BUILDING "COMMUN*IT*"— DESIGN AND EVALUATION OF A CYBER-PHYSICAL ARTIFACT FOR COMMUNITY ENGAGEMENT

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BUILDING "COMMUN*IT*"— DESIGN AND EVALUATION OF A CYBER-PHYSICAL ARTIFACT FOR COMMUNITY ENGAGEMENT

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Many subgroups in the US remain marginalized from, misunderstood by, or invisible to the larger communities they reside in. Technologies supporting community building, more generally, have focused on apps; but these apps can fall short of making visible and heard subgroups such as the LGTBQ+, immigrant, and black populations. In response to this shortcoming, we report on the design iterations and evaluation of communIT, a cyber-physical platform for making visible and heard, in public places, subgroups towards building community. To inform the design of communIT, we conducted in our lab a design studio study (N=57), a co-design activity with a to-scale prototype (N= 12), and a co-design activity with a full-scale prototype (N=28). These lab studies involving in-person participation by local university students and public high school students were followed by an online study (N=197) reaching out to subgroups across the US. We learned the following and more from these studies: preferences for communIT's design characteristics (i.e. form, embedded IT, and function); that communIT may be suitable and useful for diverse groups to share, engage, and interact; that communIT may make an impact on how the larger community perceives diverse groups; and that communIT may be helpful for groups to express their ideas, concerns, and aspirations to the larger community. Our research suggests the promise of large-scale, cyber-physical artifacts for making subgroups visible and heard towards community building.

BIOGRAPHICAL SKETCH

Born in a favela in Rio de Janeiro, Brazil, Carlos is the oldest of three siblings. He was the first in his family to complete a college degree, and the only one to graduate with a Master's and a Ph.D. After completing his Bachelor of Architecture and Urbanism from Universidade Estácio de Sá—in Rio de Janeiro, Brazil—Carlos moved to Seattle to start his M.Sc. in Design Computing at the University of Washington. Wanting to advance his academic career further, Carlos moved to Clemson University to begin his Ph.D. in Architecture. One year later, he moved to Ithaca, NY, to continue his Ph.D. in Design and Human Behavior at Cornell University. Carlos now begins a new chapter of his life at Champaign, Illinois: he now joins the Department of Industrial Design at the University of Illinois Urbana-Champaign as a tenure-track Assistant Professor.

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CHAPTER 1

INTRODUCTION

Local communities face daunting social, cultural, technological, and organizational challenges. In many local communities, subgroups such as the LGTBQ+, immigrant, refugee, and black populations are marginalized from, misunderstood by, or invisible to the mainstream of their larger, local community [3, 6]. Heightened social mobilization around racial and sexual discrimination are indicative of a polarized society; as much as ever, subgroups need support in getting their voices heard by and ideas expressed in the larger community. In this context, we ask: Can an interactive cyber-physical artifact support marginalized, misunderstood, or invisible subgroups generate media and make this media visible and "heard" in the larger community?

To begin responding to this question, this dissertation presents the design iterations and evaluation of "communIT," a cyber-physical environment [37, 38, 39, 54, 44, 17] for building community. The aim of communIT is to serve as a platform for subgroups of local communities to create and exhibit the products of this creation as a means of sharing with and building the larger community. Practically, communIT is a foldable, large-scale kirigami with embedded lighting, audio, displays, and other peripherals, that changes its physical form, lighting, and audio output to match the needs of community groups as they create media and exhibit these publicly within community public spaces. I was the student lead on all research activities elaborated in this thesis manuscript; however, I include in the "we" (i.e. the research team) referenced throughout the manuscript my three thesis committee (faculty) members and a number of masters and undergraduate students (largely from mechanical engineering and information science) that assisted with some studies reported here.

In our iterative design process, as reported in Chapter 2: Designing communIT, we conducted two co-design activities and to-scale and full-scale prototypes to explore communIT's design characteristics concerning its physical-spatiality, its embedded peripherals, and its functions. To evaluate our design, as reported in Chapter 3, we conducted a pilot study (N=28) with a local community partner and an online survey (N=197) with a broader range of the population. An online study was conducted instead of an in-person study (with participants drawn from the subgroups references in this thesis) given the "stay at home" mandate during the pandemic. From our in-lab and online studies, we found: (a) preferences for communIT's design characteristics (i.e. form, embedded IT, and function); (b) that communIT may be suitable and useful for diverse subgroups to share, engage, and interact with the larger community; (c) that communIT may make an impact on how the larger community perceives diverse subgroups; and (d) that communIT may be helpful for subgroups to express their ideas, concerns, and aspirations to the larger community.

For the design research community, this research offers an interactive design exemplar at large scale for community engagement. Moreover, the research reported here aims, in a novel way, to suggest the promise communIT has in "situating" community engagement, digitally and physically, in a physical space and time – a cyber-physical locus for building community – serving what Malcom McCullough, in Digital Ground, characterizes as "our basic human need for getting into place" [38].

Community Engagement and Object Agency

According to Dewey [9], community is not something which is an a priori given. Instead, community forms around issues that deserve consideration and debate. Building atop of Dewey's notion of community, Marres [33] states that community engagement occurs when people recognize, discuss, and collaboratively work on issues of mutual concern, as well as their consequences and connections. These connections, or "attachments" as Marres argues [33], involves the link issues have with the world—i.e. individuals, resources and objects in a community [33].

Marres' notion of attachments is based on Latour and Weibel's [28] concept of "object-oriented democracy": the idea that resources and objects are important for people's gathering around issues. Bringing an Actor-Network Theory (ANT) perspective, Latour and Weibel [28] advocates a symmetry between humans' and nonhumans' agencies in bringing about public matter issues. DiSalvo [4, 5], Le Dantec [31, 32], and Jenkins [27] further expand the discussion on the role objects have for building community. Jenkins, specifically, bring about a perspective in which objects—in his case, computing—should not merely be seem as augmenters of humans, but rather as participators—i.e. partners—in the creation and maintenance of public issues [27]. They argue that issues and their attachments not only arise from objects, but also give rise to them. Thus, the literature suggests that the sense of community arises from community engagement around issues, and that this community is not created around objects but rather with them.

Interactive Artifacts for Community Engagement

Within the design and HCI community, prior projects on how artifacts participate in community building have primarily focused on the development and evaluation of software and apps, mostly for smartphones and screens installed in public spaces. A relevant example is CRM [29, 30], a system composed of a mobile app and information kiosk that helps homeless people cope with several difficulties in a public shelter. Le Dantec [29, 30] points that CRM changed the existent socio-material relation in the shelter, reshaping the practice and dynamics of the staff and the residents. Such an effect renders CRM an empirical example of Latour's object-oriented democracy concept. The Cycle Atlanta [27] app is another significant example of an artifact that aims to cultivate community engagement. Bike riders use the app to input their trajectory and report issues on cycling infrastructure. The app participates in changing the relation between bike riders and the city administrators: the data generated by the collection of users is used by city administrator as a guide for infrastructure intervention. Besides CRM and Cycle Atlanta, other relevant examples are Memarovic's public display [35] stimulating social engagement among urbanites; numerous other displays situated in public spaces and used for community purpose (e.g. [36, 47, 2]), civic engagement (e.g. [46, 48, 11]), and media facades (e.g. [10, 9]) affording coordination and engagement of groups.

But while the examples above investigated the intersection between interactive technology and community engagement, they focus primarily on software and apps for two-dimensional screens on smartphones, kiosks, and building facades. Among the research efforts that focus on interactive architectural artifacts, some have investigated how urban dwellers interact with responsive urban installations (e.g. [40, 22, 23, 12, 7, 24, 45]); while others have reported on the design process for developing such artifacts (e.g. [20, 41, 15, 23, 8]); and how these artifacts can be used to entice group interaction (e.g. [11, 21, 13, 23]). Nevertheless, there is little research on what impact these interactive architectural artifacts, especially at a larger, "environmental" scale, may have specifically for community building through community engagement.

communIT—A Cyber-physical Artifacts for Community Engagement

Our motivation for communIT goes in tandem with the scholars' perspective about the role artifacts can have on community building as discussed above. In this research, "community engagement" is the public action—through communIT—around common issues that aims to bring about behavioral changes. communIT takes inspiration from the collection of projects presented above, especially the CRM system and Cycle Atlanta. Where we differ, however, is in the kind of artifact—a cyber-physical, architectural installation—given the lack of research on how such larger-scale, environments might impact community engagement. Another difference—in fact, a limitation of our research—is that, given the limitations imposed by COVID-19, we could not install and study communIT in situ for subgroup use and our study of the same.

communIT is an exemplar of "Architectural Robotics" [37, 38, 39, 42, 44, 17], meticulously designed, cyber-physical, interactive environments—from furniture scale to urban infrastructures. In practical terms, communIT is a kind of robot surface [18] similar to the AWE (Animated Work Environment) [26]. But while the AWE surface was a 1D surface (i.e. bending in section only), the communIT surface extends the surface behavior to 2D reconfiguration (i.e. a plane that folds like origami). With its 2D surface embedded with a large display, a white board, audio, and other analog and digital peripherals, communIT is a "system of interactive parts that affects us" [43] in the way the parts are "moved, carried, combined, … lined up, … and put back together in multiple ways" [43].

Architectural robotics has its roots in Nicholas Negroponte's vision of intelligent environments [42], William Mitchell's vision of "robots for living in" [39], and Kevin Kelly's imagined "ecology" of smart "rooms stuffed with co-evolutionary furniture" [25]. Architectural robotics follows, moreover, from Christopher Alexander's concept of a "compressed-pattern" room elaborated in A Pattern Language [1] to characterize the built environment, but since applied to cyber-human systems (e.g. [14]) and human-robot interaction (e.g. [16]). In short, a pattern language is a set of rules on how to materially configure a space in order to support a desired human behavior. The space, having a certain geometric and material configuration (i.e. function), will essentially "shape" human behavior. In a compressed-pattern room, all the functional rooms within a larger building occur within a single volume (one room). Following from Alexander's compressed-patterns, communIT is a robot surface physically reconfiguring (with embedded lighting, audio, sensors, and touch surfaces) to arrive at shape-shifting, functional states supporting and augmenting community building. Although communIT is not a room, it nevertheless shapes the geometric and material configuration of the space, changing the functions and uses of the room.

Lastly, communIT is also a manifestation of McCullough's [38] "Ambient Commons—" a digitally mediated and augmented built environment. For McCullough, the physical world—here, more precisely, the built environment—is a necessary condition for humans' experience of and interplay with things, including the digital world. McCullough explains that architecture has always been related with the flow of information. For instance, the inscriptions in the Church of Saint Trophime's facade (Figure 1) convey information and instructions for believers on how to behave. (The church façade's sculptures depict the Last Judgement.) Especially during a time when literacy was limited, a façade's sculptures was a way to convey information in architecture. McCullough points that the advance of the digital world yields buildings in which the digital and the physical world entwine (e.g. Living Light (Figure 2)).

To conclude, we envisioned communIT as an object-oriented democracy: an artefact as well as a resource that community members use to recognize, discuss, and share issues and their consequences. Specifically, communIT promises to support subgroups in creating media and sharing these media among others within the community. Through these media, subgroups might be able to express their issues, desires and aspirations among others At the intersection of this digitally mediated and physically constituted ambient commons, communIT promises to "situates" community engagement in the physical world as much as the digital word, serving in the words of McCullough "our basic human need for getting into place" [38]. communIT materializes McCullough's vision of "a tangible information commons" in which a "richer, more enjoyable, more empowering, more ubiquitous media become much more difficult to separate from spatial experience" [37]. Our longer-range goal is for communIT to serve as a platform for local community groups to co-create and exhibit the products of this co-creation as a means of sharing and building community.

Figure 1. The portal of Church of Saint Trophime, an old example of architecture conveying information.

Figure 2. The Living Light, a contemporary example of architecture conveying information.

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CHAPTER 2

DESIGNING COMMUNIT

My research objective was to design and evaluate a large-scale, cyber-physical artifact that might support community engagement through media creation and sharing. This chapter shares the whole design process of communIT. As in every design research where the goal is to create an artifact for an envisioned aim, the process for such creation is just as important—perhaps even more—as the artifact itself. Thus, the contribution of this chapter—as will become more evident in the Discussion section, Chapter 5—involves the set of design decisions we undertook throughout the design of communIT. Thus, this chapter offers not only a thorough description of the artifact and its functionality, but also how we developed these over time. The design trajectory is a form of knowledge that traces how we developed the artifact. For design researchers, this design trajectory is offered as a source to replicate, critically evaluate, and modify their own design decisions.

Some of these design decisions were deliberately taken, while others were not so much. One of the design decisions criticized by some committee members refers to the "participants" involved in the development of communIT. In short, communIT was designed with students from Clemson and Cornell University. These students are part of the envisioned groups of users for communIT. The main reason for using university students rather than other subgroups was the following: the research objective for communIT slightly changed after its design. Until its design completion, communIT aimed to increase social interaction and place attachment in underused public spaces by offering users a gathering space to create and share media. To design communIT, we selected students (by convenience sample) who were familiar with an underused public space in which we would install communIT, i.e. Ithaca Commons, a public promenade in downtown Ithaca. After the design of communIT, some members of the committee envisioned great potential for communIT to be used for a slightly different purpose: offering support to subgroups to make themselves visible and heard within the larger community by creating and sharing media. Exactly at this time, we connected to community groups that could offers us access to potential users of communIT other than college/university students.

This business of users has been exhaustively discussed with the committee members—composed of scholars from architecture and human factors, information science, and science and technology studies. One suggestion pointed to a complete redesign of communIT which was not feasible, financially (there were no extra funds for redesign) and due to time constraints. Another suggestion—the one we ended up following—involved evaluating communIT's final iteration with the envisioned end users. Although these focused user groups were not participants in the design process, communIT's functionalities promised to be relevant to them regardless. Specifically, communIT's goal to support users to create and share media still remained. Similarly, the goal to increase social interaction among users was still important for the new objective. As it will become evident in Chapter 3, many participants from the subgroups believed that communIT could offer a gathering space, a relevant attribute to create community engagement.

We believed that this note about users is relevant as the reader go through the design process described in this chapter. For those who want to replicate this research, a different selection of participants for the design might very likely yield a different artifact. What is not so certain is if such different artifacts will have a completely different impact on community building. Afterall, many times users appropriate artifacts in ways that designers cannot anticipate.

Iterative Design of communIT

What are communIT's key design feature to support community members in creating and sharing content with the larger community? To explore this question, we examined existing interactive artifacts that we believe were close to what we envisioned about communIT, and draw three key design considerations that informed our design. The first design consideration relates to the artifact's form and physicality/spatiality. Most of the research on existing artifacts includes non-buildings, such as urban furniture (e.g. [34]), architectural follies (e.g. [16]), large-scale screens (e.g. [44]), and large-scale installations [25]. The second consideration is the selection and placement of analog and digital peripherals on this superstructure, which often include embedded speakers and displays (e.g. [11, 44]. The third consideration involves the activities and interactions users would engage in when interacting with these artifacts.

We considered and explored these three design features throughout three design phases. In Design Phase 1, we further explored the elements that would comprise of this interactive artifact. In Design Phase 2, we investigated the ways in which communIT could shape the space, how people would occupy such space, and what kind of activities they would carry out. Lastly, in Design Phase 3, we explored the placement of IT elements onto the artifact's super-structure, and further examined the relationship between the artifact's physical configuration, its spatial arrangement and the activities caried out.

To approach our communIT design, we used Archer's [3] traditional design thinking process widely used in architecture [2], planning [33], art [22] and HCI [64]. This systematic design process involves the iterative dialog among four fundamental tasks: problem analysis, solution synthesis, presenting, and testing [29, 37, 38]. These four fundamental tasks will become more evident as the reader learns of each design phase. Still, to give a glimpse of each phase, in Design Phase 1, we conducted a design studio with architectural students to further find the key design elements of communIT. In Design Phase 2, we developed and applied CoDAS—a co-design methods utilizing scaled props. Our goal with this phase was to explore how communIT shaped its surrounding space, and how that spatial configuration of communIT could influence people's behavior. In Design Phase 3, we did a full-scale co-design activity to further study where the IT elements could be placed for certain activities. Each design phase provides more details on these. Lastly, we created a Scenario to illustrate an instance on how communIT might be used.

Design Phase 1: The Elements of communIT

Study 1: Early Conceptualization in the Design Studio.

