Anthropometric and behavior data applied to a generative design system

A study of public benches

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Abstract. This paper discusses ergonomic human body support in regard to people reading and talking on public benches. An applied experiment has been developed where design parameters are structured and associated to anthropometric dimensions relating to observed ergonomic postures. These are incorporated to a procedural design strategy using a geometric model with combination rules. The procedure has been tested, allowing a generation of alternative designs to emerge from ergonomic fitness parameters. The experiment helped to formulate a design methodology for optimizing the information during the product design and manufacturing processes.

Keywords. Bench; urban furniture; generative design; anthropometric data, behavior data.

INTRODUCTION
The word bench is usually defined in dictionaries as a straight and hard seat, with or without armrests and backrest, generally meant to fit more than one person. A study on public parks argues that traditional benches normally promote constraints in users’ postures because of a non-adequate shape (Bessa, Alves and Moraes, 2001). It is indicated that straight benches are the reason for which users look for places, other than the bench, to sit, in order to increase interpersonal interaction.

In ergonomics, seat designs are usually associated to work stations considering the activity realized by the user as well as information regarding anthropometrics, biomechanics, physiological and anatomical aspects of the target population. On the other hand, the dimensions of urban benches usually consider a single posture, usually with an erected trunk, slightly bending backwards, horizontal thighs and vertical legs. As reading and talking are usually performed in different body postures, this apparent design homogeneity seems to conflict with a variety of functional and even cultural aspects of the bench utilization. Since different postures occur on the same bench, the adaptive design to meet requirements emerging from different activities and classes of users (gender and age) is a difficult problem to solve.

As mass customization (Toffler, 1970; Davis, 1987) stimulates personalization and engagement of costumers in the production process, parametric modeling software such as Grasshopper, allows designers to intuitively create generative systems for
any design purpose by attributing specific functions and forms related to its use and user. Physical data regarding ergonomic and anthropometric information could relate to different uses as a way to determine optimal seating positions. This relationship would then be fed into a digital model, allowing variations according to the design goal.

The objective of this paper is to structure a design methodology for public benches integrating the anthropometric and behavioral aspects of the users (Vettoretti, 2010). The paper is divided in 6 parts. Part 1, Material and Methods, describes the adopted procedure for gathering information regarding people reading and talking on the benches, which are analyzed in part 2. Part 3 presents the design experiment’s strategy and the design parameters that are utilized. Part 4, exposes the data and the strategic design application in a parametric model using Grasshopper [1], a generative modeling plug-in for the software Rhinoceros [2]. The process of the digital fabrication of a selected model resulted from this experiment is described in part 6. In the last part the results and discussions from the process are presented, as well as suggestions for the researches development.

**MATERIAL AND METHODS**

Static anthropometry takes the dimensions of a still body while standing, sitting, lying or in any specific position, as a reference for furniture design (Iida, 2005; Panero and Zelnik, 2002). Such an approach while valuable, only provides information about anthropometric data and does not relate this to the user’s potential behavior, as a non expected use of the designed object.

In order to retrieve information about different patterns of the use of urban benches, the actions of reading and talking were identified and photographically registered in four parks in Brazil. The registered information for each performed activity was classified in types of users (identified by gender and age), types of benches (5 different models were found), and posture information. This last were sub-classified in:

- Position: related to where the user is leaning on the bench.
- Rotation: related to the user’s rotation on the bench
- Trunk inclination: related to direction of the user’s trunk inclination
- Thigh inclination: related to direction of the user’s thigh inclination
- Leg inclination: related to direction of the user’s leg inclination

Figure 1 exposes the subdivision for each posture classification.

```plaintext
<table>
<thead>
<tr>
<th>POSITION</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>ROTATION</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>R5</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>TRUNK INCLINATION</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>THIGH INCLINATION</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>LEG INCLINATION</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
</tr>
</thead>
</table>
```

**ANALYSIS**

Once the information was collected and tabulated, an analysis was made using the Chi-Square test (Siegel, 1979), and the following was observed:

