# Generating and Evaluating Design Alternatives for Digital-Physical Artifacts of Room-Scale or Larger

**Tarek Mokhtar**
Clemson Univeristy
tmokhta@g.clemson.edu

**Keith Evan Green**
Clemson Univeristy
kegreen@clemson.edu

**Ian D. Walker**
Clemson Univeristy
iwalker@clemson.edu

## ABSTRACT
A critical step in any design process is the early generation and evaluation of design alternatives. In this paper, we elaborate a process of generation and evaluation of design alternatives for a computational artifact of unusually large-scale and complexity: an intelligent civic monument we call Monumental-IT. As computation becomes ubiquitous at all scales in our everyday environment, the creative and human-centered design methods presented here serve to guide other designers designing complex, large-scale computational artifacts, particularly those for the public domain.

## Author Keywords
Design, architecture, robotics, monuments, human factors.

## ACM Classification Keywords
H.1.2 User/Machine Systems–Human factors, H.5.2 User Interfaces–User-centered design, J.5 Arts and Humanities–Architecture.

## General Terms
Design.

## INTRODUCTION
Increasingly, computation is becoming embedded into the very fabric of our everyday, built environments, at large-scale, impacting the ways we interact with each other and the things around us. While methods of iterative, human-centered design have emerged for screen-based applications and smaller-scale smart devices, room-scaled and larger intelligent artifacts, particularly those intended for the public domain, require heightened attention to issues of socio-cultural and physical contexts, human-machine interaction, machine behavior and robustness, and maintenance and safety. Consequently, the design of large-scale intelligent environments demands of designers (broadly defined), a process of design that adequately addresses the increasingly complex set of concerns endemic to built environments, generally, and intelligent, physical

environments, inevitably.

This paper elaborates the early, critical phases of an iterative design process for Monumental-IT (figure 1), a citizen-configurable, robotic monument. We elaborate the generation of alternative design concepts for Monumental-IT, the basis for their evaluation, and the critical process of selecting a final design for intensive development. The mixed methods employed here, both human-centered and "creative," promise to guide designers in designing intelligent, physical artifacts of room-scale or larger. The expected outcome is a design artifact that, in implementation, cultivates new ways for people to interact with each and their surroundings (both physical and digital).
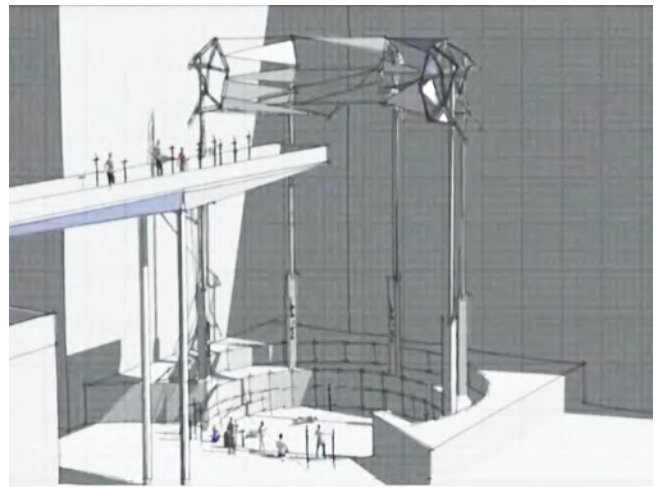


**Figure 1. A drawing of Monumental-IT as a final design.**

## MONUMENTAL-IT, DEFINED
Monumental-IT is an open, reconfigurable, and interactive monument designed to give form, color, sound and movement to users' feeling about a specified human event. The intelligent monument is comprised primarily of five tall masts terminated by actuated, hinged linkages; the movements of these scissor-like linkages reconfigure canopies of fabric tethered above the visitors (figure 2). Microphones distributed across the physical site of the monument invite users to annunciate what they feel in response to a specified human event; this audio input then is "read" by the system for its emotive value, and translated by the system into a multi-modal, dynamic expression of

sentiment. As well as the inputs offered by users locally, Monumental-IT affords remote users to access the *Monumental-IT website* and express their sentiments by way of responses (radio buttons) to a series of questions found there. The input of remote users is actuated in the monument during those periods which are void of local user input (dead spaces). We designed the core of the monument to be transportable: the masts, linkages and canopies that comprise Monumental-IT can be dismounted, moved, and reinstalled into a ground infrastructure prepared specifically for the local context. This infrastructure may be as elaborated or as fleeting and temporary as local contexts dictate. The Monumental-IT design team would encourage local communities to consider the re-purposing of this local infrastructure, should the monument not be planned as a long-standing addition to the public domain.