Seeking multiple and heterogeneous responses to the design problem, we conducted a design study in which we recruited 57 architecture students (35 female and 22 male, convenient sample) from Clemson University, to design (individually) their own visions of communIT. This study was also part of one of the semester's assignment for these undergraduate students. Architectural students were selected because they could offer design clues about the space, form, and geometry of communIT. We presented to participants the three key design considerations outlined above: the artifact's form and physicality/spatiality, the placement of its electronic hardware, and the activities people would engage in. Then, I articulated to participants the design task: design an IT-embedded, non-building artifact at a large scale for a public space that brings people together, with the following three constraints:

1. Constraint-1: Support three activities: (1) creating and sharing media content, (2) playing, and (3) a third activity of their choice that they envision for the artifact.

2. Constraint-2: Embed IT components in the artifact.

3. Constraint-3: Enable physical reconfiguration of the artifact to support the activities in Constraint-1.

The constraints 1-3 mentioned above were design attribute from the key design precedent closest to communIT highlighted within the section "Iterative Design of communIT." As it is usual in the design of artifacts, design attributes "borrowed" from precedents tend to produces similar results. Some of these precedents supported community engagement by means of media making and sharing. This design attribute directly related to Constraint-1, activity (1) "creating and sharing media." This design attribute also related to Constraint-2, because the IT elements were the "digital" part of the artifact that allowed media making and sharing. As for Constraint-3, it is a key design feature of large-scale, cyber-physical, architectural-robotic artifact. The rationale behind this characteristic has been further presented in Chapter 1, in "communIT, a cyber-physical artifact for community engagement." As a short recap, Constraint-3 is one of the key elements that would make communIT different from other artifacts used for community engagement. Lastly, the data produced were physical models and drawings. We also recorded students' explanations of the projects.

Study 1: Findings.

The data included the designs produced by participants, and their explanations and rationales for the designs they produced. We analyzed the data looking for design clues that could inform communIT's design. Specifically, we paid attention to design clues related to the artifact's shape, geometry, and functionality. We noticed two predominant architectural typologies [30]: blocks and partitions (Figure 3). For the block typology, one participant described that "*each [block] of my design can be* *pulled apart into several differently shaped forms.*" For the partition typology, another participant described "*wall-like [partitions] that define and separate spaces.*"

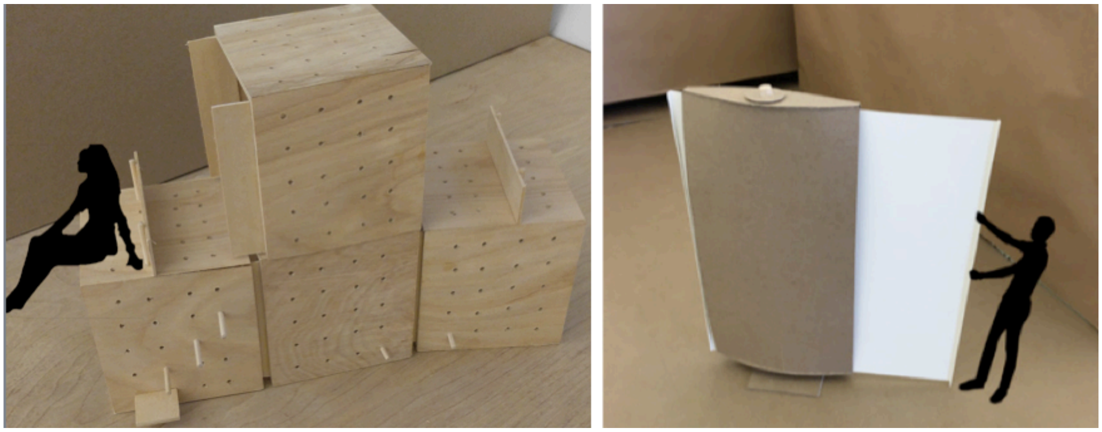

Figure 3. Designs that came out of Study 1 fell into one of the two typologies: blocks (left) and partition (right).

Most of designs generated by participants had elements that included a wall, a bench, a table and a canopy. Many designs afforded physical reconfiguration of the space, although few choose not to do so despite the requirement (Constraint-3). In the designs that did reconfigure, physical reconfiguring involved rotation, sliding, hinging and folding. Many participants expressed enthusiasm about the physical transformation of the spaces afforded by their design, as expressed by one student: "A transformable space seems more intriguing than a static one because it gives users a choice." Another participant remarked on "*opening each flap, and changing the landscape and function of the place while discovering different uses. The space you saw yesterday may be a different one today.*"

Similar to previous work [35], some participants suggested that communIT could be used to create and share content: "People could use this space to study, work and share ideas with others. We could, for instance, share a video about a project we created.” Participants suggested that communIT could be used to support socializing (e.g., [15]) and leisure (e.g., [13]); as one participant described: “*By having my object on site, people will be encouraged to stop and socialize rather than just going through the area. I would like to see it as a dynamic, social space where people meet and spend some time together.*” In addition to audio systems (e.g., [31]) and displays (e.g., [32]), included in similar systems in previous work, IT embedded in the designs produced by students included the Internet (e.g., [36]) and ambient lights (e.g., [25]).

<u>*Design Iteration 1.*</u>

Informed by these findings, we refined Constraints 1 and 2, and added Constraint-4 for exploring the design of communIT:

1. Constraint-1: Support for four activities: (1) creating and sharing media content, (2) playing, (3) socializing, and (4) leisure/relaxation.

2. Constraint-2: Embed IT components in the artifacts, including displays, audio systems, Internet, and ambient lighting.

3. Constraint-3: Enable physical reconfiguration of the artifact to support the activities specified in Constraint-1.

4. Constraint-4: Consider two typologies: blocks and partition.

As already discussed before, Constraint-1 promised to be one of the key element to support subgroups in community engagement. Specifically, the activity “(1) creating and sharing media content” is communIT’s main affordance for such a goal, as subgroups engage with others in the community through media making and sharing. Activity “(3) socializing” is also relevant for this matter. As already mentioned, it will become evident in Chapter 3 that participants from the number of subgroups found that communIT could offer a gathering space for socialization, and that this characteristic was relevant for sharing aspirations among themselves and also to others in the larger community.

We explored different candidate design concepts, one for each of the two typologies (Figures 4). Both our “partition” and “block” designs followed the constraints above mentioned, including movable aspects that transforms the space and consequently, the kind of activities community members might perform.

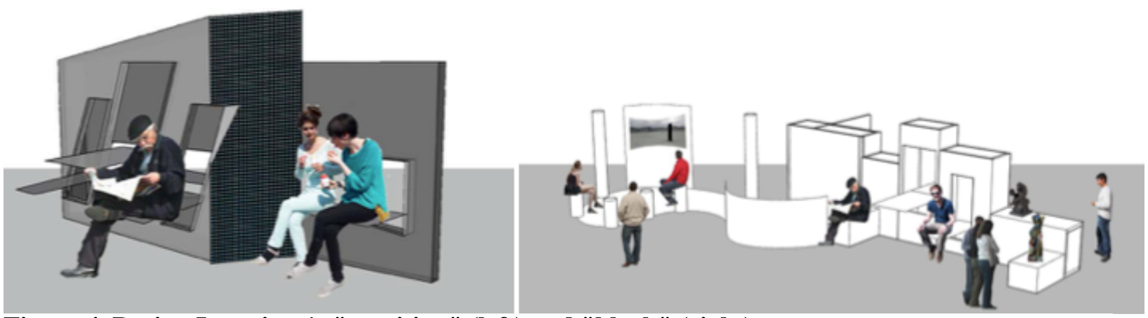

Figure 4. Design Iteration 1: "partition" (left) and "block" (right).

Design Phase 2: Space, Occupation, and Activities

Advancing communIT’s Design with CoDAS—a Method for Envisioning Large-Scale, Cyber-Physical Artifacts.

Our two early designs from the first design iteration led us to consider the relationship between the artifact’s attributes, the physical space it creates, and the location of people’s activities. More specifically, we wanted to further investigate (a) how people occupy the environment made by communIT? (b) How can communIT support their activities? As in Christopher Alexander’s A Pattern Language [1], we wanted to further understand how the material form and attributes of communIT could influence people's behavior.

Large-scaled cyber-physical artifacts like communIT arrive with critical concerns of cost, material choice, design requirements, fabrication means, and their need for municipal permitting if installed in certain ways for robust, safe use, power, and resistance to vandalism and the elements [8]. Given the complexity of realizing larger-scaled artifacts, conventional design methods prove inadequate and potentially costly and dangerous if researchers move too quickly to full-scale prototyping of these. Thus, to further advance communIT's design, we developed a hybrid methodological approach for early design exploration, CoDAS (Co-Design At Scale) that combines elements of established HCI methods—co-design [7] and user enactment [8]—to effectively develop larger-scale cyber-physical artifacts. While others [4, 7, 8] have used these methods to design various types of physical artifacts, few have used this approach to design interactive, large-scale artifacts. CoDAS has three main principles: participants co-design with researchers using a small scale-model of the artifact; participants co-create with researchers use cases as opposed to encountering and enacting scenarios prescribed by the researchers; and participants engage in user enactment within the small-scale model, following from the design and the use cases (i.e. scenarios) co-created.

The key virtue of CoDAS is that is affords the early design exploration of the larger-scale interactive systems enabled by the use of a physical, tangible scale model of the artifact and its surrounding physical environment. CoDAS allows researchers to (a) design attributes and affordances of a system, and (b) observe the environmental behavior and socio dynamics around the designed system. This permits researchers to think "big" (literally and figuratively) and also at a lower cost (of time, money, physical effort, etc.) when compared to conventional design methods. We will first describe the development and validation of CoDAS and then move to present how we used it for advancing communIT's design.

CoDAS, A Hybrid Methodological Approach.

CoDAS takes inspiration in the design methods and thinking of others in the HCI community: McCullough's concept of "Ambient Commons," [9] which recognizes the role of existing physical environments as the ground for the digital [10]; DiSalvo's "Civic Design" [5] and "Civic Tech," [12] which extend HCI to the wider life of the public but is focused much more on data rather than on the cyber-physical; Dourish's "embodied interaction," [14] defined by a phenomenological approach; and Forlizzi's design-focus on human interaction with robots [16] and, more broadly, interactive artifacts [17]. Within this intellectual field, our approach fills a gap in its attention to computer-embedded, social and collaborative artifacts of larger physical scale, and the interactions they afford, which we recognize as a significant manifestation of emerging HCI and mechanical engineering inquiry.

Co-design and Co-creation: Co-design derives from the Scandinavian participatory design tradition [18] and involves the practice of collective creativity applied by designers and non-designers when working in collaboration throughout the design process. Co-design aims to include a wide range of stakeholders, including end users and those who will be directly and indirectly affected by the products, in informing, ideating, conceptualizing, and contributing to design decisions based on their collective understanding of the cultural and societal scenarios [7].

Co-design is especially appropriate for the conceptualization of the design of large-scale public systems since involving people who would eventually encounter and use these systems helps transform a *space* into a *place*. As Yu-Fi Tuan describes it [19, p. 6]:

> *"Space" is more abstract than "place." What begins as undifferentiated space becomes place as we get to know it better and endow it with value. [...] Furthermore, if we think of space as that which allows movement, then place is pause; each pause in movement makes it possible for location to be transformed into place.*

User Enactments: The second HCI design method included in CoDAS is User Enactments (UE), first defined by Odom et al. [8], and later included in a design-method practitioner handbook [20]. In UEs, "designers construct both the physical form and the social context of simulated futures, and ask users to enact loosely scripted scenarios involving situations they are familiar with as well as novel technical interventions designed to address these situations" (p. 338). UEs however require considerable time, effort, and a full-scale physical site or voluminous lab to develop the physical form for the scenario enactment.

CoDAS, instead, preserves the spirit of UEs by creating a physical space for enacting a future scenario with the purpose of gaining insights into designing new interactive systems in emerging design spaces, but uses a small scale model of that space and its design elements, and small scale human figures to represent people in that space. As we will see in the case study that follows, participants enacting a scenario by moving the human figures in the scaled space were able to project their imagined behaviors (physical and even mental) onto the human figures.

Combining Co-design with UEs in a Social Setting Framework: A social setting framework [21] serves as the basis for combining co-design and user enactment activities. According to Lofland's social-setting framework [21], every social setting involves actors engaging in activities with others in a certain space. Recognize that these actors may or may not be human—that "actors" can be the physical and digital artifacts that are integral to interactive behaviors. In constructing this social setting framework, we ask the following environmental-behavior question: "who does what with whom using what in which setting?" [23].

The construction of such a framework requires designers to define all or at least most of these constructs (i.e. actors, activities, objects, settings) in a way that delineates the scenario under investigation. The pre-definition of such constructs will depend upon the research question. In our case study discussed below, we initially wanted to understand the activities people would mostly engage in within an urban, outdoor, public space. Given our questions, we were able to pre-define the actors, setting, and typological design elements, leaving the activities and the particular aspects of the designed artifact open for participants to select and define.

Procedures.

Scale Model Fabrication: CoDAS involves the use of scaled models as a basis for co-design, co-scenario creation, and user enactment. The elements defined in the social setting framework are fabricated in the scale model and used by participants throughout the design study (Figure 5). Participants use the scaled elements to communicate their design ideas and to enact the scenarios they co-create with researchers. For the us, the scale model is a means to capture both the physical artifact and the scenario participants envision without the need to realize a full-scale prototype and/or to be situated in its intended and actual physical surrounding (i.e. the site).

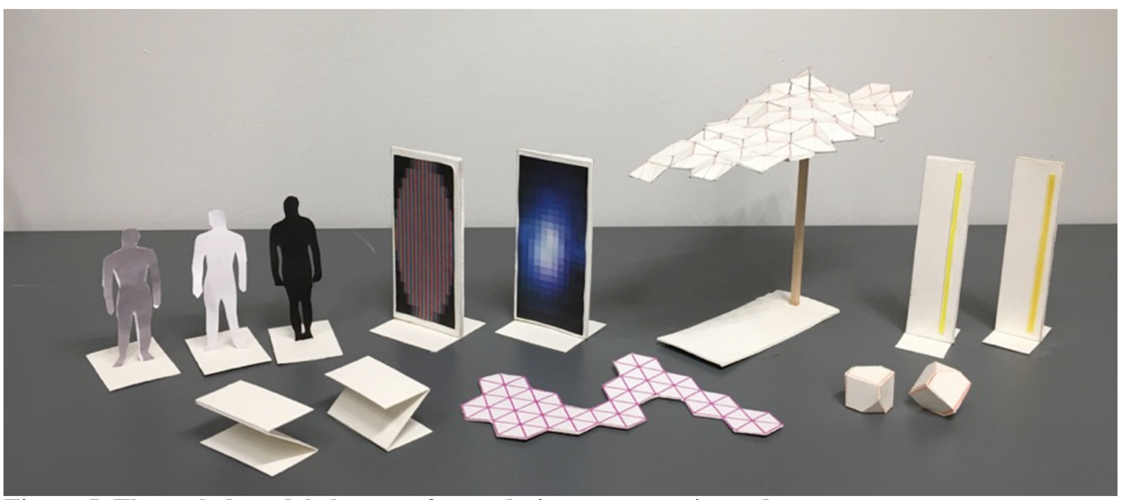

Figure 5. The scaled-model elements for co-design, co-scenario, and user enactment.

Co-design and Co-creation: Following the fabrication of the scale model, the research team invites participants to the lab to engage in the co-design of the space and co-creation of the scenario (Figure 6). The researchers ask participants to design the environment to support opportunities for different activities and experiences by positioning the scaled-elements and actors in the scaled model of the targeted environment (the site). For example, if the intended large-scale artifact is a singular body (as in a kiosk), then a reduced-sized facsimile of the kiosk is positioned in the scale-model of the environment (e.g. a corridor within a building, or a stretch of the main street with its road, sidewalk, lighting, and building facades).

Using the design and actor elements in the context of their surroundings, the participant(s) work collaboratively with the researchers, again following from the questions the researchers wish to answer in the course of the study, to design possible interactions and experiences in the space. Through this design activity, one or more scenarios take shape as well. The meaning-making process within the physical co-design and scenario co-construction can be captured via recorded audio and video and via photography throughout the activity. Alternatively, after the participant(s) complete the design and scenario co-construction activity (according to whichever parameters, as defined by the researchers), the researchers may conduct a semi-structured interview asking participants to explain their designs and scenarios.

User Enactment: The next step involves participants enacting the scenario(s) they formulated in the previously described activity. In the UE activity, each

Figure 6. Three instances of co-design activity, using scale-model elements.

participant assumes (i.e. plays) the role of the actor(s) in the scenario as an enactment of how they would approach, appropriate, use, and move through and about the space. Participants use pre-fabricated, scaled human figures to stand in for themselves and others within the physical space and social setting.

