A Pattern-Based, Design Framework for Designing Collaborative Environments

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ABSTRACT
Communication theory suggests that people tend to interact with interactive artifacts as if these were human. For decades, this understanding has been applied to designing singular, embedded artifacts at a small physical scale. In this paper, we extend the same theory and practice to the dimension of space—to designing interactive, physical environments and their components. A conceptual ground for this is found in a "pattern language" developed by Alexander et al. for designing static physical environments. Upon this ground, we construct a systematic framework for designing "collaborative environments" shaped, as well, by our own concepts, *Direct Mapping*, *Conveyed Mapping*, and *Space Agency*, to strive for more human-human-like interactions between human beings and their physical surroundings. Our lab-based study generates a hypothetical design as qualitative validation of the framework, which has significance for designing tangible, embedded, and embodied interaction as it extends, inevitably, to the dimension of space, entertaining, serving, and augmenting us.

Author Keywords
Design patterns; transdisciplinary research methods; critical making; spatial interaction; spatial reconfiguration.

CCS Concepts
• Human-centered computing → Human-Computer Interaction (HCI) → Interaction paradigms

INTRODUCTION
A Pattern Language (1977) [4] by Alexander, Ishikawa, and Silverstein was highly influential in architecture but has since become more impactful on computer science and its allied disciplines (as reviewed by [12]). *A Pattern Language* is comprised of 253 patterns guiding environmental design, presented as drawn diagrams and written narratives which "represent our best guess as to what arrangement…will work to solve…a problem which occurs over and over again" [4]. For instance, pattern 185, "Sitting Circle" (figure 1), offers an arrangement of living room furniture, whereby the selection of furnishings and their placement, relative to the walls defining the room, allow for an intimate correspondence between those who are seated as well as a path for others to circumvent this intimate gathering with the least disruption and most efficient movement. Recognize that pattern 185, typical of *A Pattern Language*, was as much about how people interact with each other—how they collaborate—as how people interact with their physical surroundings. Patterns were meant to be assembled into familiar routines of people and places that define our everyday lives.

In computer science and its allied disciplines, a pattern-based framework has been applied to the design of software (e.g. "reusable object-oriented software" [11]); to computer games (e.g. [22]; and to the expanding realm of IoT [36], given that a networked suite of interactive devices is inherently spatial as compared to human-computer interaction with a singular device, which is 1:1. A pattern-based framework has also been impactful in social and assistive robot research (see [20] for an overview), where it informs robot-environment interaction (in navigation and perceptual tasks within a room) and also robot-human interaction (whereby the robot exhibits human-like "behavioral patterns" perceived by humans as approachable, familiar, or what we define here as "collaborative"). As will be explored later in this paper, a pattern-based framework may also prove productive to the emerging domain of interactive and intelligent environments first imagined, tellingly, by a circle of

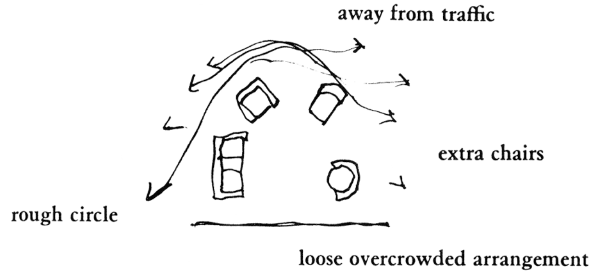

Figure 1. Pattern number 185, "Sitting Circle" [2].

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TEI '19, March 17–20, 2019, Tempe, AZ, USA
© 2019 Association for Computing Machinery.
ACM ISBN 978-1-4503-6196-5/19/03…$15.00
https://doi.org/10.1145/3294109.3295652

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Sequence	Research Activity	Interactive System	The "Lens" Used
1st	Ethnographic Study	Human-Human	Observation
2nd	Coding of Interaction Patterns	Human-Human	*From the literature:* • Grounded Theory Coding • Design Partnerships • Joint Action • CSCW Creative Workplace
3rd	Coding of Interaction Patterns	Human-Collaborative Environment	*Our own:* • Direct Mapping • Conveyed Mapping • Space Agency

Table 1. The design-research framework based on studies, theories, and other literatures.

researchers to which Alexander belonged that included Nicholas Negroponte (as elaborated in *Soft Architecture Machines*, [32]) and Gordan Pask (in "The Architectural Relevance of Cybernetics," [35]).