- The analyzed benches do not fully satisfy users while reading or talking
- The preferred bench morphology had a back rest and an inclined seat
- Men tend to read while women tend to chat
- Men tend to sit without rotation while women tend to rotate at 45°
- Rotation is important when it comes to talking, but not to reading. More than 70% of the users which were interacting with others were rotated
• Postures with position P1 and trunk inclination T1 – both favored by the typical bench design – appeared in only 20% of the cases
• Elders were more conservative in their postures. Most of the time they sat following the posture suggested by the bench morphology. Youth and adults tend to rotate on the bench and incline their trunk backwards
• Postures with trunk inclination backwards T3 are desirable in both activities
• Whilst reading, the combination of postures P3 + T3 + E2 + C3 tends to occur together
• Whilst talking, postures with rotation tend to occur with the trunk inclined backwards

THE DESIGN EXPERIMENT’S STRATEGY
A design strategy was defined using generatrixes and guidelines (Mitchell and McCullough, 1991). The generatrixes shapes were given by the anthropometric and ergonomic parameters related to the bodies’ profile, while seated. Whereas the guideline refers to a set of combination rules defined by use trends, observed during data research.

In the proposed design strategy, the space occupied by one user is defined as “module+transition”. One module is generated by the interpolation of two identical curves and gives the minimal straight space for sitting. The interpolation between two different modules is defined as transition and the association between modules and transitions results in the bench shape. Figure 2 illustrates the design strategy.

Design Parameters for Generatrixes
The information on the different postures along with the anthropometric data was simplified by schemes allowing the identification of different design parameter values such as dimensions, inclinations, angles and distances between users. These results established domains applied in the design system. The profile follows the information obtained when combining the specific value of each parameter domain (position, trunk, thigh and leg inclinations). This proposed design method allows the direct use of the observed data into the computational environment and thereafter the results are used in the bench design process.

Figure 3 introduces all the design parameters for the generatrixes with domain bounds for each. As shown in tables 1 and 2, different values were established according to target populations. Dimensional parameters were related to anthropometric data for men and women and inclination parameters were related to posture observations identified in different age users.

Design Parameters and Combination Rules for Guidelines
Design parameters for the guideline are given by the shoulder width combined with the necessary dimension of two rotated users. The maximum angularity between modules was restricted to 45° and the width used for “module+transition” was 70, 8 cm, related to the highest percentile.
Combination rules for the sequence of modules were defined based on shape grammar theory (Stiny, 1980). After a primary vocabulary for each “module+transition” was defined (figure 4), the combination rules were formulated contemplating all possible options in which users face the same side of the bench (figure 5).

For each activity there were some optimal combinations identified and related to the posture trends obtained as data search results. For reading it was excluded the A and B combinations, because of their angularity, which forces users to face each other. For conversation, it was excluded the E and F for the opposite reason.

**Flowchart for data application**

A flowchart was devised as to describe the system. The proposed sequence organizes parameter information to be applied separately, when a specific user group is targeted for bench manufacturing, for instance. This process turns possible to adapt benches design for different users and their related activities. Figure 6 introduces the proposed flowchart, which is divided in three steps. In the first step the activities sequence is defined, and in the second, restrictions for users divided by gender and age. The last step is to detail each module’s inclinations according to its previous defined activity. Each definition takes the system to a different table of data values.

**CREATING THE PARAMETRIC MODEL**

After collecting the data and establishing the domain bounds, this information was fed into Grasshopper. Each parameter was identified and distributed into different sets. Subsequently a number of rules were