Using the scaled human figures, participants then enact the scenario they co-created within the space they co-designed: its situations, how the proposed artifact(s) in their surroundings are occupied and used, which actions the participant would undertake there, and how the participant might interact with other people also present there (i.e. the additional actors represented by scaled human figures). As participants go about the user-enactment procedure, they are asked to "think aloud" in order to uncover participants' behavior and attitudes, emotions and feelings, experiences, perceptions, and understanding.

CoDAS yields qualitative data through photos, video, and audio recording as participants and designers interact with the scale model and enact the scenarios and activities they have defined in the model. This allows research teams to use their own best practices of qualitative data analysis to sort, categorize and identify important relationships [24]. These insights can later be used as resources for designing the full - scale collaborative system.

<u>*CoDAS Validation:*</u> From the transcribed audio of the Study 2, it was clear that participants were able to project their imagined behavior to the scaled human figure (an actor). When referring to the human figure they were embodying, participants

frequently uttered descriptions of the scene that began with reference to “I,” as for example:

> *I would first approach this [aspect of the design] and look at the screen or floor and, if I found something interesting [there] I would stay; if not, then I would move to this other [aspect of the design].*

The use of the first-person here suggests that the participant personified the scaled human figure and transferred her or himself to the role they associated with the human figures when engaging in the user-enactment. Similarly, participants use of the impersonal “you” referring to “anyone” suggests a personification of the scaled human figures—the imagining of real people engaging in interactive behavior, as in “*space allows you to do things that you don’t know yet.*”

Participants could also transfer agency to the scaled human figures, as suggested by another transcribed fragment “*I would observe these people as I move, but not get close to the spot occupied by them.*”

Here, the participant explores an emotional response accessed through the positioning of the enacted actor relative to a grouping of other scaled figures the participant placed in the scale model. There is, moreover, evidence of embodying the scaled figure and physically moving through the designed environment:

> *You continuously move to the center. The periphery creates a path… It's like climbing a mountain: the fun moment is not directly given by the story-- you explore it by yourself.*

Here, the participant offers, by way of an analogy, the mental leap from scale model to what they could imagine doing in the full-scale design, in the world, using their own will and body.

As suggested by these various excerpts drawn from the audio transcriptions of the Study 2, there is an equation the participants construct between themselves and the scaled human figure, where they project their imagined behavior to the human figure as they engaged in the user-enactment activity.

Study 2: Designing communIT with CoDAS.

We used CoDAS to advance communIT's design, co-constructing with participants an understanding of the artifact's attributes, the physical space it creates, and the location of people's activities.

Social Setting Framework for communIT: Our social setting framework consisted of four constructs: (a) actors under three conditions, (b) six distinct design components, (c) activities, and (d) the existing urban site accommodating the actors and design elements. We detail these below:

(a) For the human actors, we defined three conditions: actors alone, actors with people they know, and actors with strangers. This follows from [26] which suggest that people behave and engage differently in a space depending on whether they are alone or accompanied by others. As such, we wanted to gain insights into participants' projected behavior and experiences across the three distinct actor-conditions.

(b) We defined six design elements—canopy, floor, screen, bench, table, and light (Figure 5). These six elements were representations of the key design elements recurring in the designs by participants in Study 1.

(c) For activities, we created a list of fourteen activities we envisioned people might engage in within an outdoor space, including, for instance, reading, studying, playing, talking, listening to music, working, etc. In order to narrow down the initial list of activities, we conducted a survey with 41 participants (28 university students, 3 university faculty members, 2 university staff; and 7 others from outside the university, ages 16-68, 19 males, 22 females). Participants were recruited through our social networks (a convenience sample). We showed participants generic images of different public spaces and asked them to select the activities they would prefer doing under the three different actor-conditions in each space.

(d) The physical site selected was is an outdoor urban public space that is currently underused.

Constructing the Scale Model: Following the definition of the social setting framework, we physically fabricated the actors, the design components, and the physical site as a scale model using a combination of manual and digital fabrication tools.

Study 2 Procedure Using CoDAS: We invited seven participants (a convenience sample of university students, ages 18-30, 5 males, 2 females) to our lab to engage individually with the researcher team in our approach. We described each of the six design components, presenting on a large computer display a photo of each modeled component as well as a video of its potential interactive features. For instance, a photo of the modeled canopy was displayed along with a short video that communicated the kinds of interactive features. (Figure 7).

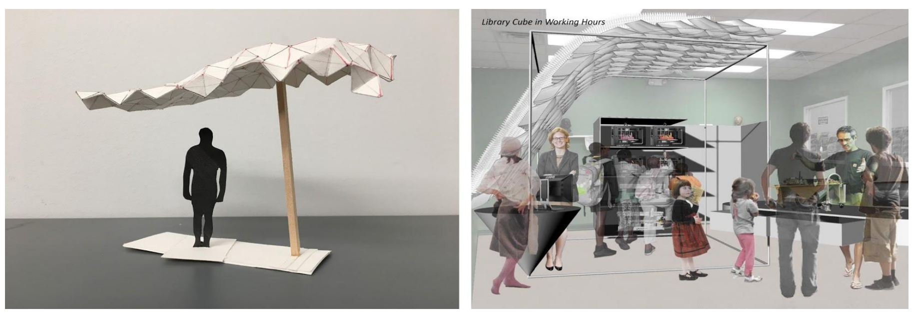

Figure 7. A model of the canopy component (left) and on still from a video showing a physical shape-shifting canopy, to show the intended behavior of the canopy component.

Using the components and the human figures described above, a participant and a single research team member co-designed three different environments and drafted scenarios of actor-interactions for each of these environments. For each co-design, co-designers started the design process by picking one activity corresponding to the actor conditions; the co-designers then positioned, in the physical site model, the scale-modeled actors and design components to yield a design and an interaction scenario defined by this action. The co-design sessions, which included the co-designers' "talk aloud," were audio-recorded, the resulting designs photographed, and the scenarios saved as a text document.

Following the construction of the design and scenario, we asked each participant to engage in enacting the scenarios within the spaces they defined using the human figures. We asked participants to think out loud while enacting the scenarios. During the user enactment activity, the co-designer from our research team would sometimes prompt the participant-co-designer with questions such as, *What are the actors doing at this instance in the scenario?*, to help focus the participant co-designer on the impacts the designs and scenarios have on their actors' behaviors, experiences, and emotions, and how these actors are negotiating this place and any other actors. The research team used the qualitative software program to organize, analyze, and generate insights out of the data gathered.

Study 2: Findings: The co-design study yielded 15 different design candidates. We analyzed these designs looking for possible indications about the physical organization and affordances of communIT. All 15 designs proposed multiple

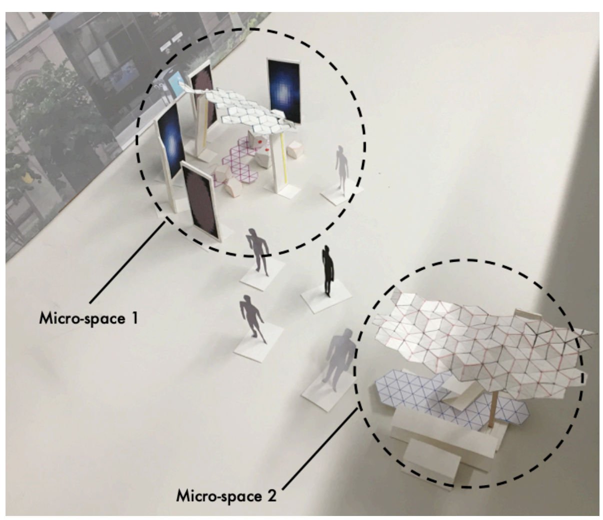

Figure 8. One of the co-design outcomes of Study 2 with two distinct micro-spaces.

activities, and all divided the space in the physical site into micro-spaces, each matching an activity it supported or augmented. These micro-spaces were created using various combinations of the small-scaled props (Figure 8).

We found that each micro-space had different attributes, such as ambiance and levels of permeability and privacy. For instance, micro-spaces designed for group activities were bigger and with fewer physical boundaries compared to those designed for individual activities (Figure 9). One participant described the individual micro-space shown in Figure 9 (left): "*I imagine this as a quiet, confined place, with these elements [canopy, wall] blocking direct contact and giving some privacy.*" On the other hand, the group micro-space in Figure 9 (right) was described by another participant as "*a fluid, semi-fixed structure, not well defined…to allow more people to get in.*"

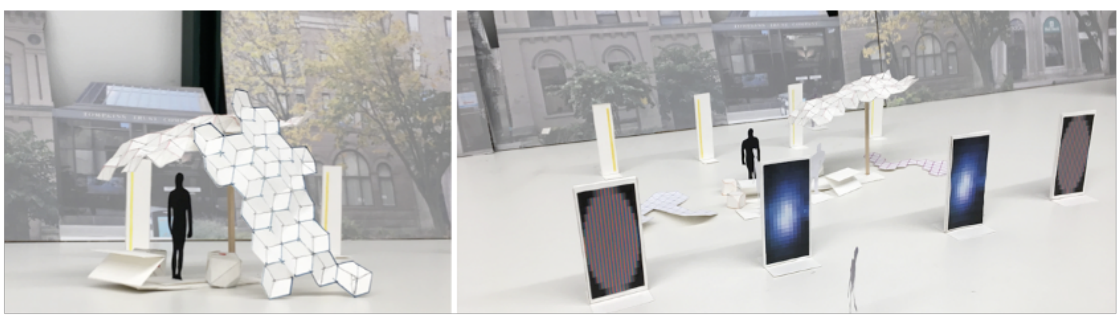

Figure 9. Two micro-spaces: one for individual activity (left) and one for group activity (right).

Some participants were especially thoughtful about the location and proximity of the micro-spaces they created. For instance, one micro-space designed to support "studying" was positioned close to another one designed for "working," but far from a third micro-space created for "playing." When asked about the potential of their designs for creating community engagement, many participants seemed positive; for instance, one participant envisioned people "*getting connected with the [artifact] and with what others are doing within [it].*"

Another participant offered: "*the interaction would spring from the setting because of the installation: the screens and the interactive ceiling would create an inviting atmosphere for socialization. The interactive lights work as a portal, where people enter in the social mode.*" These accounts reflect the co-designers' hypothesis that communIT would attract people and foment social interactions which, to us, implies community engagement within the physical space. In sum, Study 2 yielded additional information about the physical constitution and arrangement of the cyber-physical space, and its correlation with certain activities people envision engaging in. We did not, however, find evidence of relationship between each activity and the IT elements within each micro-space. This suggested that the same IT elements could be reused to support multiple activities.

Practical Advantages of our Approach: In practical ways, CoDAS offers distinct advantages as compared to other HCI methods that might be used in the early stages of the design of larger-scale social computing artifacts. Permission from municipal authorities to conduct early-stage in-situ study of full-scale prototypes is extremely difficult to secure. The same can be said of securing approval for the same research involving human participants by IRB boards. Full-scale components are meanwhile costly and difficult to manually manipulate by co-designing participants due to their size and weight, very likely limiting the exploratory design space of the investigation. The smaller scale, meanwhile, permits the design team and its participants to have an overall understanding of the many components involved, as well as more comprehensive understanding of the physical site, at low cost, and with a very low hurdle for IRB approval.

Design Iteration 2: We used the findings of Study 2 to once again refine our design constraints, this time adding a fifth constraint—create micro-spaces and consider how they support the activities. Following our new list of constraints, the team engaged again in our own design of communIT. Our goals in this iteration were to (1) further investigate the physical form of communIT and the affordances of each of its configurations; and, (2) explore the creation of various micro-spaces and the location of the IT elements within them.

We engaged in exploring different combinations of positioning, combining, and clustering of the different props to yield micro-spaces that matched the human activity envisioned for the artifact. At this stage, designers could select the aesthetical language they believe appropriate to their designs. In our case, we took inspiration from origami and its variant kirigami—origami that, as a rule, allows for folding and cutting along the lines of the folds. We explored how kirigami changes the affordances of the artifact to create various micro-spaces. Figures 10 and 11 show some of our design explorations of the block and partition typologies using kirigami; for the block concept, we pulled apart the resulting kirigami to create the blocks.

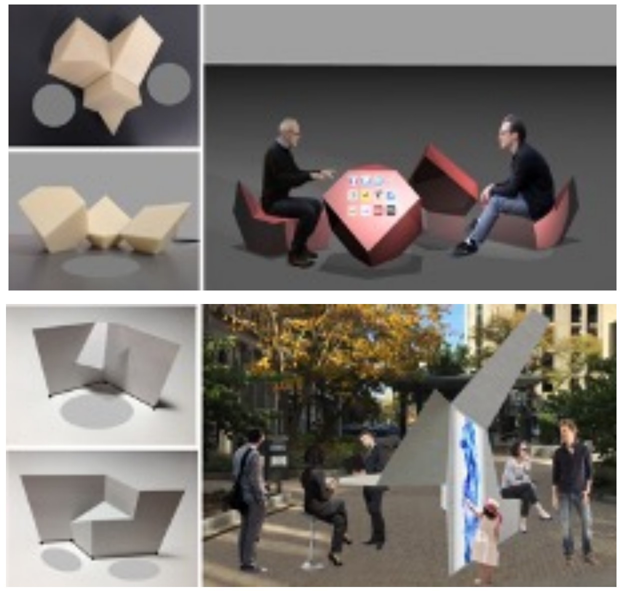

Figure 10 and 11. Design exploration of blocks (top) and partition (bottom).

We critically reviewed both candidate designs, being mindful of the design constraints and the core objective of community building, and chose the partition concept following the rules of kirigami to further iterate. Two key shortcomings of the block design were: (1) its relative incapacity to readily define micro-space boundaries; and (2) its relative incapacity to create micro-spaces using a limited number of blocks. Two key strengths of the partition design using kirigami were: (1) its economy in making micro-spaces—one plane, when folded, can accomplish much of what we sought in a configurable design; and (2) its capacity to serve as, at once, a functional and a sculptural artifact that may prove enticing to those encountering it.

Design Phase 3: The Artifact's Physical Configuration, and the Spatial Positioning of IT and Activities.

Study 3: Co-design with Full-Scale Prototype: Following from Study 2 and our Design Iteration 2, we aimed to understand possible configurations of the prototype, including folding and positioning of analog and digital hardware, and the activities these configurations afforded. At this stage, we fabricated a full-scale wooden prototype of our Kirigami option for the Design Iteration 2 (Figure 12). We also fabricated the full-scale analog and IT peripherals. To allow quick mounting and unmounting of larger, more cumbersome, or otherwise costly peripherals (e.g., a large display), we used a printed image of the peripheral mounted to a rigid, lightweight panel.

Figure 12. Participants reconfiguring the full-scale communIT prototype.

Peripherals included displays, speakers, lights, and even coat hooks and clocks. Altogether, we included multiples of 15 different peripherals to locate on the prototype superstructure. We used Velcro for quick attachment of peripherals. We recruited 28 Cornell University students (18 female, 10 male) to participate in fifteen 30-minute sessions, with two participants per session. We positioned the prototype in a public outdoor space of the Cornell campus for the study. Given weather conditions, we moved the prototype to an indoor public space for about half of the sessions. At the session, we introduced participants to the prototype and the peripherals and asked them to: (a) physically manipulate the prototype's moving panels, determining the ideal physical configuration to support a specific activity (e.g. sharing content); (b) attach the peripherals onto the prototype's surfaces to communicate to us which peripherals would support a given activity, and where the peripherals should be located to best do so (Figures 13, 14, 15, 16).

Study 3: Analysis and Findings: The data collected consisted of photos of the participants' designs and notes taken by a researcher assistant during the co-design activities. We analyzed the data collected from the 15 different designs produced in the co-design activity using MaxQDA software. In the process, we followed an open-coding approach [39], moving from codes to categories to themes to statements. We iteratively read through the notes taken and correlated those with the participants' designs. We highlighted excerpts and identified insights, themes and recurring patterns in the data, finding five recurring design patterns. Each design pattern suggested a particular relationship among the following elements: the physical configuration of the artifact, the size of micro-spaces, the activities participants would engage in, and the positioning of the peripherals on the artifact's surfaces. These design patterns are analogous to the pattern language elaborated in Alexander et al.'s A Pattern Language [1].