But the pattern language of Alexander et al., being based on professional "best guesses" [4] and conceived for designing static environments, is arguably an inadequate framework for designing computational systems that are spatial, collaborative, or both, given the complex interactions such systems afford. Consequently, this paper posits the question, *What is a pattern-based framework for designing computational artifacts that are integral to or constitute a collaborative environment*? In our effort to respond, we recognize such artifacts as "agents," defined as "any complex environment, including the built environment" [2], that is aware of, transmits, and receives information from the world, and also manipulates aspects of the world.

Rather than a framework drawn from "best guesses," our pattern-based framework overviewed in Table 1 is: (a) based in ethnography, (b) informed by a consideration of the literature (especially, communications theory), and (c) shaped by three of our own concepts—*Direct Mapping*, *Conveyed Mapping*, and *Space Agency*. Later in this paper, as a means to validate our framework, we report on a lab study that sought patterns in human-human interaction that we translated into patterns of interaction between humans and a collaborative environment of our own design. This singular case suggests an early, qualitative validation of the framework. We envision, in the future, our framework informing the design of wide-ranging tangible, embedded, and embodied artifacts as these become increasingly collaborative with us and extend, inevitably, to the dimension of space—supporting, entertaining, and augmenting us.

THEORETICAL FOUNDATIONS

In developing our pattern-based framework, we drew inspiration from the literature of communication theory—particularly the two concepts, "Computer as Social Actor" (CASA) [30] and "The Media Equation" [37], both of which suggest that people tend to interact with interactive artifacts as if these were human. This intimate, "Pygmalion," human-artifact relationship in fact dates to antiquity [33, 46], was recuperated in the Renaissance [3]), and persists still today in embedded artifacts. CASA and the Media Equation are concepts that advance our understanding of the human-artifact rapport when the artifact is interactive or intelligent by way of digital means. Collaborative environments and their integral components heighten the complexity of this rapport still further. In this section, we consider CASA and the Media Equation, and their import to the framework.

CASA and the Media Equation

With the rapid development of computational technologies, and as computer-embedded systems become more interactive and intelligent, researchers of the 1990s conceptualized the research paradigm, Computer as Social Actors (CASA) [30]. As part of this conceptualization, Reeve and Nass proposed "The Media Equation" (1996), a general communication theory that describes the tendency of people to interact and communicate with computer media as if this media were human [37]. Since then, many psychological experiments studying human communications have informed human-computer interaction design [31]. Initially, design researchers applied these psychological findings to virtual, avatar designs [45]. More recently, design researchers have been transferring "common, interpersonal communication phenomena" [31, 37] to tangible, embedded, and embodied systems such as social robots [14, 15], and robotic furniture [42] (the latter being pertinent to our case study, presented later in this paper). As will be elaborated here, our case study extends this conceptualization to a robotics-embedded collaborative environment supporting and potentially augmenting work activity. The case study aims to make evident that studying human-human collaboration reveals patterns of interactions that translate to patterns of how people and a collaborative environment might interact. Such patterns could then shape how collaborative environments and their components are designed, and the interactions such agents afford.

ANALYTICAL FOUNDATIONS

In developing our pattern-based framework, we also drew inspiration from four analytical foundations from the literature: the grounded theory coding method, and the literatures of design partnerships, Joint Action, and Creative Workplaces drawn from the CSCW (Computer-Supported Cooperative Work) community. We briefly consider these foundations and their import to the framework.

Grounded Theory Coding Method

"Grounded theory coding method" [8] is a well-accepted and commonly used coding technique for analyzing transcripts of ethnographic studies [24]. Charmaz identifies four steps [8] in the grounded theory coding process: "initial coding," "focused coding," "axle coding," and "theoretical coding." At a minimum, grounded theory coding should include "initial coding" and "focused coding" (as our research team accomplished in the case study, soon to be considered).

There are several reasons to use grounded theory coding method in a pattern-based design framework; the most important one is that grounded theory coding requires researchers to "stop and ask analytic questions" of the data collected [8]. Such questions not only "further our understandings to the studied life," but also "help us direct subsequent data-gathering toward the analytic issues we are defining." [8] In this way, design researchers are not only identifying interaction patterns, but also exploring deeper questions such as the *why* and *how* certain interactions occur. Asking these questions is vital for deeply understanding human-human interaction that lends well to coding robust, human-artifact interaction patterns.