**Figure 2. Moving linkages and fabric canopies of the final Monumental-IT design.**

For our test bed, we selected historic Charleston, South Carolina [USA] in proximity to the old Slave Mart, where tourists and other individuals passing by the site could communicate, through their voices, their feelings. Effectively, this intelligent civic monument makes visible, at large-scale, the sentiments of human beings – individual citizens – about a profound human event which, in our test case, is the history of slavery marked by the historic Slave Mart building, now a museum dedicated to this event. Our *Monumental-IT video* provides more details of the project than can be presented in this short space (http://www.youtube.com/watch?v=uEqRgyBTP4A).

**EARLY PROCESS OF DESIGN IN FIVE STAGES**
Particularly in developing a computational physical artifact of this scale and complexity, a human-centered design approach is critical, where "the user should be involved throughout the design life cycle" in an "iterative design process" [14].

The iterative design process for Monumental-IT follows these six steps: (1) *defining targeted users in the form of*

*personas* which cultivate for the design team an understanding of intended users, and the aspects of the design alternatives these users might appreciate or not; (2) *generating and describing numerous alternative design concepts*; (3) *subjecting the alternative designs to a conceptual screening process* to arrive at the design(s) which promise to be engaging, feasible, and usable, and that fulfill the broader philosophical and conceptual aims of the research; (4) *engaging in the concept resolution of fundamental components* (e.g. the physical structure and its mechanics) of the envisioned design artifact that need focused study prior to furthering any single design alternative in a holistic manner; (5) *prototyping the selected design(s)* by employing low and high-fidelity prototyping materials and embedding sensors and actuators; and (6) *designing/establishing system behaviors*. By this stage in the process, a prototype has been identifies as the focus of refinement through further cycles of design, testing and evaluating using heuristic evaluations and usability surveys.

In brief: in the case of Monumental-IT, we designed twelve alternatives (which seemed to us, in the process, a sufficient number of alternatives to represent a wide range of prospects) using two "personas"; we compared the prototypes, representing their strengths and weaknesses according to conceptual-design criteria; we selected the best two alternatives to prototype at 1:6 scale; and we subsequently evaluated the prototype designs using usability evaluation methods with "experts" and "real users" towards selecting one design for intensive design development. The outcome of our iterative design process, our final prototype for this research, is presented in figures 1-4 and in our video.
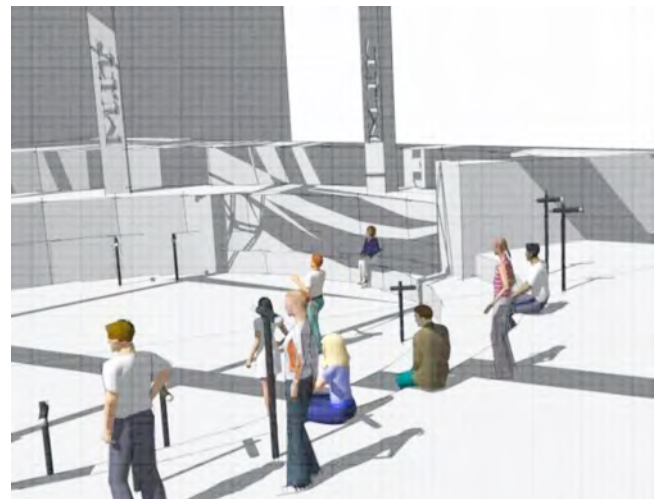


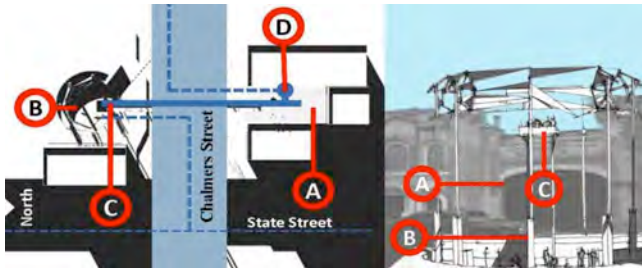**Figure 3. Visitors at the microphones of Monumental-IT.**

**Figure 4. Monumental-IT in its test-bed, Charleston.**

## 1. "Personas": Towards Understanding Targeted Users

"Personas" are fictional user-profiles representing envisioned user groups, conceived by the design team to assess alternative design concepts. These "user archetype(s)…guide decisions about product features, interactions, and even visual design. By designing for the archetype, whose goals and behavior patterns can be understood, it is possible to satisfy the broader group of people represented by that archetype" [6].