Figure 13 depicts what we call Design Pattern 1. On the left is the actual design, and on the right a corresponding schematic drawing (top view) that we created to synthetize this pattern. The gray bubble in our schematic drawing refers to the micro-space—the area of influence of the Design Pattern. In Design Pattern 1, the artifact was configured in an upright position (i.e. all panels folded to form a wall-like structure). Participants ascribed the following activities to this configuration: sharing content (e.g. presenting and lecturing), playing videogames, and watching movies. The IT elements selected were displays and an audio system. In addition to these elements, a few participants who created designs relating to Design Pattern 1 also positioned a white board to scribble and draw.

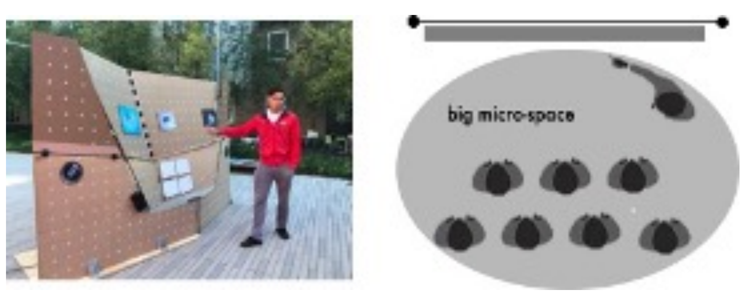

Figure 13. Design Pattern 1: Student's design (left) and our corresponding schematic drawing (right).

One participant described this as, "*a huge interactive wall that people can use to present work and ideas to others.*" When asked to further elaborate on how people used his design (Figure 13, left), and how many people would engage with the space, the participant offered that, "*...for instance, a person can give presentation to a group of people there [pointing at spot few feet afar, in front of the artifact], let's say 6 or 8* *people… but people can also use this as a huge screen to watch a movie… or they can even use this as an interactive screen to make artwork.*"

Figures 14 and 15 show designs that reflect Design Pattern 2. A participant in session 6, described the configuration in Figure 14 as "*a big-shared table to work and study.*" Another participant (session 8) with a similar design had an expanded view of its functionality, stating that "*I don't want the space to be 100% for study only; people can sit here and socialize. [It's intended to be] more open, more social.*" Design Pattern 5 is similar to Design Pattern 2 in terms of physicality. However, the two patterns are different in terms of activities and space scale. The similarity and differences are illustrated in Figure 16.

Overall, Study 3 advanced our understanding about communIT's three main components: the physical and spatial arrangement of the artifact; the activities people would engage in with the artifact; and the location of IT hardware on the artifact. This understanding is summarized in Figure 16, which presents a schematic of all five Design Patterns resulting from the co-design activity of Study 3 (note, in the figure, the use of color to code the different micro-spaces that define each of the five Design Patterns).

Figure 14. Design Pattern 2: student's design (left) and our schematic drawing (right).

Figure 15. A researcher and two participants co-designing the location of IT elements.

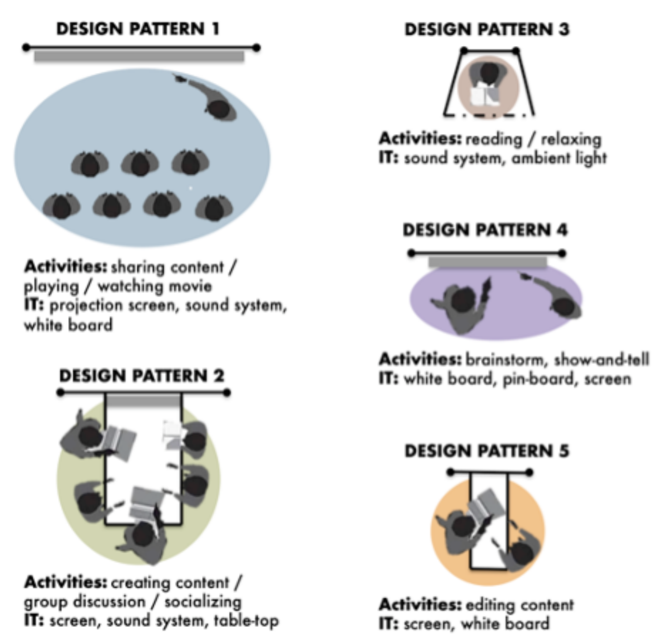

Figure 16. The five Design Patterns found in Study 3.

Design Iteration 3: We used the five Design Patterns found in Study 3 to, once again, reiterate our own design of communIT. Our main design objective was to create a reconfigurable kirigami artifact that could capture the characteristics of the five Design Patterns in various combinations. After extensive design exploration using a cut-and-fold paper technique, we reached a design candidate that we judged met this objective and the various constraints as developed over the course of the various user studies and design tasks. The judgement of the design candidates involved the research team of students and faculty members through several weeks. Figure 17 illustrates an instance of these meetings where a subgroup of the larger research team considered the potential of each design candidate.

Figure 17. Keith Green, Jon McCkenzie and Carlos Aguiar analyzing the potential of the design candidates.

We named this iterated design of communIT, “Design Iteration 3” (Figure 18 and 19). Each physical configuration of Design Iteration 3 yields different combinations of the five Design Patterns, and consequently different arrangements of activities, micro-spaces, and attributes. For example, “configuration 1” has a combination of four different Design Patterns, each with their own activities, micro-spaces, and information technology components embedded in it. Figure 15 depicts the plan and elevational views of our iterated design, Design Iteration 3 configured as what we call configuration-2 that combines Design Patterns 2-5.

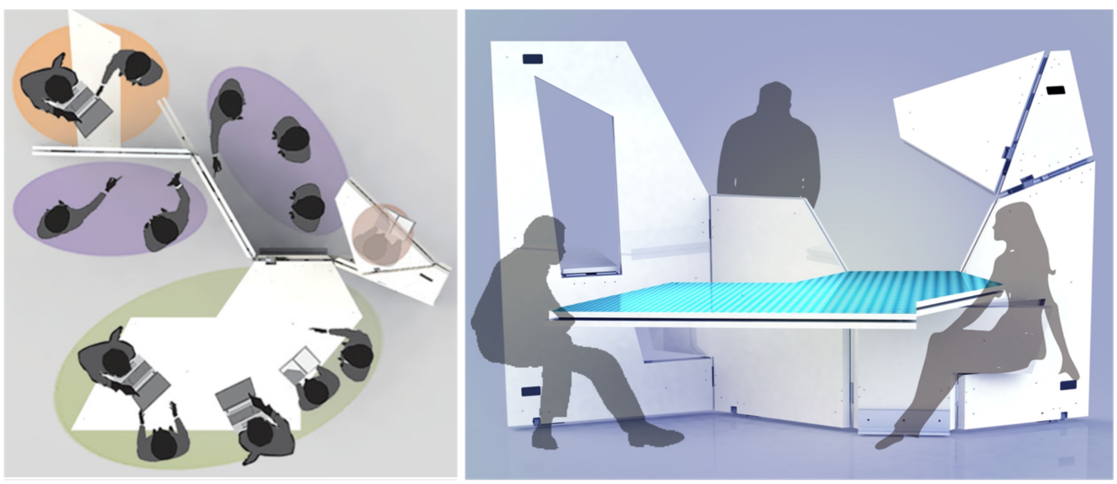

Figure 18 and 19. Plan (top view) and elevation (front view) of communIT, configuration 2.

<u>*Full-Scale Prototype Fabrication:*</u> We fabricated a full-scale prototype of Design Iteration 3 (Figure 20-23). The fabrication of a full-scale prototype required us to specify the materiality and dimensions of the artifact. One of our decisions involved the composition of the panels (Figure 22 and 23): two layers of Polystyrene foam CNC’d from a 4 ft by 8 ft insulation board. The layers are spaced 0.5 inches apart

using 3D printed plastic spacers, forming a hollow core that both reduces overall weight and allows for wires to run through the panels.


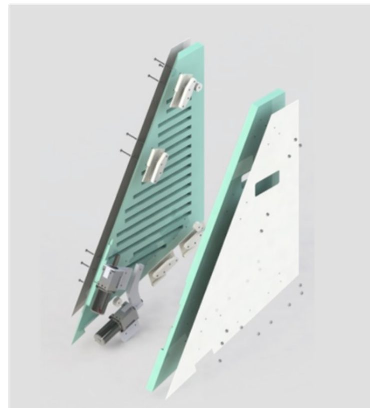

Figure 20 and 21. communIT's full-scale prototype (left), and a 3D model showing the material composition of communIT's panel (right).

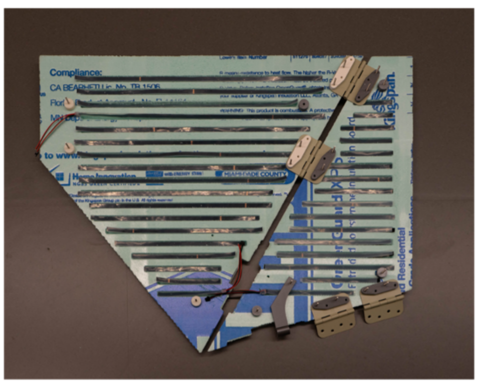
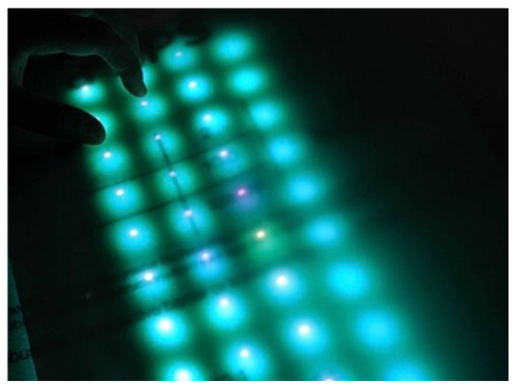

Figure 22 and 23. The physical model showing the material composition of communIT's panel (left), and communIT's panel with embedded lights (right).

The two faces of the foam "sandwich" are 0.06-inch thick, translucent, acrylic sheets, laser-cut to the geometries designed. The two faces of communIT are different. On one face of communIT, behind the acrylic, are embedded strips of LED lights. Embedded into the foam with the help of grooves milled into the foam sheets, each strip of LEDs is 2.56 inches apart vertically from each other with a total of 22 rows of LEDs. The translucent acrylic permits the embedded LED lights to glow and diffuse

(Figure 23) to create a large and foldable lower-resolution display. Also embedded into the wall are four USB powered speakers.

Scenario.

We following Carroll's "scenario-based design" [6] to help us situate communIT within a context we envision it working. Specifically, this scenario illustrates an instance of how communIT might help diverse groups co-create and communicate with the larger community. This scenario depicts a community subgroup using communIT to create and share content as a means to gain visibility and understanding within the larger community. Our scenario begins with Jasmin, a Black woman leading a local African-American group. In response to George Floyd's death, Jasmin's group was seeking community channels to protest racial discrimination. Sam, a librarian at the downtown public library, invited Jasmin's group to co-create and exhibit an interactive exhibition using communIT, a large-scale artifact recently installed in the library's ample entry space.

As encouraged by the librarian, six members of the group arrive at the library with a laptop filled with images, video, and texts that would form the core content of the exhibit. Upon arrival, the group encounters communIT for the first time, a free-standing, billboard-sized wall of hinged panels. Sam explains that the panels of communIT can reconfigure to create horizontal surfaces for collaborative work; that the panels on one face were a whiteboard and on the other face were a low-resolution display; and that some panels had embedded in them audio speakers (Figure 24. a).

Additionally, the panels could be hinged via tablet control or by embedded proximity sensors so that the exhibit behaves as a kinetic sculpture.

For the exhibit, using communIT’s surfaces, Jasmin's group considers: the timing and location of the images and video-clips stored on the group’s laptop; how the artifact might be physically configured; and how numerous surfaces might move (“hinge”) over time. The group members advance their work (Figure 24. b): one member starts by scribbling notes on a panel’s surface, another member marks panels for the sequence of images they’d display, while still another member connects the laptop with to communIT to transfer files to it. Other members walk around communIT, discussing various plans and details for the exhibit. After a few hours, the group reconvenes to save the production.

As they step-away from communIT, communIT assumes the starting configuration for the exhibit. Among visitors to the library in the days that follow, Mariana, an immigrant from South America, and Mathew, a young gay man who works as an editor at a nearby publisher, are intrigued by the presence of communIT—its display of images, sounds, videos, and the scrawled drawings on moving hinged surfaces that appear to be about the urgent racial situation of this community and the nation at large. Mariana, ahead of Mathew, approaches communIT; she notices that her movements towards, around, and away from communIT have some impact on the sequencing of imagery and sounds and physical movements of the large-scale artifact. Mathew, too, comes closer to communIT, and the two library patrons recognize that their behavior and communIT’s is interlinked, enticing them to interact further with the content of Jasmin's group.

Despite not being members of the Black community, Mariana and Mathew feel empathic to the group’s challenges – problems not unfamiliar to them and the subgroups they identify with. Upon leaving the library lobby, Mariana and Mathew see mounted, on a short column, a screen that invites them to answer two questions: Do they feel they understand better the struggles faced by members of the group that created the exhibit? and, After experiencing the exhibit, might they respond to members of that group in a more understanding way? (Figure 24.c). Mariana and Mathew both answer the two questions by pressing the green-lit “happy face” as their response to each of them before leaving communIT. In the days that follow, the impression of the exhibit stays with them.

Figure 24. (a) Jasmin’s group configuring communIT; (b) Jasmin’s group using communIT to create and share content; (c) Mariana and Mathew interacting with communIT.

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CHAPTER 3

EVALUATING COMMUNIT

In Chapter 1 we presented our motivation for the project, and in Chapter 2 we presented the three design phases of communIT development. It is important, however, to evaluate the impact communIT may have on subgroups of people, and how well it promises to deliver the envisioned aim for it.

In this chapter, we present results of two user studies: an early, in-person early pilot study with Dryden High School students, and a final online study. Our initial plan was for the final evaluation study to be also an in-person study. However, given the limitations imposed by COVID-19, we had no choice but to design and conduct an online study instead of an in-person one. We present below these two evaluation studies in more detail.

Early Pilot Study.

As we were fabricating a communIT full-scale prototype, we conducted an early pilot-study with a targeted user group within the local community: public high school students in a media art class from a rural region in upstate New York that exhibited more diversity than other semi-public spaces we studied, such as the local (non-profit) history center. Attending the school are rural poor students, more affluent, middle-class students, students of color, students from recent immigrants or visitors, and students who identify as LGTBQ+.

The objective of the pilot study was twofold: (1) to learn how the community group would use communIT to support their group activities, and (2) to learn what role communIT might play in the view of the participating group, in sharing their products and building community.

The study was conducted in the students' high school art room (Figure 25.a). We gave participants a to-scale (1:10) model of communIT's (at that time) current design, plus human figures. We recruited 28 (12 male, 14 female) participants who gave their consent to take part in the study. Participants were divided in 8 groups. We asked each group to accomplish the following: (1) identify a physical site in their community that they thought was apt for installing communIT; (2) co-create content (e.g., images, videos, electronic music, comics, animated gifs) of their choosing that communicated an issue of their interest or concern; (3) for each of the co-creation activities, create a photo collage that shows how they envisioned communIT supporting their co-creation; and (4) present their outcomes to our team.

Figure 25. (a) Participants presenting their outcomes; (b and c) participants' photo collage showing communIT in a public library and in a classroom.

Results of the Early Pilot Study.

The data collected consisted of student’s photo-collage and their response to a questionnaire. (The questionnaire we used is attached in the appendix of this manuscript.) Similar to our analysis in Study 3, we followed an open-coding approach [2], moving from codes to categories to themes to statements. In our analysis, we found that students identified sites for communIT within their public library and parks and within their school (Figure 25.b. and c). This finding corroborates with our original intention to place communIT in public spaces such as libraries and parks. Students recognized communIT as a tool to create, share, and retrieve content. For instance, one student mentioned that communIT "*would give workers and students access to online content…, online courses, and Google classroom. This is for people who don't have access to internet or computers.*" This finding demonstrates the potential of communIT as a tool to create and share media. Some students envisioned communIT as a platform to communicate, to a broader community audience, their views on issues of concern to their student community and age group. This finding is also positive because it shows evidence of how communIT could be used to engage members in the community. The topics mentioned by the students included issues pertaining to sexual orientation, the environment and ecosystem, and children with special needs. One student volunteered, "*just because we are different in this small thing [sexual orientation], it doesn't mean that we are different in everything else.*" When asked what role communIT's would play in communicating this view to the larger public, the student responded that communIT could "*broadcast this message to others via educational videos presented on communIT, which could lead to a round-table to present each other's view.*" Once again, this positively illustrate communIT's potential to work as a tool for community engagement by media making and sharing.