### Table 1
Dimensional parameters related to anthropometric data

<table>
<thead>
<tr>
<th>Dimensional parameters</th>
<th>average population</th>
<th>W 5%</th>
<th>W 95%</th>
<th>M 5%</th>
<th>M 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>{a} seat height from floor (cm)</td>
<td>39,4</td>
<td>39,4</td>
<td>48,3</td>
<td>43,2</td>
<td>52,8</td>
</tr>
<tr>
<td>{b} seat depth (cm)</td>
<td>38 - 44</td>
<td>41,2</td>
<td>51,3</td>
<td>41,9</td>
<td>52,4</td>
</tr>
<tr>
<td>{c1} backboard height from seat, until 30° inclination (cm)</td>
<td>35 - 50</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>{c2} backboard height from seat, after 30° inclination(cm)</td>
<td>93</td>
<td>75,2</td>
<td>88,1</td>
<td>80,3</td>
<td>93</td>
</tr>
<tr>
<td>{d} backboard depth (cm)</td>
<td>5 - 44</td>
<td>41,2</td>
<td>51,3</td>
<td>41,9</td>
<td>52,4</td>
</tr>
</tbody>
</table>

### Table 2
Inclination parameters related to postures observations

<table>
<thead>
<tr>
<th>Inclination parameters</th>
<th>observed population</th>
<th>youth</th>
<th>adults</th>
<th>elders</th>
</tr>
</thead>
<tbody>
<tr>
<td>{e} angle between backboard and vertical (degrees)</td>
<td>5° - 90°</td>
<td>5° - 90°</td>
<td>5° - 90°</td>
<td>5° - 35°</td>
</tr>
<tr>
<td>{f} angle between backboard and seat (degrees)</td>
<td>95° - 180°</td>
<td>95° - 180°</td>
<td>95° - 180°</td>
<td>95° - 115°</td>
</tr>
<tr>
<td>{g} angle between seat and base (degrees)</td>
<td>55° - 180°</td>
<td>55° - 180°</td>
<td>55° - 180°</td>
<td>55° - 105°</td>
</tr>
</tbody>
</table>
applied to each set in order to relate it to the others. For example, if the angle between the seat and the back rest is larger than 30°, the back rest is higher than the other ones. These relationships allowed the creation of unlimited ideal profiles (curves) for any kind of activity. The profiles were then arranged along a previously established guideline. In order to create a seamless bench, where different uses can take place, it was necessary to interpolate the different curves, since each activity demands very different parameters inside the domain. Such results were obtained through a loft operation between the ideal profiles. By changing parameter values, such as seat height or backboard depth, one can generate an infinite array of design options, as shown in figure 7. The definition of the activities and combination rules sequences along the guideline might influence the shape of the guideline itself as shown in figure 8.

**DIGITAL FABRICATION**
The material for the prototype fabrication was 6mm corrugated cardboard. Several 1:10 models were fabricated in order to test the process and the usability with articulated mannequins. One of these was chosen for full size fabrication (1:1 scale) with a length of 3 meters and a width of 1.8 meters, including 3 “module+transition” (3 postures base).
Figure 7
Family of benches

Figure 8
Different activities and combination rules sequences for guideline
The laser cut machinery used had a work area of 60x90cm, imposing the bench subdivision in 18 pieces of 60x60x90cm. At the end, 419 layer sections were cut and 18 modules assembled. Figure 9 exemplifies the assembly of one piece and the user’s test. Once all the modules were brought together, the designs seamless surface emerged (figure 10).

RESULTS AND DISCUSSION
It was argued that the wide range of postures assumed by users during reading and conversation activities is not usually considered in urban bench projects. Setting the adequate dimensions and shapes of such a bench constitutes an intricate problem which can only be achieved by new design and fabrication technologies. A design methodology integrating anthropometric and behavior aspects of users was then proposed, using Grasshopper as a platform for absorbing and processing data.

The system accomplished the seating profiles and the resulted interpolations shaped the final surface. It should be noted that the interpolation results in an infinite number of ideal sections constituting a data base for alternative designs within the structure of the same design brief. The generated alternative surfaces have, in turn, enabled different potential postures to emerge during the generative process. This is a relevant point of the research that exemplifies how the design methodology could support the designer’s creative process. Further research could focus on the development of methods for usability tests, in order to assess the fitness degree of the bench shape from the user’s points of view.
REFERENCES