Each persona "is a narrative that describes the flow of someone's day, as well as their skills, attitudes, environments, and goals….[A] persona must be specific to the design problem; it may also have a fictional photo, but at the end it is a design tool" [6]. Personas have utility, also, as a communication tool to help clients and lay audiences understand imagine the likely interactions between intended users and the design artifact.

For Monumental-IT, we employed two personas. A 24-year-old M.A. student in History, **Megan B. Ross** is enrolled at a public university in the Southeastern U.S. Megan is socially active and keeps up with the latest trends. While she owns an iPhone and a laptop computer, she characterizes herself as not partiuclarly tech-savy. She is studying the history of slavery in and about the city of Charleston, where she will reside for six months. A 54-year-old professor at a research University in the Northeast, **George Smith** teaches and researches the ethics of freedom in the United States. Vacationing in Charleston, George characterizes himself as tech-savvy. He is recognized amongst his colleagues for his strong analytical skills.

Our intent in designing Monumental-IT is for the monument to engage and accommodate all users, inclusively; the two "personas" introduced here, however, made tangible to the design team probable user groups towards our realization of a usable, attractive and useful system. We envisioned the behavior and attitudes of Megan and George upon discovering and interacting with Monumental-IT; and from this fictive enactment, the two personas guided the basis of our concept generation – "an approximate description of the form, behavior and working principles" of this intelligent monument [15].

## 2. Generation and Description of Alternative Designs

The main formal problem in designing Monumental-IT was the configurability of its physical, dynamic structure, especially given that there exist few examples of dynamic structures in the history of architectural design, let alone, the design of monuments [16].

Our research team propagated more than thirty design sketches for the monument, narrowed down to twelve designs (see Table 1) based on team deliberations, again envisioning Megan and George as representative users. To simplify the concept selection phase, we assigned each of the twelve design alternative a descriptive title in accordance with its external features: Rotating Tube (A), Fan Leaves (B), Waving Strips (C), Solid and Void (D), Flower Leaves (E), Rotating Gears (F), Spider Arms (H), The Mesh (I), Hydraulic Plates (J), Strip Wall (K), Skin Wall (L), and Skeleton and Skin (M).
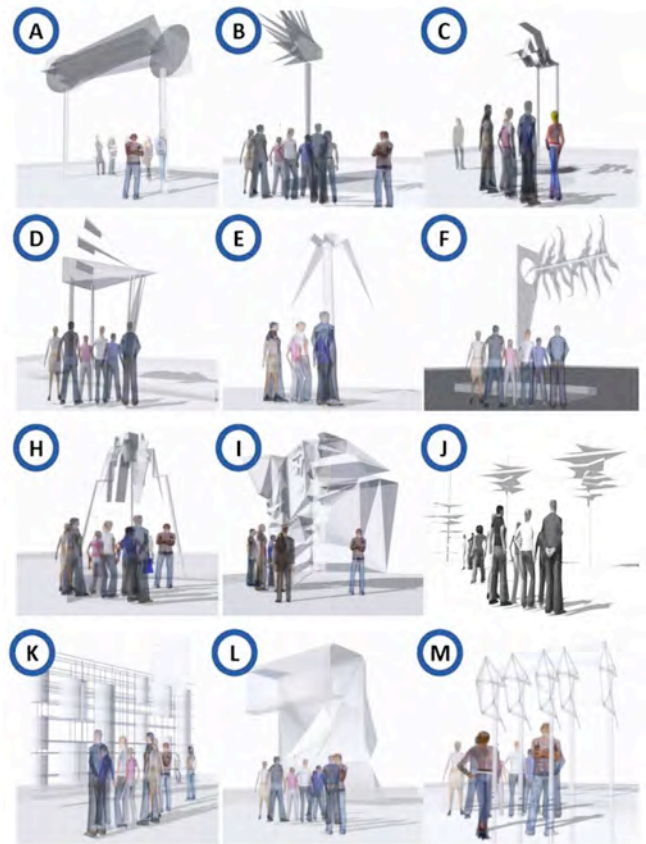


**Table 1. Twelve alternative design concepts**

Following the identification and naming of the twelve design alternatives, the team described each one according to its underlying form, kinematics and working principle. Given the limited space here, Table 2 provides these descriptions for design alternatives K, L and M to offer a sense of this stage of our iterative design process.