Online Study.

Due to the pandemic that halted in-person study, we conducted an online survey to further evaluate communIT. Although we would rather have continued our evaluation via our chosen, in-person field methods, an online survey would allow us to reach a wider geographically dispersed community. The survey we conducted follows the method of prior HCI research (e.g., [1, 3]) that holds that, in an online study, participants can vividly transport themselves into the experimental settings and provide valid feedback on their perceptions and emotions.

We therefore asked participants to imagine themselves interacting with communIT and then respond to our online survey. Primarily, we wanted to know if participants perceived communIT as suitable, useful, and impactful for their group; whether they recognized communIT as a tool to share, engage, and interact with the large community; whether they thought communIT might help them express their ideas, concerns, and aspirations to the larger community; and what they thought about communIT's impact on how the larger community perceived their group.

Participants.

One hundred and ninety-seven participants (57 male, 62 female and 29 other, with the remaining participants preferring not to answer) were recruited throughout the United States using "CloudResearch," a platform powered by Amazon TurkPrime. For this study, we recruited only Master Turkers – more experienced Amazon Turk survey-takers. Workers were paid a higher market rate of 4 dollars (USD) for participating in the 15-minute, IRB-approved study. We did not collect demographic information other than gender.

Procedure and Measures.

We assessed participants' perceptions toward communIT via a 19-question survey (Table 1) conducted using Qualtrics Survey Software. The survey was divided into two parts. The first part (Q1-Q7) aimed to understand which social groups each participant mostly identified with, and to assess each participant's perceptions of (a) their groups' beliefs as to how they were perceived by the community, (b) their group's engagement with the larger community, and (c) the tools and resources their groups use to engage with others.

Before the second part of the survey, participants watched a video (1:32 minute duration; https://www.youtube.com/watch?v=Ni0GnuAEOKg&feature=youtu.be) that introduced communIT's main attributes (e.g. screen, white board, speakers, and lights), affordances, and behaviors. The affordances included activities that people could do with the artifact, such as sketching, brainstorming, editing and presenting media.

Lastly, behavior consisted of the physical transformation of the artifact, where it would hinge and fold its panels when transforming from one configuration to another. The second part (Q8-Q19) assessed participants' perception of communIT in relation to their groups' internal interactions, as well as to their engagement with the larger community. Participants' perception towards communIT, the central element of analysis, was divided into three elements: (a) suitability of communIT, (b) usefulness of communIT, and (c) impact of communIT, all measured on 1-7 Likert scales and followed up with open-ended questions. We also included three additional questions to further understand participants' views toward communIT: whether participants were open to experiment with communIT (Q10); locations in which participants envisioned it installed (Q16); and any additional comments participants had about it (Q19).

Table 1: Survey questions

Q#	Question type	Question content
Q1	Open ended	Which social groups do you mostly identify with? Write all the groups that apply. These can be, for example, groups related to your age, gender, sexual orientation, origin, and ethnicity.
Q2	Likert	I feel my group(s) are understood within the larger community.
Q3	Open ended	How do you think your group is perceived by the larger community?
Q4	Open ended	How does your group share, engage, and interact with the larger community?
Q5	Likert	When I share, engage, and interact with the larger community, I feel my group is better understood by others.
Q6	Likert	Tools and resources that afford sharing, engaging, and interacting would help the larger community understand my group(s) better.
Q7	Open ended	What tools and resources would help your group share, engage, and interact with others in the larger community?
Q8	Likert	I have a basic idea of what communIT does.
Q9	Likert	I could explain the basic idea of communIT to someone else in a few words.
Q10	Likert	I would like my group(s) to try communIT for sharing, engaging and interacting.
Q11	Open ended	Please type below the following phrase accurately: "Paint the meadow"
Q12	Likert	I feel communIT is unsuitable for my group(s).
Q13	Likert	communIT would be useful to my group for communicating to the larger community something about my group (e.g., who we are, what we do, what we are thinking about, what we believe in).
Q14	Open ended	How would your group(s) use communIT to share, engage and interact within the group(s)?
Q15	Open ended	How would your group(s) use communIT to share, engage and interact with the larger community?
Q16	Open ended	In which places would you have communIT installed?
Q17	Likert	I believe communIT might make an impact on how the larger community perceives my group(s).
Q18	Open ended	What kind of impact do you think communIT will have?
Q19	Open ended	Any comment or suggestion on how to improve or change communIT?

Data Analysis.

Because we wanted to allow participants to self-define their subgroups, Q1 was open-ended (“Which social groups do you mostly identify with?”). To determine the groups that participants identify with, we coded the responses, identifying three major groups: Immigrants (n=21), Black (n=12), and LGBTQ+ (n=23). Immigrant participants identified themselves as either Immigrant or as ethnic groups different from American (e.g., Cantonese, Indian, and Arab). Participants from the Black group identified themselves as Black or African American. LGBTQ+ participants consisted of those who categorized themselves as homosexual, pansexual, LGBTQ+, lesbian, bisexual, and gay. We didn’t include other self-defined identities with too few counts (e.g., businessman (n=3), and salesperson (n=2)). Immigrants, Blacks, and LGBTQ+ individuals were hereon referred to as members of a Subgroup (for our study, Subgroups amounted to n=49, excluding from the statistical analysis only 3 participants who identified as belonging to more than one Subgroup). The remaining participants we call Other Participants (n=99), even though we recognize that further diversity may exist within this group.

Two questions asked participants whether they understood and could explain communIT (Q8, Q9). For the statistical analysis, we only included participants who affirmatively (i.e., those who responded 5, 6, or 7) that they understood communIT (n=148). We calculated Pearson's Correlation Coefficient to test the correlation among Suitability, Usefulness, and Impact. We also performed independent sample t-tests to compare the means of the Subgroups and Other Participants groups. Additionally, we used ANOVA to compare the means of the three groups within Subgroups (Immigrant, Black, LGBTQ+). We treated the scale items—from 1 (strongly disagree) to 7 (strongly agree)—as continuous variables.

For the qualitative analysis of the open-ended responses, we considered all participants except those who either did not answer or who wrote nonsensical jumbles of words (the total n removing the exceptions = 187). The qualitative analysis followed an open-coding approach [2], moving from codes to categories to themes to statements. We iteratively read participants’ answers, highlighted excerpts and identified insights, themes and recurring patterns in the data, and finally created assertions.

Results.

We first report on participants' perceptions of how they are understood by and interact with the larger community. Then, we report on how participants perceive the suitability, usefulness, and impact of communIT to better engage with and be understood by the larger community. The findings include the statistical analysis to compare the Subgroups and Other Participants groups, followed by our qualitative open-ended analysis that provides a more nuanced understanding and interpretation of participants' perceptions and thoughts.

Being Perceived by and Interacting with the Larger Community: The first set of questions sought to understand the degree to which participants thought that the groups they identified with were understood by the larger community. Table 2 presents the descriptive statistics comparing the Subgroups and Other Participants groups; Table 3 presents statistics comparing the Immigrant, Black, and LGBTQ+ groups.

Table 2: Comparison between Subgroups and Other Participants on being understood by the larger community.

Question #	Subgroups (n=49)	Other Participants (n=99)	t-value	DF	P-value
Q2 – being understood	4.83 (1.93)	5.52 (1.32)	-2.497	145	0.0136
Q5 – better understood when interact	5.17 (1.46)	5.23 (1.15)	-0.296	145	0.76
Q6 – tools to interact help being understood	5.23 (1.24)	5.30 (1.27)	0.076	145	0.93

Table 3: Comparison between the Subgroups groups on being understood by the larger community.

Question #	Immigrant (n=20)	Black (n=10)	LGBTQ+ (n=19)
Q2 – being understood	5.55 (1.57)	4.50 (2.22)	4.22 (1.98)
Q5 – better understood when interact	5.70 (1.12)	4.90 (1.72)	4.72 (1.53)
Q6 – tools to interact help being understood	5.40 (1.09)	5.30 (1.41)	5.00 (1.32)

Participants in the Other Participants (M=5.52 SD=1.32) perceived themselves as more understood than those from the Subgroups (M=4.83, SD=1.93) (t(145)=-2.497, p=0.0136). One participant from the Other Participants said that "*my group is* *generally respected…*". Another said, "*many in the group hold positions of power.*" Among the Subgroups groups, results show a statistically significant difference ($t(143)=-2.68$, $p=0.04$) on being understood (Q2) between Immigrant ($M=5.55$, $SD=1.57$) and LGBTQ+ ($M=4.22$, $SD=1.98$) groups. An LGBTQ+ participant reported, "*I feel LGBTQ is perceived as wrong, at times even sinful… and in the eyes of lawmakers, my group is denied, not represented, or even considered valid.*" On the other hand, an immigrant participant offered, "*I think my group is perceived positively by the larger community.*" We did not find significant differences between the means of Black and Immigrant participants, nor the Black and LGBTQ+ participants.

We did not find a significant difference between subgroups ($M=5.17$, $SD=1.46$) and others ($M=5.23$, $SD=1.15$) ($t(145)=-0.296$, $p=0.76$) on being better understood when interacting with the larger community (Q5). Similarly, subgroups ($M=5.23$, $SD=1.24$) and others ($M=5.30$, $SD=1.27$) were not significantly different on whether tools helped their being understood (Q6) ($t(145)=0.076$, $p=0.93$). The high means (about 5 out of 7) suggest that both groups would feel better understood when they shared, engaged, and interacted with others, and both groups believed that tools that afforded sharing, engaging, and interacting would help the larger community understand their groups better. Table 3 details the means and SDs of the three Subgroups groups on these questions; the differences between these Subgroups groups are not statistically significant.

In their open-ended responses, participants from both groups reported similar ways as to how their groups interacted with the larger community (Q4) and the kinds of tools and resources they used to interact with others (Q7). Most resources involved social media, community forums, social events, community centers, and group clubs. Some participants did not specifically mention any tool or resource, but instead they specified some characteristics of the tool. One participant from Subgroups, for instance, mentioned a desire for "*tools to share information about the history of our culture,*" while a participant from Other Participants pointed to "*a platform that shares plans and information regarding what the groups do and what they stand for.*"

Other participants described why they engage with the larger community. For instance, an LGBTQ+ participant offered that "*we engage to inform people about our minority group and issues within,*" while a participant from the Immigrant groups reported a need to be engaged with the larger community "*to look out for each other and try to help others who are not in our group but part of our community.*" Several participants sought the opportunity to interact with diverse groups to share their ideas and thoughts. A participant from the Subgroups groups wanted "*to connect and discuss how to fit in better,*" while another wanted the "*…opportunity for the larger community to meet and engage with members of the LGBTQ community, coming together in a place to express themselves.*" Several participants from the Other Participants also wanted more debate and "*…to say what they [others] need to say to the larger community without ridicule or judgement.*" These responses point to the promise of communIT as a means to further the engagement of various subgroups both within the group itself and with the larger community.

<u>*communIT for Engaging with and Across Groups:*</u> Table 4 presents descriptive statistics comparing the Subgroups and Other Participants groups on suitability, usefulness, and the impact of communIT for engaging within and across groups. We

found strong correlations among these three measures: Suitability and Usefulness: r(145)=0.77, p<0.001; Suitability and Impact: r(145)=0.56, p<0.001; Usefulness and Impact: r(145)=0.73, p<0.001. On suitability, participants in the Subgroups (M=5.06, SD=1.49) had a more positive view towards communIT than those in the Other Participants (M=4.41, SD=1.86) (t(145)=2.10, p=0.0375). Similarly, on usefulness, participants in the Subgroups (M=5.17, SD=1.34) had a more positive view towards communIT than those in the Other Participants (M=4.60, SD= 1.70) (t(145)=2.035, p=0.0436). We did not find a statistically significant difference between the groups on impact. These results indicate a general perception difference between participants of the two groups in regard to the Suitability and Usefulness of communIT. Additionally, these results also indicate that—for Suitability and Usefulness—participants' opinions in the Subgroups converged more than the ones in the Other Participants.

Lastly, Table 5 presents additional details on the three groups within Subgroups on suitability, usefulness, and impact; we did not find statistically significant differences between the means of Immigrant, Black and LGBTQ+.

Table 4: Comparison between Subgroups and Other Participants on Suitability, Usefulness, and Impact.

Question #	Subgroups (n=49)	Other Participants (n=99)	t-value	DF	P-value (t test)
Q12 – suitability	5.06 (1.49)	4.41 (1.86)	-2.497	145	0.0375
Q13 – usefulness	5.17 (1.34)	4.60 (1.70)	-0.296	145	0.0436
Q17 – impact	4.69 (1.57)	4.45 (0.79)	0.076	145	0.427

Table 5: Comparison between the Subgroups groups on Suitability, Usefulness, and Impact.

Question #	Immigrant (n=20)	Black (n=10)	LGBTQ+ (n=19)
Q12 – suitability	4.55 (1.60)	5.30 (1.33)	5.50 (1.33)
Q13 – usefulness	5.25 (1.33)	5.10 (0.99)	5.11 (1.56)
Q17 – impact	5.10 (1.33)	4.30 (1.82)	4.44 (1.65)

The question on usefulness (Q13) was followed by two open-ended questions to further understand how participants think they would use communIT (Q14, Q15). In our qualitative analysis, we found no apparent differences between the two groups on how they would use communIT to interact, engage, and communicate, both within their groups and with the larger community. Overall, most activities engaged with communIT involved brainstorming, collaboration, discussion and sharing and producing content (e.g., infographics, pictures, cartoon, and videos). For example, one participant from Subgroups reported that their group "*could develop videos, graphics, or texts to display on communIT for other groups to view and discuss our ideas.*" Another participant from Other Participants intended to "*use [communIT] to have discussion groups, learning forums, and for spreading the word about our ongoing charity projects...*".

Further, participants from both Subgroups and Other Participants groups reported similar purposes for these activities, most intending to use communIT to engage in debate and raise acceptance of different opinions. One participant from Other Participants offered that "*our collaborative thoughts and even our divided opinions could be used as a mean to pull the larger community into our circle. This would be useful as such to generate discussion, which could in turn lead to more widespread involvement from others.*" Other participants wanted to use communIT to raise understanding and inclusion among diverse populations. For example, an immigrant participant said, "*we could use it as a tool to show our culture through video and music*", while a gay participant said, "*communIT would make it easier for the community at large to see what my group is about.*" These findings indicate that, regardless of whether individuals identify with a Subgroups group or not, they see the potential of communIT to serve as an engagement tool that bridges between groups in the community to increase understanding, acceptance, and discussion.

In their open-ended responses, several participants referred to the physical characteristics of communIT as a multipurpose, reconfigurable platform for sharing, engaging, and interacting within and across groups. For example, one participant offered, "*each person could work individually or [in] small teams and then come up with ideas to present to other members of the group…*" Another participant characterized communIT as "*an all-in-one tool that could be used to personalize/specifically configure various setups depending on the context during scheduled events.*" These accounts indicate that participants saw communIT as a flexible platform that would allow them to work individually, in small groups, or as a bigger group, and to reconfigure and transition between these modes of interaction. Furthermore, some participants expressed that, when working individually or in small groups, they would still be able to interact with, and feel part of the larger group. As one participant reported, "*[communIT lets us] separate into groups but [I'm] still immersed as a whole*".

As a large-scale physical artifact, participants also saw communIT as a gathering place, "*bringing people closer together through communication and learning.*" Another participant saw communIT "*as a focal point for bringing together members of my group and the larger community.*" One participant said that "*communIT provides a balance of both in-person and digital gatherings to share information with a broader audience.*" Many expressed that the physicality of communIT would serve as a catalyst for social interaction: "*It might broaden people's social networks and make them interact with others they might not have before.*" Other participants said their groups would use communIT, in the words of one participant, "*as a place to spend a bit of time there before moving on to other things.*"

In the follow-up, open-ended question of the impact of communIT (Q18), many participants from all groups believed that communIT could instigate discussion and understandings across various populations, fostering, in the words of participants, "*a greater feeling of community*" and "*a feeling of unity and mutual cooperation.*" But, while we did not find apparent differences between the groups in their open-ended responses on how they would use communIT, our analysis did indicate a slight difference between the Subgroups and Other Participants on how participants see its impact. Specifically, the comments of participants in the Other Participants related to communIT's general social impact. As one participant put it, "*[communIT] would let society see different groups as more alike than different and they could relate to each other better.*" On the other hand, the comments of participants in the Subgroups related to the impact of communIT on their specific subgroup. As one participant offered: "*[communIT would] help us show others about our unique traditions and values, and try to involve them in understanding our identities*".