Design Partnerships, Joint Action, and CSCW

In developing our framework, we attended to a review of the literature pertaining to how design partners "design-think" [10, 23, 25] and both gesture and communicate through design, with special consideration of "face-to-face gestural interactions" occurring during the design process [6]. Insights from this literature inform the ethnographic study of human-human collaboration, offering sign-posts to the activity of observation.

From the psychology literature (e.g. [21]), interactions between human beings working closely together may be categorized as "joint actions," which describes both "emergent coordination" and "planned coordination." People perform "joint actions" when they "coordinate their actions in space and time to produce a joint outcome" [21]. When two people work together (as we observed in our case study of collaborating, human designers), the collaborating couple or group performs "joint actions" with clear goals and purposes, a "coordination" pattern of human-human actions characterized as "planned." Human-human coordination may also "emerge," unplanned [21].

Furthermore, our framework was informed by the literature from "design communication" (e.g. [43]) and CSCW. We found particular relevance in CSCW research focusing on Creative Workplaces [38, 47] with a focus on empirical studies recording sequences and frequencies of different design activities [43] and properties of "work space informal communications" such as "frequency, duration, and whether [such communications are] pre-arranged" [47]. These studies inspired us to further investigate how social cues "shape task coordination and communication" [38].

Creative Workplaces

Towards conceptualizing our framework, we also found inspiration in empirical studies focused on physical settings salient to creativity in the workplace. Martens [26] outlined typically characteristics of the creative office: it is "informal," "family like," and provides a degree of user "control over the space." Furthermore, McCoy and Evans [27] identify five abstract dimensions of the creative workspace: "nature," "challenge," "freedom," "support," and "coherence." For each of these, McCoy and Evans elaborated its formal characteristics: "spatial form (size, dimension & shape)," "light," "internal organization of objects," "characteristics of bounding surface," "color," "texture," and so on. [27]. Stokols et al. [44] meanwhile argue that "levels of environmental distraction (noise, foot traffic, etc.)" are significantly related to "perceived support for creativity at work" [44]. Additionally, Martens [26] and McCoy [27, 28] performed literature reviews on "physical work spaces" and "creativity" that suggest that creative workplaces offer a variety of personalized spaces, secluded private spaces (offering "freedom, security and control") and "open offices" [26]. The Creative Workplaces findings and characterizations were helpful to us in forming an understanding of the physical context that shapes the collaboration of human partners.

What might seem a haphazard encounter with various literature has, taken together, significant implications for understanding human-human partnerships as afforded by the physical environment, and especially those environments which are interactive and moreover "collaborative."

THREE NEW "TRANSLATIONAL" CONCEPTS

Designing an environment that is perceived as human-like, or what we call here "collaborative," brings new design challenges. In designing a collaborative environment, the designer transfers observable human-human interaction patterns as much as, and as precisely as possible, to human-environment interactions so that users interact with their physical surroundings as if the environment and its component parts were human-like in at least some respects. Towards this aspiration, we introduce three novel concepts to guide the design process of mapping human-human interaction patterns to human-environment interaction patterns.

Direct Mapping

In the proposed design framework (as captured in Table 1), observations of human-human interaction are coded as patterns—a coding procedure that is not trivial but also not unfamiliar to many design researchers. Subsequently, such human-human interaction patterns are translated into human-environment interaction patterns. This translation is very much itself a design process—part-science, part-art. Some human-human interaction patterns can be "directly mapped" to human-environment interaction patterns. For instance, people actively engaged in collaboration with one another frequently use their arms to form gestures that communicate their ideas. In direct mapping, these physical gestures formed by human arms are recreated rather directly in the cyber-physical system.

We use the term "Direct Mapping," thus, to describe a design process in which human-human interaction patterns are directly copied, imitated, and applied to human-environment interaction designs. For instance, a robotic arm might closely replicate the gestures observed in the human-human work space. Presumably, the same gestures enacted by the robotic artifacts would convey the same messages to a collaborating human as did the human arm. This presumption has already been verified in human-robot interaction research [13, 14, 19], and [41] where Direct Mapping predominates. For example, Hoffman et al. designed a lamp robot called "Kip" [13] that directly maps various human expressions. Another example focused on the built environment, comes from Ju et al. [19], whereby an automatic door "gestures" those entering a building as if it were a doorman opening the door.