## 3. Concept Screening

We employed Ulrich and Eppinger's procedure of *concept screening* [15] for concept selection. In *concept screening,* "rough initial concepts are evaluated relative to a common reference concept using the *screening matrix*," [15]. The reference concept we selected for our comparison is the "Muscle Body" by the Hyperbody Research Group of TU Delft [13]. We selected the Muscle Body for the following reasons: (1) The Muscle Body is an interactive installation at room-scale employing sensing and actuating technologies as would Monumental-IT; (2) The Muscle Body is designed for a public space for public use; (3) The Muscle Body is well known by the design team; and (4) The Muscle Body shares the fundamental characteristics of openness and re-configurability that we envision for Monumental-IT.

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**Concept K: *Strip Wall***

**Form:** A mesh structure of vertical, solid, metal elements which expand and shrink, much like a heart beating inside a skeleton.

**Underlying Kinematics: Horizontal Motion**

**Working Principle:** Shape memory alloys comprising the solid elements are actuated using pulleys and motors, expanding and shrinking horizontally, opening and closing the mesh.

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**Concept L: *Skin Wall***

**Form:** A Z-shaped structure covered with a fabric skin expands and contracts, much like living skin on a static body.

**Underlying Kinematics: Horizontal and vertical motion**

**Working Principle:** The fabric skin is actuated using pulleys and strings attached to motors, moving in tandem with the skeleton beneath it.

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**Concept M: *Skeleton and Skin***

**Form:** Elastic, fabric canopies deform as their 5 skeletal armatures of 12 hinged members rotate.

**Underlying Kinematics: Horizontal and vertical motion**

**Working Principle:** The closed-loop chains are actuated by servo motors, forming different configurations by changing motor speeds, rotational angles, and directions of rotation.

**Table 2. Concept descriptions for designs K, L and M: Form, Underlying Kinematics, and Working Principles.**

In *concept screening*, we prepared the *selection matrix,* employing design criteria and human-centered design criteria that follow the philosophical and conceptual foundations of this research, as well the lessons learned from our previous design research in interactive physical environments [8], [9], [10] and related work informing it, as considered by us in [8]. These criteria are identified as follows: *openness* (the extent to which the design availed itself to personal interpretation), *configurability* (the extent to which the design accommodated changes in form), *structural stability* (a major problem in designing kinetic structures), *aesthetics* (to what extent were the design qualities drawing the interest of users), *technological viability* (whether the suggested technology was apt and feasible for its design application), *legibility* (the extent to which users were likely to perceive apparent meaning in the

**Concepts**

| | Selection Criteria | A Rotating Tube | B Fan Leaves | C Waving Strips | D Solid & Void | E Flower Leaves | F Rotating Gears | G Muscle Body | H Spider Arms | I The Mesh | J Hydraulic Plates | K Strip Wall | L Skin Wall | M Skeleton & Skin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Design** | Openness | - | - | 0 | - | 0 | 0 | 0 | + | + | + | 0 | 0 | + |
| | Configurability | - | + | + | - | + | 0 | 0 | + | 0 | - | 0 | 0 | 0 |
| | Structural Stability | + | - | - | + | - | + | 0 | - | + | + | + | + | + |
| | Aesthetics | - | 0 | 0 | 0 | - | 0 | 0 | 0 | 0 | - | 0 | 0 | 0 |
| | Techno. Viability | 0 | 0 | 0 | 0 | - | 0 | 0 | - | 0 | + | - | + | 0 |
| **HCI** | Legibility | - | - | + | + | 0 | 0 | 0 | + | - | 0 | + | 0 | + |
| | Impressionability | + | + | 0 | 0 | + | + | 0 | + | - | - | + | + | + |
| **Sum** | Sum +'s | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 4 | 2 | 3 | 3 | 3 | 4 |
| | Sum 0'S | 1 | 2 | 4 | 3 | 2 | 5 | 7 | 2 | 3 | 1 | 3 | 5 | 3 |
| | Sum -'s | 4 | 3 | 1 | 2 | 3 | 0 | 0 | 2 | 2 | 3 | 1 | 0 | 0 |
| **Rank** | Net Score | -2 | -1 | +1 | 0 | -1 | +2 | 0 | +2 | 0 | 0 | +2 | +3 | +4 |
| | Rank (1=highest) | 7 | 6 | 4 | 5 | 6 | 3 | 5 | 3 | 5 | 5 | 3 | 2 | 1 |
| | Continue? No/Yes | N | N | N | N | N | N | N | N | N | N | N | Y | Y |