Finally, while most participants expressed enthusiasm about communIT, a few were reticent about its impact, saying that it would ultimately depend on how people end up using the artifact. One participant wrote that communIT "*has the potential to have a positive impact albeit the magnitude of such an impact largely depends on the participators more than anything else.*" Similarly, another participant said communIT's impact "*depends on how it's perceived in the community*." One participant said that., "*in a normal world, I could see [communIT] being useful for project collaborations, but in the covid-19 reality…, it would have group members too close together to be safe.*"

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CHAPTER 4

MODEL FOR A RIGID, 3D MECHANISM INSPIRED BY POP-UP ORIGAMI, AND ITS APPLICATION TO A RE-CONFIGURABLE, PHYSICAL ENVIRONMENT

Abstract

communIT's design was inspired by "pop-up" origami (i.e., kirigami). And because origami has had wide-ranging application in mechatronics, robotics, design, and aerospace engineering, we offer in this chapter a geometric analysis and model for this rigid, three-dimensional mechanism. In pop-up origami, a cut is introduced to the folded sheet to expand formal possibilities. We present vertex and parallel pop-up origami mechanisms, model the former using the Denavit-Hartenberg Convention, and uses communIT's design as a case study to illustrate the capacity of origami to fold and unfold on demand. We explore this case, calculating its actuation forces, while recognizing that the model presented here has potential to generalize widely.

Introduction

This chapter presents the technical component involved in the design and fabrication of communIT which occurred early on in the development of this thesis research. The development of physically complex artifacts requires, many times, further technical studies in areas such as mechanics and mechatronics. Specifically for communIT, the technical component involved primarily two elements: (a) evaluation and understanding of the forces actuating in the super-structure, (b) and the study of the artifact's panel's motion. These were two relevant contributions due to the unusual shape and scale of the artifact. Our findings are relevant to those researches who investigate and explore the design of similarly complex artifacts of the kind of communIT.

Origami

Origami is the ancient art of folding a single sheet of paper to create a three-dimensional sculpture. In recent years, origami has received attention from researchers in mechatronics and robotics as a potential for applications at very small physical scales. For example, [10] presents a sheet, 1.7 cm square, that self-folds into a functional 3D robot that can walk, swim, and then dissolve in liquid. At the other end of the physical scale, origami structures have served as the basis for habitable, physical environments. The Miura Ori pattern of origami has, for instance, been applied to form the structural envelope of a chapel building [1]. Origami has also served as the basis for a variety of mechanical systems [16], from nano-devices to retinal implants, heart stents, air bags, inflatable masts for satellites, solar panels, and mirrors [15].

While origami is mostly recognized as a three-dimensional sculpture formed by folding a sheet of paper, a variation of origami called kirigrami, otherwise known as "pop-up" origami, introduces a single, internal cut into the folded sheet of paper to expand the formal possibilities of the resulting from [17] [2] [18]. In this paper, we characterize and explore the potential of pop-up origami for mechanical systems of wide-ranging applications at wide-ranging physical scales. One property of origami (including the pop-up variant) that benefits mechanical systems is its capacity to fold and unfold on demand. It is this property that we harness in our own design of a suite of physically re-configurable outdoor furniture to be installed in a public, urban square which, for this paper, serves as a case study.

From Pop-Up Books to Mechanical Systems.

Paul Jackson's Cut and Fold Techniques for Pop-Up Designs [8] provides a comprehensive introduction to the art of creating pop-up (origami) books using folded paper. Jackson describes the most basic elements of any pop-up origami mechanism and the techniques for creating one using paper. Generalizations of the designs from Jackson's book provided the foundation and inspiration for the models produced in this paper. Figure 26 offers the basic concept of Jackson's origami.

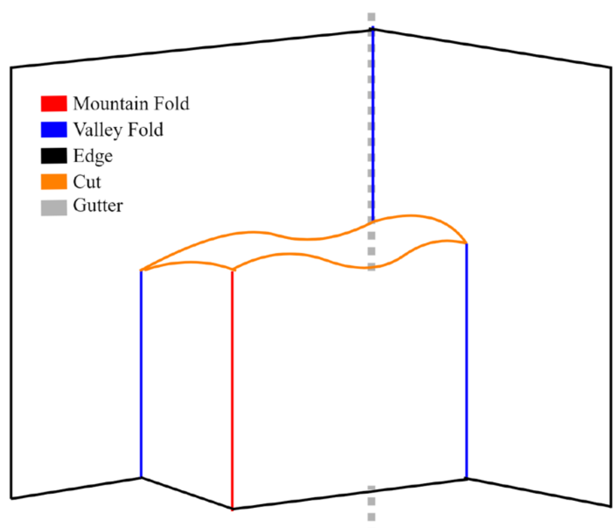

Figure 26. Parallel pop-up mechanism in open configuration.

We describe pop-up origami mechanisms using accepted terminology found in Jackson's book. These mechanisms are briefly explained here and visualized in Figure 26 Folds are described as either mountain or valley depending on whether the fold is meant to be viewed as convex or concave, respectively [17] [8]. Any configuration can be inverted by changing all mountains to valleys and all valleys to mountains [8]. Each pop-up mechanism has an axis of symmetry which is known as a gutter [17] [8]. In order to be classified as a "pop-up," a paper mechanism must meet the following criteria:

(a) The mechanism is created from one paper sheet.

(b) The mechanism must have exactly four straight folds.

(c) The mechanism possesses two flat-folding configurations, "open flat" and "closed flat," such that a book could be fully opened or fully closed without violating the mechanism's range of motion.

(d) One or both of the center folds must be co-linear with the gutter.

(e) The mechanism must contain exactly one cut which is entirely on the interior of the paper.

(f) All folds begin at the cut and terminate at the edge of the paper.

(g) The cut begins and ends at the start of the two outermost folds, and need not be a straight line.

These criteria allow for eight different fold locations, each with two different fold types, for a total of 1120 different folding patterns. Of these, only 8 patterns are physically realizable (i.e. it is not possible to create a mechanism where all folds are mountain type). Jackson elaborates these valid configurations in Cut and Fold Techniques for Pop-Up Designs [8].

The Engineering of Large-Scale Pop-Up Mechanisms.

When considering the applications of pop-up design at a larger physical scale (e.g. our case study), the mechanism must meet the following amended criteria. The amendments primarily recognize the engineering limitations of a pop-up such as replacing paper folds with mechanical joints.

(a) The mechanism is constructed of exactly four flat panels, attached by four revolute joints.

(b) The neighboring edges panels are straight and parallel to the shared joint's axis of rotation.

(c) The mechanism has at least one flat-folding configuration.

The main difference between paper and large-scale construction is the thickness of materials. At paper-scale, thickness is negligible and building materials are highly flexible, but large-scale construction introduces greater opportunity for collision as panel thickness increases, and materials are more rigid.

General Forms of Pop-Up Origami Mechanisms.

Jackson's pop-ups fall into two broad categories, referred to in this paper as "vertex" and "parallel" type mechanisms, which Winder et al. describe as one-piece, single-slit planar and one-piece single-slit spherical mechanisms, respectively. These mechanisms each constitute one degree-of-freedom, four-bar mechanisms [17]. These two cases are characterized by the relationship between the folds of the mechanism, and allow for rigid, three-dimensional motion without buckling or locking.

Vertex Mechanism.

The vertex mechanism type (Figure 27) demonstrates spherical motion about a fixed point (vertex) in space. Instead of the parallel fold axes shown in Figure 26, these axes converge at a point on the gutter. This has been shown to allow for motion by creating a spherical four-bar mechanism [17].

Parallel Mechanism.

The parallel mechanism (Figure 26) is a special case of the vertex mechanism where the vertex point is infinitely far from the intersection of the cut and the gutter.

However, it is easier to express this as its own type since it behaves as a planar, four-bar mechanism.

Geometric Model of the Vertex Pop-Up Mechanism.

For this paper, the vertex pop-up mechanism is chosen to explore further, given that it has application to the author's use case (which will be elaborated further ahead).

In order to solve for the structural mechanics of a popup mechanism, it is necessary to locate points of force application in a common frame. This is accomplished by defining points relative to frames attached to each link and using a homogeneous linear transform to find those same points relative to other frames.

Denavit-Hartenberg Convention.

The Denavit-Hartenberg (D-H) convention [6] is a convenient way to describe kinematic transformations between coordinate frames that are related by either revolute or prismatic joints. Although normally used in robotics applications for determining the kinematic chain of a multiple degree-of-freedom end manipulator [3], these conventions are a good tool for describing the configuration of each joint of a pop-up mechanism.

Craig provides instructions for calculating robotic kinematics using what has been called "modified" D-H parameters. The definition of each parameter is shown in Table 6 and considered in [3].

Table 6. D-H parameter definitions

Parameter	Definition
a_i	Linear distance from z_i to z_{i+1} measured in the x_i direction
α_i	Angular displacement between z_i and z_{i+1} measured about the x_i axis
d_i	Linear distance from x_{i-1} to x_i measured in the z_i direction
θ_i	Angular displacement between x_{i-1} and x_i measured about the z_i axis

Angle Definitions.

Figure 26 shows the necessary parameters to fully define the joint axes of the pop-up mechanism. Only three independent vertex angles (alpha in Table 6) are required since the fourth is dependent on the other three. Figure 27 shows the placement of the link frames for each link.

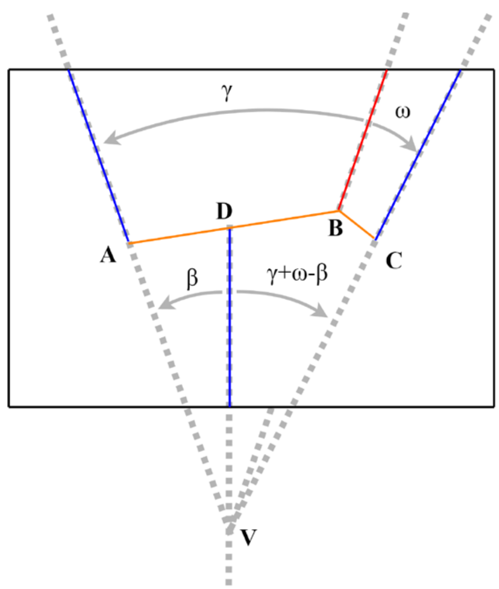

Figure 27. Open flat configuration for vertex pop-up kinematics.

In order to specify a given pose of the mechanism, the angles of each revolute joint of the mechanism must be determined. In the case of a pop-up mechanism, specifying one joint angle (*alpha* in Table 6) determines all of the angles. For a, the vertex pop-up, these angles are governed by spherical trigonometry. Figure 4 defines intermediate variables that will be used to express the joint angles of the mechanism in terms of the single input angle (ø in Fig. 29). Spherical trigonometry provides the following relationships between the internal angles [7].

$$\delta = atan\left(\frac{sin(\phi)}{cot(\gamma)sin(\beta) - cos(\beta)cos(\phi)}\right) \quad (1)$$

$$\epsilon = atan\left(\frac{sin(\phi)}{cot(\beta)sin(\gamma) - cos(\gamma)cos(\phi)}\right) \quad (2)$$

$$\psi = acos\Big(cos(\beta)cos(\gamma) + sin(\beta)sin(\gamma)cos(\phi)\Big) \quad (3)$$

$$\mu = acos\left(\frac{cos(\beta+\omega-\gamma) - cos(\omega)cos(psi)}{sin(\omega)sin(\psi)}\right) \quad (4)$$

$$\kappa = acos\left(\frac{cos(\psi) - cos(\omega)cos(\beta+\omega-\gamma)}{sin(\omega) * sin(\beta+\omega-\gamma)}\right) \quad (5)$$

$$\zeta = acos\left(\frac{cos(\omega) - cos(\psi)cos(\beta+\omega-\gamma)}{sin(psi) * sin(\beta+\omega-\gamma)}\right) \quad (6)$$

Link Frames.

Given the link frames presented in Figure 28 and the angles defined in Figure 29, the D-H parameters defining the configuration of frame *i* are provided in Table 6.

Table 7. communIT Link Frame D-H Parameters

i	a_{i-1}	α_{i-1}	d_i	θ_i
1	0	$-\beta$	0	$\pi - \phi$
2	0	$-\gamma$	0	$\pi - (\epsilon + \zeta)$
3	0	$-(\beta + \omega - \gamma)$	0	$\pi - \kappa$
4	0	$-\omega$	0	$\pi - (\delta + \mu)$

Using the D-H parameters, it is possible to describe points on each joint in different coordinate frames. The transformation between coordinate frames is accomplished using a homogeneous transform. A point whose coordinates are expressed in frame h can be represented instead in frame *k* using the relationship shown in 7. The construction of the homogeneous transformation matrix is well established and, consequently, will not be presented here [3].

$$^{k}\vec{P} = {}^{k}_{h}R\,{}^{h}\vec{P} \tag{7}$$

Structural Mechanics to Determine Actuation Force.

The practical construction of a large-scale pop-up mechanism is a main goal of this project. Because a pop-up possesses a single degree of freedom, the entire mechanism can be actuated with a single input force or torque. However, sizing an appropriate motor or other actuation device is not trivial when a mechanism exhibits complicated three-dimensional motion. Therefore, a simple analytic method for solving the actuation effort is derived.

<u>*Simplifying Assumptions.*</u>

The spherical, four-bar mechanism formed by the vertex pop-up has one degree of freedom. However, in an arbitrary four-link, closed-chain mechanism where the joint axes are neither parallel nor convergent on fixed point, the mechanism is over-constrained. Therefore, a few simplifying assumptions must be made in order to solve for the actuation force using the second law of motion and the Newton-Euler equations. These simplifications are provided below as well as shown as a diagram in Figures 30-33.

(a) Joints are modelled as friction-less. Therefore, each revolute joint has only two unknown reaction moments.

(b) Link 0 is assumed rigidly attached to ground.

(c) Link 3 is assumed effectively mass-less (or otherwise supported against the force of gravity).

(d) The joint at point C is modelled as a ball-and-socket. Therefore, all reaction moments at this joint are zero.

(e) The joint at point D is modelled as free-floating in the z-direction. That is, point D supplies no reaction force along the joint axis.

Static Solution.

With the above simplifications, free body diagrams (Figures 29 – 33) can be constructed. There are 17 unknowns: *Fax, Fay, Faz, Fbx, Fby, Fbz, Fcx, Fcy, Fcz, Fdx, Fdy, Max, May, Mbx, Mby, Mdx, Mdy*. There are three Newtonian force balance equations each for links 1, 2, and 3 – for a total of nine force equations. There are three Newtonian moment balance equations each for links 1, 2, and 3 – for a total of nine moment equations. With 18 equations and 17 unknowns, a designer is free to choose an appropriate unknown actuation effort and solve for values to create static

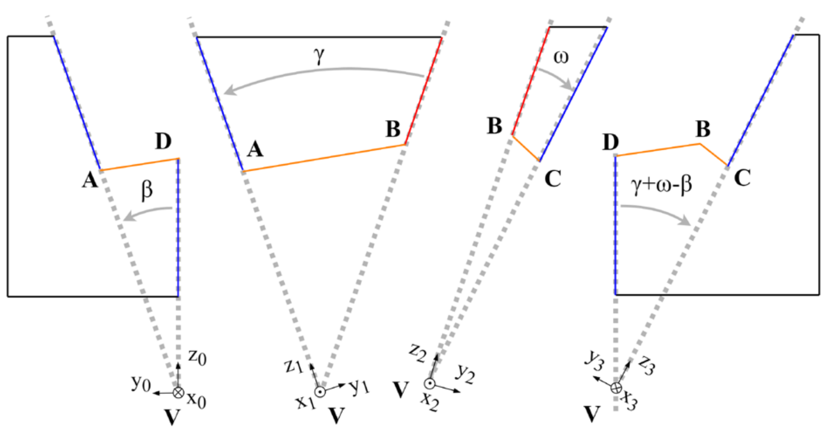

Figure 28. Vertex pop-up frame definitions.

equilibrium. This gives the designer an approximation, within a factor of safety, of expected necessary actuation effort for the system, and is computationally more

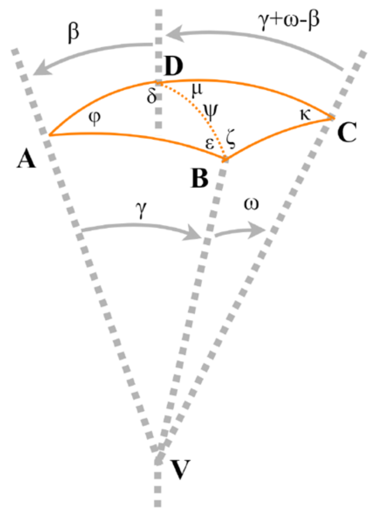

Figure 29. Diagram for solving spherical joint angle relationships.