Conveyed Mapping

There are many human-human interaction patterns that cannot be directly mapped to human-environment interactions. Obvious examples include eye contact, facial expressions, a sense of humor, and other subtle gestures. It is indeed difficult to imagine how an environment-as-agent, no matter how interactive or intelligent, could offer "eye contact" "smile," or "wink" to its human collaborators. Many of these subtle but significant social cues are used for reaching a common ground amongst human collaborators, during verbal communication, as defined and studied in the theory of "Grounding in Communication" [9]. Although these communications cannot be directly mapped to, say, a smart device, the meaning of these communications delivered by such a device—the messages it conveys—can be understood by human recipients. Consequently, we strive to design human-machine interactions in which the artifact conveys sufficient (i.e. discernable, perceivable) approximations of cues that humans naturally convey using subtle, social cues. For example, although a room cannot "nod its head" to encourage a conversation, maybe the room can "blink" green LED lights during a conversation to convey a semblance of encouragement to a human partner. We therefore use the term Conveyed Mapping to describe a design process in which human-human interaction patterns cannot be directly mapped to an artifact but nevertheless can be mapped in such a way as to convey the same core message as found in human-human interactions. The conveyance comes by way of a substituted gesture that the system is designed to deliver (e.g. approval by "green blinking lights" as a conveyance of "head nodding").

Space Agency

In recent years, HCI research has, on one hand, focused on designing objects that might take a more figurative form (e.g. the aforementioned "Kip" [15]) or a more abstract form (e.g. a "mechanical ottoman" [41]) that is, in both cases, perceived by users as human-like. On the other hand, HCI research has increasingly focused on the dimension of space, extending "ubiquitous computing" to (for one) "smart cities" with special attention to "natural interfaces, context-aware applications, and automated capture and access" [1]. These two tendencies of HCI suggest the importance of human-like agency and "cyberspace" [17] that, taken together, suggest the need of HCI designers to focus attention increasingly on realizing an "information space" [7], one that seems familiar, or (at least) one that invites collaboration. However, HCI researchers entering this research domain have tended to focus more on embedding technologies into *existing infrastructure* rather than designing newly realized, cyber-human environments [1]. We call the latter a "Space Agent" (see figure 2) an interactive or intelligent artifact that is both environmental (i.e. space-making) and human-like in (at least some of) its behaviors. Situated in HCI's intellectual landscape

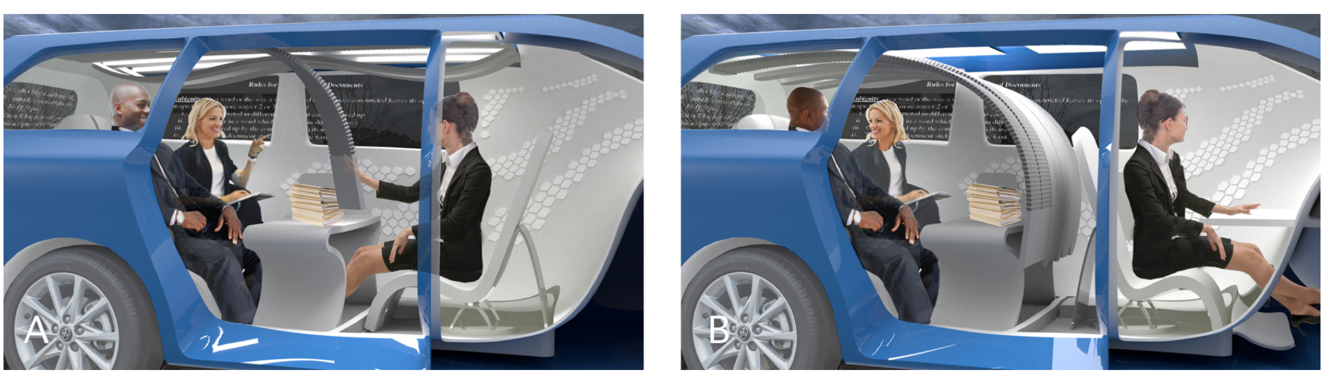


Figure 2. Our vision of how Space Agents (here, robot surfaces) might be implemented in a fully-autonomous car.