**Table 3. *Concept-Screening Matrix.* Muscle Body (dark shading) is the comparison case. Designs L and M (light shading) were selected for further investigation.**

design, and *impressionability* (the extent to which the design might make an impression on users after they engaged it). In the concept-screening matrix, the previous twelve concepts have been listed at the top of the table, and the criteria are listed on the left-hand side. The concepts are rated against the reference concept (The Muscle Body) using the following code: (+) for "better than," (0) for "same as," and (-) for "worse than," in order to identify particular concepts for further consideration (Table 3).

After calculating the sum of the *better than*, *same as*, and *worse than* attributes, a net ranking score was calculated by subtracting the "*worse than*" from the "*better than*" ratings. "Those concepts with more pluses and fewer minuses are ranked higher" [15]. The selected concepts were L: *Skin Wall* and M: *Skeleton and Skin*, both of which were considered further via low-fidelity prototypes at 1:6 scale for testing user interaction and usability.

## 4. Concept Resolution

Before developing physical, working prototypes of the design alternatives, L: *Skin Wall* and M: *Skeleton and Skin*, several aspects of the intelligent-monument concept required resolution, most importantly: (1.) the selection of hardware dedicated to actuating the robotic components of the monument; (2.) the manner of mapping the audio inputs (human vocal effects) to human emotion; and (3.) the manner of mapping human emotion to the colored lighting that we envisioned to be integral to the monument.

As for the first aspect to resolve, it was relatively straightforward to determine which hardware was most apt to actuate the robotic components of the monument. The research team selected continuous rotation servomotors for actuating both alternatives L and M, considering the formal character of these two designs, their anticipated range of behaviors, an economy of means, and overall system robustness, given the application.

The second aspect to resolve was how the intelligent monument maps an audio input (a human vocal effect), captured by its microphone, to a distinct human emotion. Clearly, the speech recognition system of Monumental-IT needed to be capable of differentiating distinct vocal emotions offered by each visitor via the microphone; but this aspect of concept resolution was a little more involved than was the specification of hardware for actuation. Towards resolving this mapping problem, we drew from research on vocal effects in natural and synthetic speech. While for robotic applications, Gibilisco categorizes vocal effects to just three frequency ranges or "formants" (f1 for frequencies less than 1000Hz, f2 for ranges from 1600Hz to 2000Hz, and f3 which ranges from 2600Hz to 3000Hz) [5]; Murray expands the vocal effects to seven categories (frequency, intensity, pitch, rate, quality, change in pitch, and articulation) [11]. For Monumental-IT, we found a a more apt middle-ground in Breazeal's characterization of vocal effects (for social robotics applications) in terms of frequency and intensity [3]. Focusing on only frequency and intensity to characterize vocal effects, and employing Murray's attribution of these effects to the four emotions – Fear, Anger Sadness and Happiness – we arrived at the following conceptual resolution for vocal effects employed in Monumental-IT (Table 4):

|  | Fear | Anger | Sadness | Happiness |
|---|---|---|---|---|
| **Frequency** | Very Much Higher | Very Much Higher | Slightly Lower | Much Higher |
| **Intensity** | Normal | Higher | Lower | Higher |

**Table 4. Vocal effects mapped to four human emotions**

The third aspect to resolve was to determine how distinct emotions might be mapped to the colored lighting that we envisioned as integral to the monument. While the team 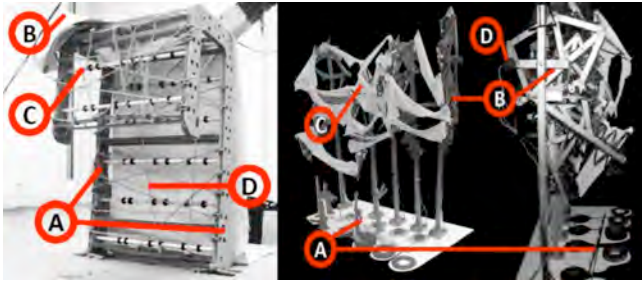was fairy confident in resolving the concept of vocal inputs just considered, we recognized "no general validity" in previous research efforts to associate color and emotion [2], [4], [7]. With no evidence to inform this aspect of concept resolution, the design team reasoned to tentatively assign the "vibrant" color red to anger, the "cold" blue to fear, "multi-colors" red, yellow, green, and blue to represent happiness, and white to represent sadness. In our iterative process of design, we tested our assumptions of color and emotion by means of surveying participants, who were asked to ascribe the four distinct emotions to images showing the color coding just described, superimposed onto the physical prototypes in the way the team envision they might be experienced. The results of the survey are presented later in this paper.