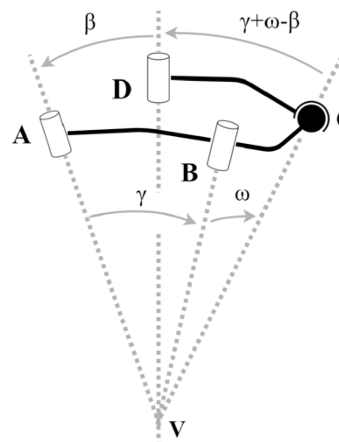

Figure 30. Mechanical simplifications made for analyzing structural forces of vertex pop-up mechanism.

efficient than running a full mechanical simulation.

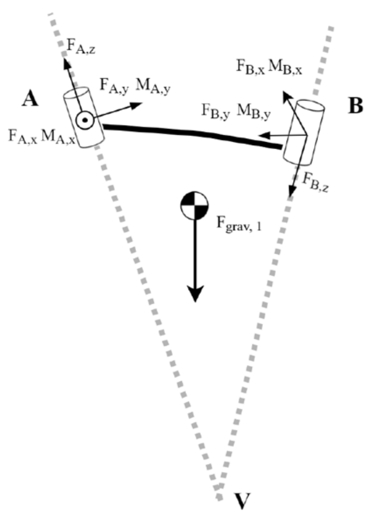

Figure 31. Free body diagram for link 1.

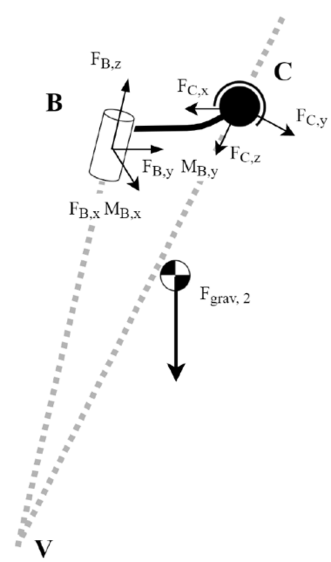

Figure 32. Free body diagram for link 2.

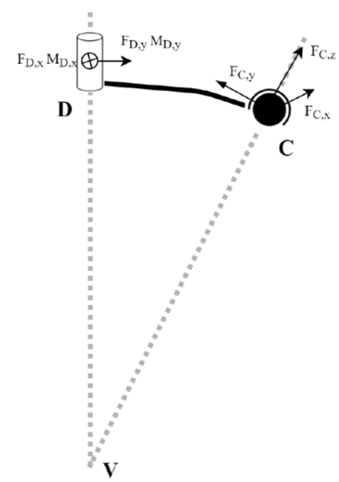

Figure 33. Free body diagram for link 3.

Modeling Parameters.

The D-H parameters for the communIT mechanism are provided in Table 8. It is important to note that in this application, *w* and ß are equal. Furthermore, the link angles *øi* are left in variable form as they are dependent on 1 – 6. Because it is one degree-of-freedom, upon specifying *ø*, all other angles can be determined.

Table 8. Vertex Pop-Up Link Frame D-H Parameters.

i	a_{i-1}	α_{i-1}	d_i	θ_i
1	0	$-25°$	0	$\pi - \phi$
2	0	$-35°$	0	$\pi - (\epsilon + \zeta)$
3	0	$-15°$	0	$\pi - \kappa$
4	0	$-25°$	0	$\pi - (\delta + \mu)$

Force Analysis Results.

The actuation effort solved for in this analysis is the reaction force necessary to accomplish static equilibrium, applied at the far corner of link 3 (see Figure 36). For this analysis, centers of gravity are estimated using a computational geometry program

(Solidworks, 2017). A MATLAB script solves for the unknown force across the entire range of possible configurations, and the results are presented in Figure 35. An actuator placed at the location shown in Figure 36 would need to exert a maximum estimated reaction force of 200 Newtons or 45 lbs to keep the mechanism in equilibrium. Therefore, a motor capable of applying approximately 600 Newtons or 135 lbs of force is recommended for this mechanism.

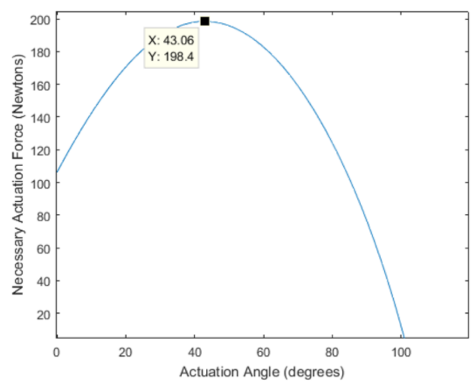

Figure 34. communIT actuation force solution results. Actuation angle is the defined in Figure 35.

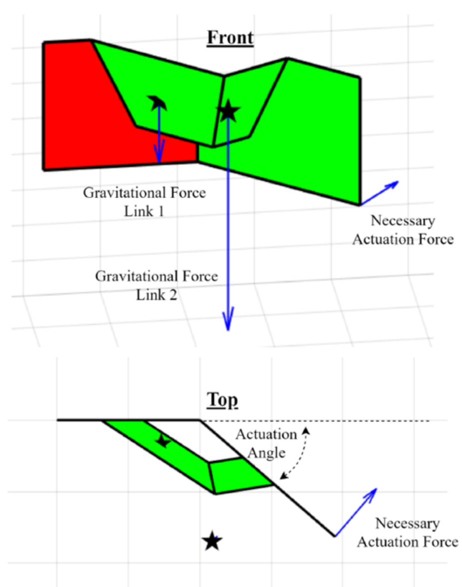

Figure 35. communIT loading generated by MATLAB. Stars denote centers of mass. Forces of interest shown in blue. Red panels (link 0) is rigidly attached to ground. Link 3 is modelled as mass-less.

User Case: "communIT," a Reconfigurable, Cyber-physical Environment.

The prior analysis on the vertex pop-up mechanism is performed as an intermediate step in the longer arc of the research reported in this thesis. Figure 36 shows computer renderings of three configurations of "communIT" (Design Iteration 2).In addition to the early design and motion planning research reported here, the research team at the same time envisioned, early on, the origami wall standing in an underused space (the aforementioned Ithaca Commons) as shown in the photocollage images of Figure 34.

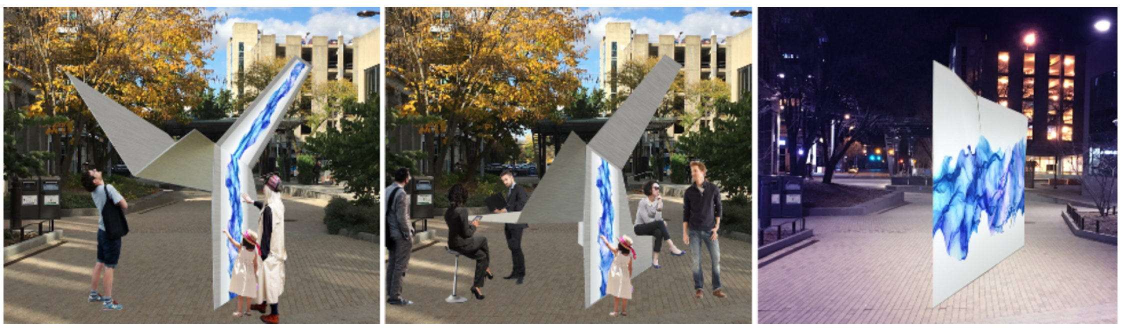

Figure 36. communIT (Design Iteration 2) in its three configurations.

<u>*Shortcomings and Limitations:*</u> The key limitation in using the CoDAS method is that participants are projecting their own behavior on scaled figures, artifacts, and environments, rather than experiencing and responding to the many qualities unfolding in time that define real space—not only qualities seen, but also those heard, touched, and smelled. CoDAS demands a leap of imagination by study participants that researchers cannot fully capture and interpret; arguably, the participant cannot as precisely communicate perceptions of the places designed and the interactions these places afford as one could in a real-world environment.

<u>*Discussion and Further Application of Kirigami:*</u>

More broadly and beyond the application in communIT project discussed in Chapter 4, the vertex pop-up mechanism offers a replicable and modular platform for wide-ranging applications at wide-ranging scales. Its capacity to physically transform and consequently create multiple "spaces"—as offered in Design Study 2 as “micro-spaces”—might prove appropriate to offer varied services and uses in a relatively small area. A robotically-driven origami mechanism of the kind of communIT (with embedded lighting, audio, sensors, and touch surfaces), have varied applications. We can for instance envision pop-up origami mechanisms at the core of flat-packed emergency housing and mobile hospital units, transported by shipping container (sized 8ft x 8ft x 20ft) to provide a variety of critical resources in response to natural or human-made disasters.

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CHAPTER 5
DISCUSSION AND CONCLUSION

Discussion

This dissertation presented the research outcomes of a series of studies to design and evaluate communIT, an interactive, large-scale, cyber-physical artifact designed to build community. In Chapter 1, we presented the background and motivations for our research project. Chapter 2 served to present the "Research through Design" process and design outcomes. We also introduced CoDAS, a method we developed during Design Phase-2 to advance our understanding of communIT. In Chapter 3, we reported on two evaluation studies: a pilot-study with a local group, and an online evaluation of communIT with a larger population group. Lastly, we presented in Chapter 4 a technical analysis of the forces in one of our design iterations for communIT. In this concluding chapter, we now discuss how this research contributes to the literature. In short, there are two main research contributions: one related to the role communIT may make in building community, and the other pertaining to the design process of communIT.

Design and knowledge—communIT as a response.

To clarify the kind of contribution the communIT research makes to the literature, we first draw from the theory of design to discuss important topics, such as the nature of design and the kind of knowledge design produces. Design differs from both science and engineering. While science is mostly concerned with validity and engineering with performance, design is concerned with the process undertaken to conceive a product. Problems in science and engineering are controlled, specific, and nuclear, whereas problems in design are under-constrained and ill-defined. Most design solutions are unknown at the start of the design process. In fact, the design process itself is not just a means to finding a solution, but also a way to better delineate the problem. Thus, the problem—not only the artifact—is a kind of knowledge that design activity produces. It might be obvious that the outcome of design is an artifact, but it becomes clearer that problems are also a product of design when one notice how differently designers can define the problem space.

The problem and the solution impact and relate to one another. It might be easy to see how problems impact the solution, but in design, the opposite is just as true. At first glance, it is strange to say that the solution impacts the problem because it presupposes that an object—as a response to a design problem—exists before the problem itself. However, the object comes as an incomplete, fuzzy idea; as a "yet to be artifact." This fuzzy idea of the solution impacts the problem framing. Design typologies, for example, make part of this incomplete idea of an object that influences the definition of the problem. For instance, when designing a building, the architect would have different types of questions compared to the questions of an industrial designer when designing a lamp. Part of this difference in the constitution of the problem is due to the simple fact that buildings and lamps, as different typological artifacts, ask for different concerns. Thus, the design activity produces not just an artifact, but instead the artifact-problem—an inevitable twin output.

And when we look at design as a verb, we see a twofold action: an attempt to understand and frame a portion of the present world, its conditions and issues; and an attempt to change this present condition into a more desirable, idealistic future. The first task—the construction of the present—relates to the problem, while the second—the projection of future—relates to the artifact. Is that all? Not quite. Design will also involve testing, especially as it gets closer to research and farther from practice. In this testing, there are a couple of concerns, e.g. how well the artifact responds to the problem, and ultimately, how much the artifact fulfills the idealized future.

Thus, we can argue that designing involves a threefold action: presenting a sample of what the present is, imagining a version of what the future can be, and testing the relation between these versions of present and future. And these three tasks are not performed only once. Designers are always reformulating the present and the future as they test them. This cyclical reformulation is necessary because, once again, problems are ill-defined and solutions are fuzzy. The cycles help designers to better produce a problem-artifact. To us, this threefold task is one of the main contributions every design activity makes to the literature. This, we believe, is one of the biggest contributions of this dissertation, shared in Chapters 1, 2 and 3: a present issue, an idealized future, and an evaluation of the role communIT may have. The storyboard presented in Chapter 2 illustrates, more specifically, the role communIT may make in building community. We will further reflect about this contribution ahead.

communIT—a cyber-physical artifact for building community: What are the present, the future, and the path from the former to the later? What is the problem, the solution, and the process? To better organize our discussion, we will look at the problem and solution now, and leave the process for the next subheading. We can start thinking about the problem and the solution by looking at the main research question of this dissertation: Can an interactive cyber-physical artifact support marginalized, misunderstood, or invisible subgroups generate media and make this media visible and "heard" in the larger community? Here, the present issue is evident: some subgroups—like LGBTQ+, black, and immigrants—are marginalized, misunderstood, or invisible to the larger community. This, in a nutshell, is the present problem communIT research aims to respond to.

As for the desired future—also a motivation for our research—it involves mitigating such marginalization by supporting these subgroups to express their ideas, concerns, and aspirations to within the larger community. The research question also indicates how we intended to help bringing about this future situation: by means of a cyber-physical, interactive, large-scale artifact that affords media making and sharing.

Lastly, an additional point to bring to our attention: the research question starts with "can," which indicates that we are exploring whether this type of artifact can: (a) respond positively to the present issue, and (b) help bringing about this idealized future. But this evaluation goes beyond the "can," as we also want to understand "how." Chapter 3, in the "Procedures and Measures" subsection under "Online Study" provides further detail of what we wanted to evaluate in communIT.

Having laid the way to our discussion, we now turn toward the results shared in Chapter 3. Our quantitative results from Q12-suitable and Q13-useful indicate that participants feel communIT would be suitable and useful for their local group to engage in collaboratively creating and sharing their products with the larger community. This indication is positive—being useful and suitable for media making and sharing is the first step for communIT's relevance in community engagement. One of the most basic form of protest involves, after all, making and displaying messages to others.

In parallel, findings from Q17-“impact,” indicate that the majority of participants believed that communIT may make an impact on how their groups are perceived by the larger community. We also were able to observe in Q15-“share larger” and Q18-“kind of impact” that participants believed that their groups could use communIT to express their ideas, concerns, and aspirations to the larger community. Participants expressed their intention to use communIT as a platform to communicate with the larger community. If, on one hand, Q12-“suitable” and Q13-“useful” suggested the usefulness and suitability of communIT for media making and sharing, on the other, findings from Q17-“impact,” Q15-“share larger” and Q18-“kind of impact” indicate that communIT is relevant for groups to express their views to the larger community.

These findings collectively and positively support communIT’s promise to play a role in community building as diverse groups engage in creating and sharing their products with the larger community. Moreover, the findings suggest that community engagement may arise out of the participation of community groups (i.e. the Subgroups) to create and share their outcomes (e.g. videos, text, etc.) using communIT. This corroborates with the literature presented in Chapter 1. Specifically, what we found goes in line with what Marres [3] suggests: that not only individuals, but also resources and objects are essential for a community engagement around issues of mutual concern.

There is another relevant point: when we examine some participants' extracts we discover that communIT goes in tandem with what Jenkins presented in [4]. For instance, a participant said "*communIT would make it easier for the community at large to see what my group is about.*" This align with Jenkins' view that artifacts are not merely a tool but instead a partner in the creation and maintenance of public issues. Members of subgroups saw communIT as an important object to gather other people around issues of their concern; this also suggests communIT's potential as an object-oriented democracy [1].

In addition, the results from Q14-"share within" and Q15-"share larger" indicate that participants recognized communIT as a platform to engage and interact with members of their own groups and share with the larger community. These findings resonate with the findings of Q6-"tools afford" and Q5-"better understood," respectively: tools that afforded sharing, engaging, and interacting would help groups communicate to the larger community in a way that make them understand better; sharing, engaging, and interacting with others helps one feel better understood. We can imply that participants believed communIT may make an impact on how the groups are perceived by others because they recognize communIT as a tool that allows engagement and interaction across diverse community groups. Once again, this illustrate the potential of communIT to work as an object-oriented democracy, playing an active role in community engagement.

Lastly, in Q18-"kind of impact," several participants offered that communIT would create a place for gathering and, therefore, would increase social interaction. This also resonates with what we found in Q4-"how share" and Q7-"what tools," where participants indicated they wanted a tool to promote informal gathering for social interaction.

