roof-shades b) roof-braces c) roof-columns-seating & bike racks

Fig. 7. Combined deformation lattices.

The connections are 1) roof-shade, 2) roof-brace and 3) roof-column-seating & bike racks. It provides the substantiated functional quality of the prototype through the manual deformation. These additional lattices assigned to the six basic component groups allow a smooth transition from one configuration to another, in which formal change in the components is continuous, not independent.

3.4. Simulation-based deformation

Finally the deformation of selected parametric variations is guided and controlled by the influence of sun direction/ exposure to the selected variant. Sun direction/ exposure variants become main design variables for this process.

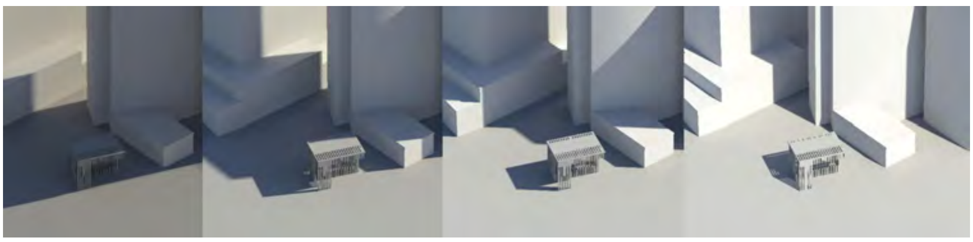


Fig. 8. A sunlight simulation on a bus stop prototype in Waikiki.

The simulation-based deformation starts with the movement of the sun as the trigger for generating the variations of the bus stop prototype.

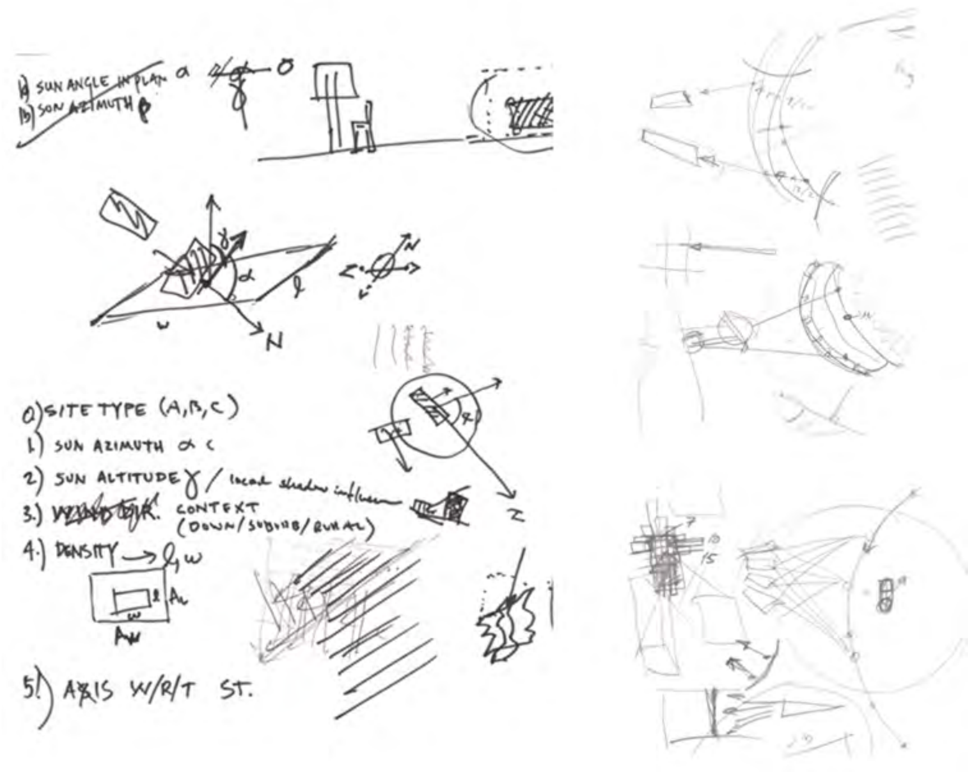


Fig. 9. A diagram of a sunlight simulation and its deformation strategy.

The azimuth and altitude of sun for each site and the time frame of sun path become critical factors to decide the deformation of a given prototype as shown in Figure 9. The implementation of the computational method was made within the combination of MEL (Maya Embedded Language), autodesk MAYA and Ecotect. Using Ecotect, sun path is accounted as a database to project possible design variations. The sun path model data of Honolulu is extracted from Ecotect and the extracted DXF model is applied to MAYA environment as a source for initiating the simulation-based deformation. The components of the bus stop prototype became targets for the deformation that generates the most optimal design solution against sun exposure.