There were other aspects of Monumental-IT that were part of our concept resolution phase of design; what we offer here are three key aspects of the design that demanded resolution, and how we resolved them. What is clear and important to note from this and the previous stages of our design process so far considered, is that some design decisions were, for the team, more practical, some design decisions were evidenced-base, some design decisions were aesthetic, informed by design precedent, brainstorming and creative play, and some design decisions (e.g. our emotions-color mapping) were reasoned yet mostly subjective in those cases when the team could find little or no evidence for informing the design process. Recognizing these mixed circumstances endemic to complex design problems like this one, the design team took utmost care to address each design challenge of the iterative design process, employing whatever means to best inform the developing design of Monumental-IT.

## 5. Physical Prototyping

Prototypes of design alternatives L: *Skin Wall* and M: *Skeleton and Skin* were realized largely with digital fabrication tools in paper, cardboard, metal, wood, plastic and fabric as 1:6 scale models embedded with motors and lighting (figure 5). These physical, functioning prototypes were subjected to human-centered design methods to evaluate the usability of each design, to understand its different components, and to study robot actuation. Specifically, we employed heuristic evaluations involving "experts" in the domain fields of usability engineering, electrical and computer engineering, and architecture, and we also employed usability surveys. The aim of these investigations was to identify one of the two design alternatives for focused design development, and to better understand the potential of Monumental-IT as an intelligent, digital-physical, large-scale built environment.

The first prototype of design "L" was 60 cm wide and 80cm high made of corrugated cardboard sheets and Lycra fabric. The skin was actuated using nylon strings anchored at different points of the fabric at 15cm intervals. The strings were attached to three servomotors controlled by an
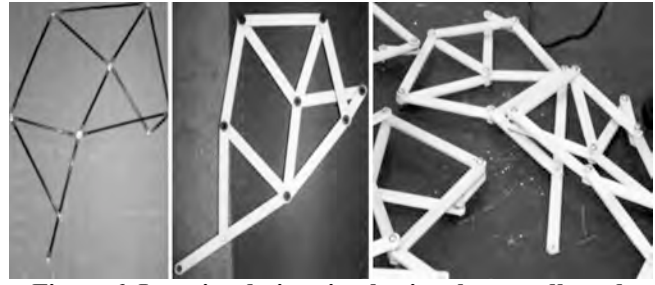
**Figure 5. First prototypes: alternatives "L" and "M"**



**Figure 6. Iterative designs in plastic tubes, cardboard, and wood. Laser-cut aluminum was finally used.**

Arduino microcontroller, programmed in Arduino [1].

Initial testing of "L" suggested that the various physical configurations afforded by the design were not adequately distinguishable to represent distinct emotional states. Also, it became evident that variable weather conditions, namely wind direction and speed, would significantly alter the behavior and legibility of "L".

The first prototype of design "M", at the same 1:6 scale as that for "L", was comprised of the key components identified earlier: microphones to capture users' speech; closed-loop, kinematic chain structures (hinged links) actuated by servo motors; elastic fabrics (skins) attached to the chain structure; LEDs, and Arduino microcontrollers, programmed in Arduino. At first, the chain structures were fabricated using plastic tubes (figure 6 – left); but we discovered that the tubes obstructed a clear path of rotation. Evidently, the linkage-hinge mechanical system of "M" required further investigation. Consequently, a second version was realized using corrugated cardboard which allowed for unobstructed rotation (see figure 6 – center). This second version served the purpose of allowing the team to study the behavior of the moving monument – the key intent of this earliest phase of prototyping; however, and as we half-anticipated, the cardboard structure was only adequate for the earliest phase of investigation, as the joints between linkages were not capable of supporting the dynamic loads of the moving assembly, and the friction caused by the joints of the second version hindered rotation.