To conclude, this research offers a contribution related to the problem-artifact, i.e. a sample of a problem-artifact. Specifically, this research offers a response to a problem and indicates how such response might help mitigate the present issue, moving toward to an idealized future. As we presented in Chapter 1, there is little research on the kind of role and impact cyber-physical, large-scale artifacts, like communIT, may have on community engagement. For the design research community this dissertation offers an interactive design exemplar at large scale that promises to support subgroups to create media and make this media visible and “heard” in the larger community.

Design and knowledge—the design process of communIT: While producing and testing a problem-artifact is a relevant contribution to the design field, we believe this is not enough. As pointed above, the process of problem framing and solution synthesis is what mostly concerns the designers. And although some argues that the design process produces "artifacts that embodies knowledge" [5], and that these artifacts are "objects [that] speak for themselves" [4], we would also argue that it is difficult to fully understand how these artifacts became materialized without looking at the process. To “listen” to these artefacts—i.e., to understand the push-and-pull forces that affected its materialization—is perhaps an impossible job when we have at hand only the artifact and the problem it supposedly responds to. Artifacts without explanation might become mute objects.

And at this point, one might ask: why is it so relevant to also understand the process of problem-artifact construction? The short answer is: the process might strengthen and further supports the problem-artifact. To better explain, we can draw a parallel between argument and design. As in an argument where a set of premises support a conclusion, in a design, the set of decisions taken throughout a design process will support a problem-artifact. When we present the problem-artifact along with this process, we can reveal the wholeness of the "design argument." To share this design argument is to open the design black-box, revealing the method, approach, and decisions taken. We believe this is a better way to evaluate the strength of a design argument—presenting the problem, the solution, and the process.

The process is important because the construction of an artifact is hardly ever an exact, precise activity. This construction does not produce an optimal response to a problem. Design is soft and complex—the problems are blurred and the responses are not clear. Design arguments, in this sense, are inductive, not deductive. Despite the advances in the design and aligned fields, design methodologies, tools and techniques are not infallible. And neither are designers. With our available design toolkit, we can only produce, once again, a sample of what the present is and what the future can be with our intervention.

And as in an inductive argument, where the stronger the premises the greater the probability of the conclusion to be true, in a design, the more cogent the process the more convincing the problem-artifact is. This is the second biggest contribution of this dissertation: to share and reflect about the process by which we produced the problem-artifact. In what follows, we will reflect about this process.

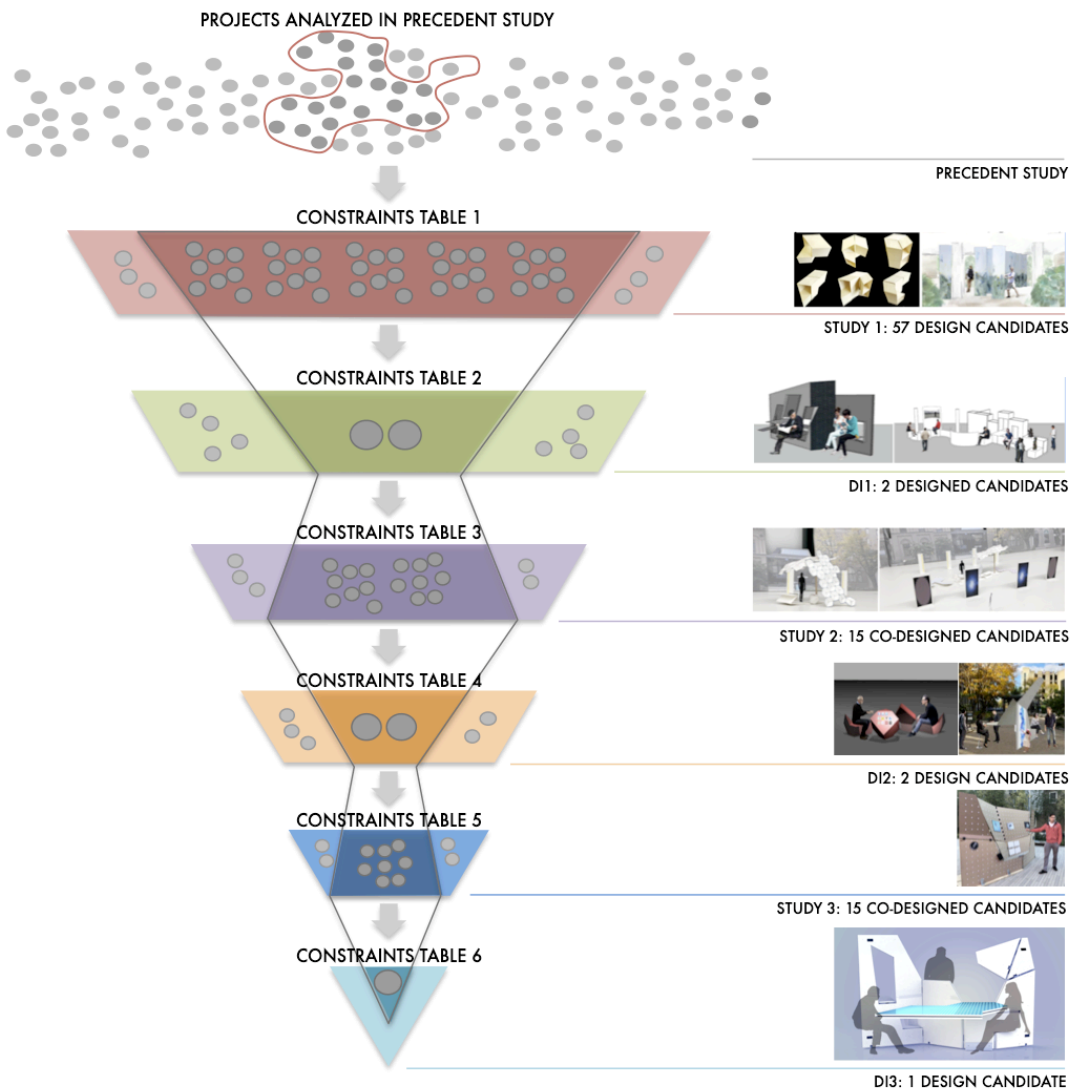

Figure 37: Model of communIT's design process.

<u>The design process of communIT:</u>

To begin our conversation I would like to introduce and describe Figure 37. This figure depicts the main design decisions we undertook throughout the design of communIT. In total, there are seven different design steps. These steps are indicated on the right side of the figure, organized chronologically from “Precedent Study” at the top to “Design Iteration 3 (DI3): 1 Design Candidate.” Below each design step, there is one or two images that corresponds to the design output. The right side of Figure 37 offers further information. Just below the “Projects Analyzed in Precedent Study,” we find a collection of these gray-colored points. These points symbolize all relevant precedent projects relevant for communIT. There is an amoeboid contour in the center that “surrounds” some of these points. This contour symbolizes the projects selected and analyzed in the precedent study. Those points outside this ameboid contour were not analyzed. It is unreasonable to think that a precedent study would recognize all relevant projects. This is why the image deliberately indicates that some of these relevant projects are unknown by the researchers.

We also find five colored, trapezoid shapes and one triangle, each one of these shapes is also populated with gray-colored points which, in this case, symbolizes the design candidates of each design step. There is also a zig-zag line that offsets inwardly these trapezoids. This zig-zag shape also separates the gray-colored point (i.e. the design candidates) in each of the trapezoids and in the triangle. Those gray-colored point outside the zig-zag are the candidates that, despite their feasibility, were not produced or selected in the design steps. This is to indicate that, in each design step, there were just a number of design candidates that are either produced of selected. As we already presented, it is unreasonable to think that a design activity could produce all possible design candidates for a given design problem.

Lastly, the zig-zag shape “closes-in” and “opens-up” from one design step to another. This is to indicate the “divergent” and “convergent” movements of our design process. In the convergent, we apply a set of constraint to reduce the number of candidates. In the divergent movement, we produce a great number of possible variations for the design problem. In our design process, we involved participants (i.e. students from Clemson and Cornell Universities) to produce innumerable possible design candidates for the respective studies (Studies 1-3). These correspond to the divergent movements. After each Study, we analyzed the candidates produced and extracted key design features that consequently informed my own design. My own design corresponds to the convergent movement.

Overall, we involved numerous participants to help us see a great number of possible design responses, and to find key design patterns and features. After that, we aimed to interpret the reasons behind participants design decisions rather than literally following (without understanding) their designs. These reasons, patterns, and design features, in consequence, were the guideline for our own design product. At least for us, a design is not simply the middle ground of all of the participants' designs. We instead drew on participant input "clues" informing for us the design characteristics of the artifact in relation to certain functions.

Although the zig-zag path suggests a linear progression towards "a satisfying" [10] solution, we must acknowledge that it should not be seen as linear. For each of the steps taken, we have selected and decided which candidates better satisfy the constraints. Clearly, other steps could have been taken if other groups of participants were involved. This mean that other design aspects could have received greater level of importance, and consequently other solutions would have been created. The design attributes of communIT, therefore, were dependent on what the participants envisioned during each Study. For instance, when participants envisioned communIT for collaborative uses among larger groups, participants tended to produce spaces physically larger and with less-defined physical boundaries. Spaces for supporting single users tended to be more enclosed, spatially. Perhaps, other groups of participants might not have suggested such a preference.

This model, thus, is one among many possible models of the design of communIT. A model that is a product of the particular context in which communIT was designed, considering the people (i.e. participants and researchers) involved in the process as well as the agency power distributed thought them. Although this model provides some illumination of "how we did communIT," it has its limitation as to revealing the inner working of the black-box of our design process. Further insights on the social powers structure and the distribution of powers within it are needed to more broadly comprehend the push-and-pull of communIT's design. Still, despite its limitations, what we offer here is more than just our black-boxed artefact. We offer a trajectory, a path—with several details on the questions and decisions we undertook. This path is available for other researchers to replicate, critically reflect, and perhaps modify as they search for satisficing [10] responses to support marginalized, misunderstood, or less-visible subgroups in the larger community.

Limitations

As in every research enterprise, there are some limitations to the investigation presented in this dissertation. The first main limitation relates to participants. As already presented in Chapter 2 and discussed in the present Chapter, the design of communIT considered students from Clemson University and Cornell University.

However, the evaluation of communIT included other participants that were not necessarily students. The selection of these different groups of participants is discussed in more detail in the Introduction of Chapter 2. Here, we limit ourselves in pointing that the selection of different groups for different phases might pose threats to validity.

More specifically, the Clemson and Cornell students might not represent the needs and aspirations of the population to which communIT was designed for—i.e., members of the community that might be discriminated against and misunderstood by the larger community. Examples of these groups ate black, immigrant, and LGBTQ+ subgroups. Our design involved university students in assisting us in finding key design patterns and features, which, at a later time, were used by us as a guideline for our own design product. And if these students might not have expressed specific desires and needs that were particular to these minority groups, then some specific characteristics of communIT might not have been carried out with deliberate thought. Even though our Evaluation—Chapter 3—suggests communIT's potential to serve members of the Subgroup, we nevertheless recognize that this "dilemma of participants" might threaten our findings.

The second main limitation of this research relates to what we presented in Chapter 3—Evaluation of communIT. Our initial plan was to conduct an in-person, in-place evaluation of communIT's last prototype. However, due to the limitations imposed by COVID-19, we had no choice but to design and conduct an online study instead of an in-person one. Even though this online study gave us a valuable understanding of how communIT might impact certain subgroups, such understanding was based on participants' virtual interaction with communIT. Participants did not directly interact with the physical artifact situated in-situ, and they might either under or overestimated communIT's attributes and capacities. This interaction constraint, we also recognize as a limitation of this research.

Future Implications

In recent events within the USA and also worldwide, we have witnessed an escalation of hate, violence, and threat against certain sub-groups. Nevertheless, with such violence also comes a reaction from other groups within society. Many social people went out to protest and voice their indignation towards these acts against minority groups. Social movements—e.g., Stop AAPI Hate—have brought hundreds of people on the streets to protest against violent acts on minority groups. And when we see these protests in the newspapers, TV, and other media, we mostly see demonstrations, marches, and motorcades. However, another kind of protest also suggests the promise of communIT, which is the appropriation of public infrastructure to exhibit products and messages.

Figure 38 is an example of such infrastructure appropriation for protest purposes. We can see here that a simple external cable box becomes a partner that continually broadcasts these messages beyond the duration of marches. This sort of artifact relates to communIT (Figure 39), as they play a role in community engagement. However, this research suggests that communIT might offers other affordances that expand the kind of media produces and shared and the kind of interaction people may have in a community.

In parallel, when we look at previous projects on how artifacts participate in community building, the literature shows projects that primarily focused on software and apps for smartphones and screens. There is little research on the kind of role and impact cyber-physical, architectural robotics artifacts may have for community engagement. In short, a future implication of this research—large-scale, configurable, interactive artifacts might prove valuable platforms for community engagement by media making and sharing. Installed in public outdoor and indoor spaces, these kinds of artifacts might help support marginalized, misunderstood, or invisible subgroups to make themselves visible within the larger community.

Figure 38. An example of a urban infrastructure appropriated to share messages.

Figure 39. communIT being used for media making and sharing.

Conclusion

Large-scale, *social*-cyber-physical artifacts can be a key component of what might build community. And as social computing systems become embedded into larger-scale artifacts, the wholeness of the design process presented in Chapter 2 offers a promising approach to exploring this emerging research space and making its outcomes especially meaningful to the cultivation of community engagement.

Design methods such as CoDAS introduced here allows designers to advance conceptual and interaction design as imagined by participants through the vehicle of scale-model actors, design components, and physical surroundings. As illustrated in Design Study-2 (in Chapter 2), the accounts of participants in our own implementation of CoDAS suggest that a participant's engagement and exploratory behavior with the scale model can offer an understanding of: (a) the attributes and affordances of design components, (b) the ambiance and spatial organization of the design, and (c) the interactive behaviors across actors.

Equally relevant is the use of large-scale prototypes in co-design studies to envision artifacts of the kind of communIT. While CoDAS offered an affordable and quick way to collaboratively imagine the characteristics of such artifacts, the co-design activity using large-scale prototypes further advances the understanding of the interactions people may have with such artifact. Specifically for communIT's design, the large-scale, co-design activity helped us to further realize (a) the physical configuration of the artifact, (b) the placement of IT element, and (c) the activities participants would engage in.

Of course, design problems of the kind undertaken here are wicked [9], under-structured [10], ones that do not produce a singular solution or a "one best way" [11]. The design process presented in Chapter 2 is, therefore, one among many possible paths we could have taken in what me be characterized as a "Research through Design" [14] investigation. Likewise, our current design iteration (Prototype 3) is one of innumerable possible design responses. For instance, communIT design would have been a completely different artifact had we selected the "block" typology instead of the "partition" one. Artifacts are but one particular response to a particular problem framing [13, 12, 11]. As a consequence, the problem framing, not just the design responses, equally influences the direction of the design trajectory. If we were to further iterate communIT, the consecutive user studies and design iterations would consequently alter communIT's design in expected and unexpected ways.

As for communities, these are complicated social forms [1] comprising both humans and nonhumans. They are also emergent forms, and their future development is dependent upon how they articulate and enable their activities, interests, and aspirations, amongst themselves and with other groups [6, 5]. For some [2, 3, 12, 7], community forms when the group recognizes, raises and discuss issues and their consequences. In this community action, artifacts can potentially play a role in building community. The potential for such human and non-human gatherings is made evident, for instance, in Latour and Weibel's notion of "object-oriented democracy" [1] which might characterize the capacity for communIT, an object drawing people to it, at the same time gather people around issues and their consequences.

With communIT, the broader impact we strive for is articulated eloquently by Eric Klinenberg in "*Palaces for the People: How Social Infrastructure Can Help Fight Inequality, Polarization, and the Decline of Civic Life*":

> *"People forge bonds in places that have healthy social infrastructures—not because they set out to build community, but because when people engage in sustained, recurrent interaction,*

particularly while doing things they enjoy, relationships inevitably grow [8].”

But while apps are said to reanimate social and civic lives, this research argues, instead, that the materiality of artifacts play a fundamental role in the way community is formed. Even more promising is the potential of embedding information technology in the physical fabric of the built environment, to augment the public, material space as loci for civic discourse and for addressing community challenges. As a cyber-physical, interactive, large-scale artifact, communIT is a way to bridge cyberspace and bricks-and-mortar to build local communities—the building blocks of a nation—through the interactions of individuals, groups, and the larger community.

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