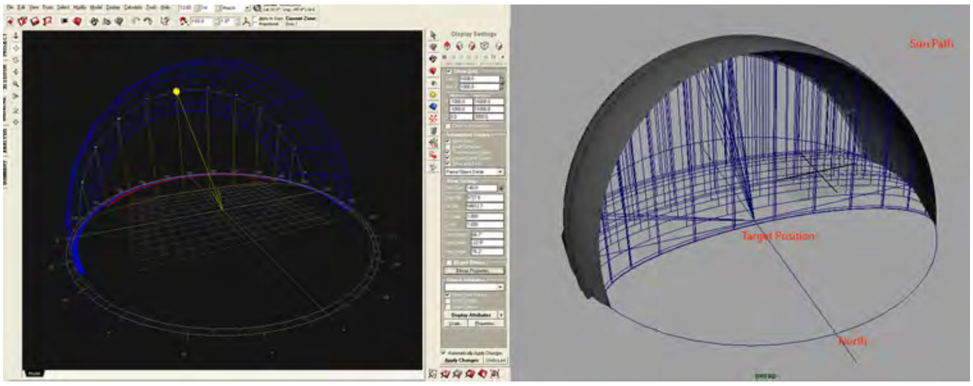


Fig. 10. Sun path on spring equinox in Ecotect & an imported model in MAYA.

In Maya, particle systems consist of emitters, particles, and fields. Emitters are the source objects to create particles. Particles are abstract geometry that has no shape or form. If fields are applied to particles, the particles animate and render to simulate natural phenomena.

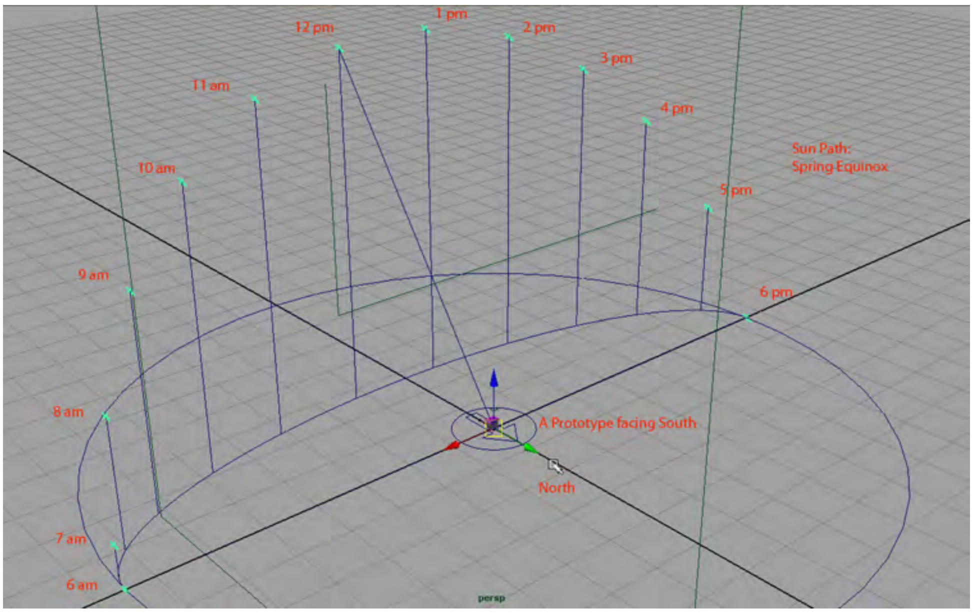


Fig. 11. A field system settings at sun path time frames on a bus stop variant.

In this simulation-based deformation process, each time frame of the imported sun path data model is set to an individual field as a source for the deformation of the component groups correspond to the assigned time fields as shown in Figure 11. Particles are applied to the controlling vertices of deformation lattices applied to the component groups of the bus stop variant such as 1) seating, 2) roof, 3) shades, 4) bike rack, 5) wind braces, and 6) columns through soft body function in MAYA.

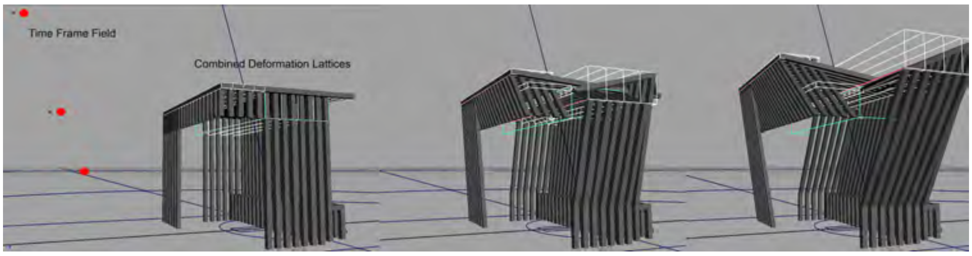


Fig. 12. Deformation by the combined lattices according to time difference.

The control vertices of the lattices transform the component groups of the bus stop variant with maximizing the area of shading according to the influence of the time fields as shown in Figure 12. Regarding each hour as a field that instantiated a formal change in the prototype, the particles applied to the control vertices of the lattices under the influence of the fields will behave as if a sunflower would follow the sun; in this process, the deformation lattice modifies the morphology of the roof and the shades to create a shaded area for the seating. The intensity of the direct overhead sun around noon is accounted for in the basic design, and is strategically maximized for the various direction of the sun. The bus stop then would become a “sunflower” that responds to the calls of climatic design.