In initial testing of the two prototypes, the various physical configurations afforded by the design "M" promised to be, more so than "L", sufficiently distinguishable to represent the distinct emotional states intended. As well, it became evident that 'M' would less likely be impacted by variable weather conditions as was "L". While these findings were not clearly evident from the design drawings (3D models) of "L" and "M" when explored across the twelve alternatives, the physical scale models of "L" and "M" availed to the team the dynamic, reconfigurable physicality of the two alternative designs, enabling us to arrive at the conclusion to exclude concept "L" from further study, and to focus our attentions on refining design "M".The hinged linkages of "M" needed further study. The next iterative prototype of "M" was made using wood linkages joined by

hinges of bolts and nuts. This iteration presented further challenges: the rotation of the mechanical system was retarded due to frictional force of the hinge assembly and its heaviness. We improved rotational speed through the implementation of smaller bolts and lighter materials (aluminum) for the linkages. These mechanical changes also served to overcome another critical challenge: the embedding of the motors compromised the structural integrity of the overall monument, particularly as the structural loading is dynamic. It was evident that the momentum of the moving structure affected the connections of the structural posts (masts) with the bases. To further improve the behavior of the prototype, the post-to-base connection was strengthened.

**6. Designing/Establishing System Behaviors**
By this point in the design process, we had identified a single design selected from a range of alternatives, we had adequately resolved its structural and mechanical systems for the purpose of prototyping, and we had resolved some number of key concepts (e.g. colored-lighting and vocal mapping to emotion). To further the design, the team established a combination of lighting and movement behaviors for each of the four emotions the monument was intended to exhibit. The strategy for displaying color has already been considered. The strategy for the monument's movements, its "choreography," was initially developed through lab discussions. Both color and movement were iteratively designed and evaluated by user studies as described below. As initially designed, the four modes can be described as follows and in figure 7:

"Fear" mode (i.e. the "blue configuration"), in which the blue LEDs turn on, and the hinged links atop masts 1, 3 and 5 actuate, alternatively, at very slow speed, one quarter rotation of the kinematic loop;

"Angry" mode (i.e. the "red configuration"), in which the red LEDs turn on, and all the hinged links (atop masts 1-5) actuate together, at full speed;

"Happy" mode (i.e. the "multi-color configuration"), in which the different LED colors randomly turn off and on, while the hinged links actuate, in succession (1-2-3-4-5), at normal speed; and,

"Sad" mode (i.e. the "white configuration"), in which all LEDs turn off, and the structural elements actuate in succession (1-2-3-4-5), in full rotations of the kinematic loops, at slow speed.



**Figure 7. Still images of the four modes as initially designed.**

**EVALUATION OF EARLY PROTOTYPE AND ANALYSIS**

Working from prototype "M" described above, heuristic evaluations and usability evaluation techniques were employed for further design development and evaluation of Monumental-IT. All evaluations were performed in our lab with user consent and IRB approval.

Participating in the heuristic evaluation were five "experts" from the domain fields of usability engineering, electrical and computer engineering, and architecture. On a form created by the team, experts identified problems with and made recommendations for each stage of engagement with the monument, from the first sighting the monument to leaving its physical site; the experts were then asked to rate the severity of each problem identified, using Nielsen's five Severity Rating Scale [12]: (0) no usability problem, (1) cosmetic, (2) minor, (3) major, or (4) catastrophic problem. The average severity ratings for usability problems were used to identify priorities for improving the design of Monumental-IT. From the completed heuristic evaluation forms, the research team collated, summarized and prepared a complete set of usability problems identified by the experts identified (Table 5). Following the heuristic evaluations, sixteen users (from the larger university community – students and faculty) were presented with the prototype performing the four modes in succession. Users were then asked to complete a survey aimed at providing feedback about the monument's design as presented in the prototype, particularly with respect to verifying our mapping of programmed mode (color, form and movement) to emotion.

We found that our modes, as initially designed, did not map well to the intended modes of "emotion" modes (table 6). Participants mapped: the blue configuration to sadness (rather than to fear); the white configuration to happiness

| Heuristic(s) Violated | Descriptions | Severity Ratings |
|---|---|---|
| Visibility of System Status | How do users know that the monument is waiting for their inputs? | 2.6 |
| | The users need priming to start getting involved. | 2.2 |
| | The skin doesn't offer much: it doesn't create an environment. | 1.6 |
| Aesthetic and Minimalist Design | Users don't know what to do next after speaking to the microphones or stepping on the footsteps | 2.2 |
| | The speaker and the footsteps are not integrated in the design of the monument. | 3 |
| | There is no need for an acoustic beep to indicate formal physical cue. | 2.2 |
| User Control and Freedom | The users do not know if the system accepts their voices or not. | 2.2 |
| | Do people need to reset a button after speaking to the microphones? | 1 |
| | The skin doesn't offer much: it doesn't create an environment. | 2 |
| Differentiate Monumental-IT's Configurations | The skin doesn't offer much: it doesn't create an environment. | 1.6 |

**Table 5. Usability Problems identified and rated following the Heuristic Evaluations of "Experts"**

(rather than sadness); and the multi-color configuration equally to sadness and fear (rather than happiness). The red configuration did, however, map well to "angry" as initially designed. Informed by these outcomes, the team re-mapped the configurations (or "modes") to emotions, accordingly.

The survey included, as well, a qualitative component. To the question, "*How would you describe Monumental-IT in one sentence?*" for instance, some revealing responses included: "making history interactive," "evolving and changing humans' identities in a way of representation," "making history interactive." Overall, user responses exhibited a very positive attitude for and appreciation of our developing prototype and, more broadly, our concept of a citizen-reconfigurable monument; nevertheless, one user had a less favorable view of our prototype, characterizing it as "a gigantic, confusing, whirling monster."
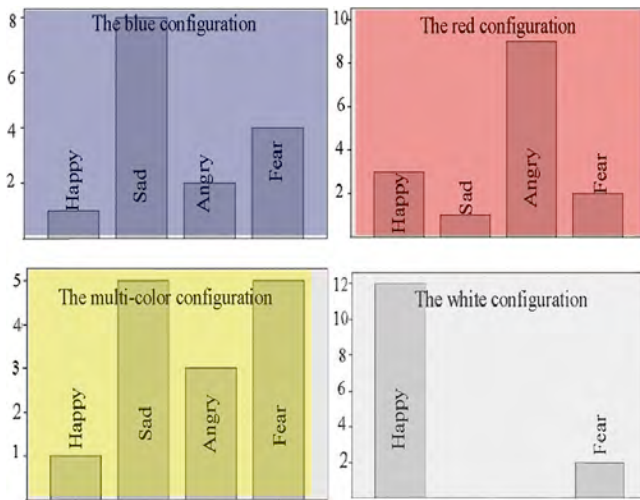
**Table 6. Numbers of users (y-axis) mapping a given modes to one of the four emotions.**

The learned lessons from this pilot study, focused on the early prototype of Monumental-IT, were the need to:

- Re-assign the movements and colors of Monumental-IT to their respective emotional states following from the outcomes of the user survey.

- Eliminate violated heuristics (minor and major violations) identified by "experts" by redesigning and implementing the concept again as a physical, functioning prototype at 1:6 scale. This includes, for example, re-designing the fabric "skin" components to be less capricious (decorative) and more space-making (to form more of a canopy over users).

- Include sound in subsequent prototypes, mapping sound to emotion as had been done for both vocal effects and color. Evaluate the effects of sound on usability and human-robotic interaction of Monumental-IT.

- Further refine the overall design of the Monumental-IT design by continuing the process of iterative physical prototyping and evaluation.

## CONCLUSION

For any design activity, the earliest stages of generating and evaluating design alternatives, and ultimately selecting one or more for further refinement, is a complex undertaking that has no single, agreed-upon methodology. When the design activity is focused on developing intelligent digital-physical artifacts at the scale of a room or larger, the undertaking can become daunting. We explored the early phases of such an undertaking, tracing the design evolution of Monumental-IT, a citizen-reconfigurable monument that invites people to engage and share, to ponder and interpret collective human history, locally and remotely. Our early design processes included, on one hand, design advances that were well-informed by User-Centered Design (UCD) approaches involving users throughout the design and development process [13]; on the other hand were our design advances shaped by the research team through regular discussion, brainstorming, creative play, and debating activities that drew from a multitude of inspirations.

After the early stages of design presented here, the team proceeded with further design developments of the prototype, informed by the learned lessons above as well as the same mix of methods. The final design outcome from the Monumental-IT project is presented in figures 1-4 of this paper as well as in our video of the project (its URL provided earlier). Our elaboration of these early stages of design, as well as the overall arc of the project presented in the video, are intended to inspire and guide interdisciplinary design teams (like ours), undertaking the inevitable challenges of designing room-scaled or larger intelligent, digital-physical environments. It might be said that the process of design elaborated here shares much in common with monuments themselves as cultural products of history.

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