Fig. 13. Sunlight simulation-based deformations.

4. Discussion

With combining 1) definition of a prototype, 2) parametric variation, 3) manual deformation, and 4) simulation-based deformation, an integrated parametric design strategy is developed in the design of 4,000 bus stops in Honolulu.

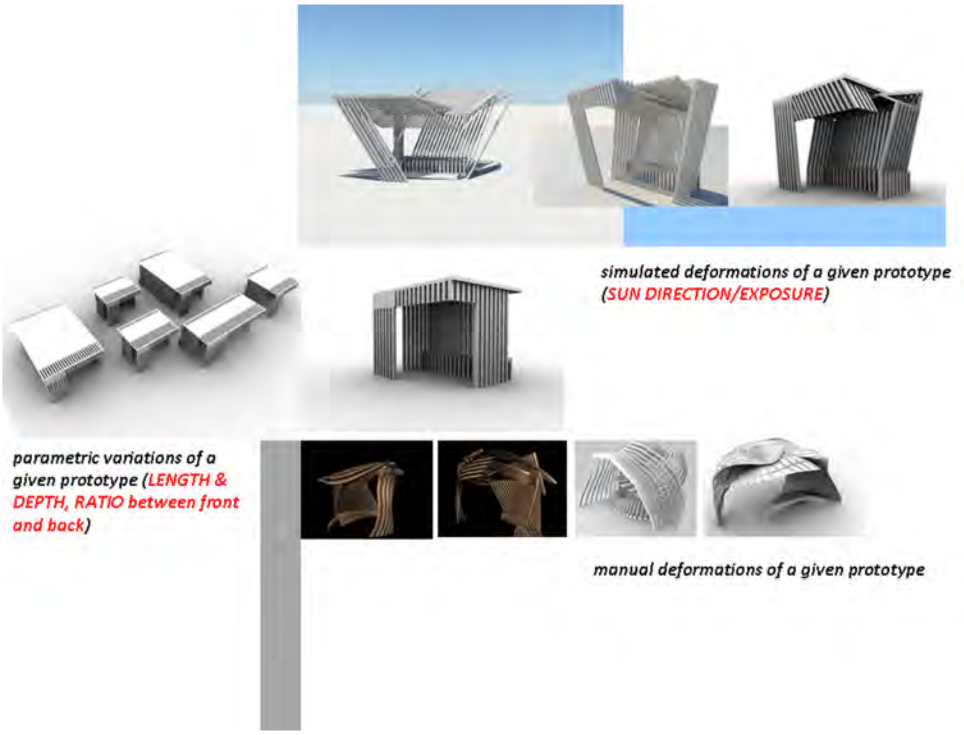


Fig.14. Overview of the integrated parametric design strategy.

Compared to existing design methods, which are 1) designing each bus stop individually or 2) making a mass-production of one fixed model, the integrated process provides site-specific variations of a prototype with maintaining an individual design quality of each variation and a commonality among the variations. The proposed design strategy includes only three design variables such as length, depth, and sun path in order to generate various design alternatives. Considering the complexity involved in the design of a bus stop, multi-objective criteria including construction process, cost, and structural stability have been developed for the future development of the parametric design strategy. This entails the usage of various design optimization methodologies in architectural design in order to deal with the exponential growth of design alternatives from a design computation of the multi-objective criteria for the further development of the parametric design strategy. In this research, various combined deformation lattices were employed as an instrumental component for making an optimized morphological transformation of a bus stop according to the sun direction/ exposure simulation. It allowed a user to perform manual deformations and simulation-based deformations, which are affine changes. When a design problem requires high level of complexity in its building programming, a computational design strategy for performing topological changes of a design prototype needs to be developed to provide a higher level of design freedom and satisfy the given functional requirements.

References

1. Caldas, L. (2008). Generation of energy-efficient architecture solutions applying GENE_ARCH : An evolution-based generative design system. Advanced Engineering Informatics, 22, 59–70.
2. Duarte, J. (2005). Towards the mass customization of housing : the grammar of Siza's houses at Malagueira. Environment and Planning B : Planning and Design, 32, 347–380.
3. Jedrzejuk, H., & Marks, M. (2002). Optimization of Shape and Functional Structure of Buildings as well as Heat Source Utilization Example. Building and Environment, 37 (12), 1249–1253.
4. Koralevic, B. (ed.). (2003). Architecture in the Digital Age : Design and Manufacturing. Spon Press , New York.
5. Michalek, J., Choudhary, R., & Papalambros, P.Y. (2002). Architectural Layout Design Optimization. Engineering Optimization, 34(5), 461–484.
6. Park, H.-J. (2008). Parametric Variations of Palladio's Villa Rotonda. International Journal of Architectural Computing, 6(25), 145–170.
7. Park, H.-J. (2009). Body+Space : Exploring Morphological Transformations of Body Movements in the Design of a Transformable Structure. CAADRIA2009, Yulin, pp. 85-92.
8. Wilkins, M.R. & Kazmier, C. (2005). Mel Scripting for Maya Animators. Elsevier Inc., San Francisco.