Focused Coding	Initial Coding	Insights from Former Research & Theories
Non-verbal, bodily communication	arm gestures; shape, direction & feelings; mimicking characters, etc.	Four types of gestures for design tasks and meetings: kinetic, spatial, pointing & other [6].
Inspiration cues	brain storming; abstract ideas; bold designs; share personal stories and experiences; ideas on drawing boards, etc.	Create idea maps and leverage ideas from others to generate more creative and diverse ideas [40].
Facial expressions, eye contact, social cues.	eye contact with audience; showing interest and enthusiasm; positive confirmation; conversational encouragements, etc.	Four themes (with 13 models) for observed social cues and task outcomes; rapport in negotiation (laugh); establish procedural grounding (gaze); deictic in shared contexts gestures (points); non-verbal feedback to avoid interruptions (nod) [38].
Cheerful & relaxed atmosphere	funny pictures or news; smiling face stickers on walls; cheerful talks; chatting and gossip; snacks, etc.	"SYMLOG three-dimensional-space"—a positive working atmosphere encouraging creative discussions and improving work efficiency [5].
Place-based cues	Tell stories of a remote place: travelled there before; lived there before; having friends there; perception of the culture; local practices and policies, etc.	Using lights, sounds and movements to simulate environment, seasons, feelings of the places described in story books [39].

Table 2. Study results of the initial design partnership study – five examples.

somewhere in the space between smart objects, intelligent environments, and smart cities, Space Agents are capable of performing some manipulation tasks we might expect from a humanoid or industrial robot (e.g. grasping, reaching, supporting, pointing, twisting, carrying, pushing, lifting) while also capable of reconfiguring the spatial envelope of the room to shape, essentially, "different rooms" matched to the unfolding of human-artifact collaboration.

We use the term "Space Agency," thus, to describe that design attribute in which human-human interaction patterns are embodied in a collaborative environment or its constituent components to forge productive and satisfying human-environment interactions.

CASE STUDY: COLLABORATIVE WORK ENVIRONMENT

We used our pattern-based framework, overviewed in Table 1 and elaborated in the previous sections, to design a collaborative work environment inspired by recent interactive and intelligent environments, including the *InteractiveWall* [16] by the Hyperbody Research Group (TU Delft), *Lift-Bit* [34] by Carlo Ratti (MIT), *AWE* [12] by co-author of this paper Keith Evan Green (Cornell), and the *ambientROOM* by Hiroshi Ishii (MIT) [18]. We envisioned our collaborative environment comprised, in part, by one or more Space Agents. For this collaborative environment (in more practical terms), we envisioned a Space Agent as a tendon-driven robot surface that is a cross between a human arm and a physically reconfigurable "ribbon" several feet in length (see figure 2). Performing manipulation tasks and defining the physical envelopes of rooms, Space Agents have potential, promising application to interiors of many kinds, including dwellings, hospitals, autonomous vehicles, spacecraft, and space habitation. Figure 2 shows our Space Agent robot surface implemented in a fully-autonomous ("level-5") vehicle. Our design objective is twofold: (a) to provide inhabitants many "rooms" configured by these robotic surfaces within a relatively compact habitable space; and (b) to envision such robotic surfaces not as components of a passive frame but as intelligent agents partnering with their inhabitants in human-collaborative environment activity—what we've called here "Space Agency."

We began the design cycle by observing human pairs partnering on a design task. From these observations, we generated patterns modeling human-human interactions which we then translated to patterns of interaction for a human designer collaborating with an intelligent, "human-like," physical space to accomplish the same design task. Interactions of human design partners were systematically coded as informed by Charmaz's "grounded theory coding technique" [8], design-partnership studies defined as "joint action" [21], and the CSCW literatures [47] (particularly that of the "Creative Workplace") [26]. Study results were mapped to human-environment interaction patterns guided by our three concepts introduced here for the first time: Direct Mapping, Conveyed Mapping, and Space Agency.

Ethnographic Studies of Design Partnerships

Our ethnographic study focused on understanding face-to-face interactions between design partners collaborating on a design task. In our study, we observed four groups of designers (12 participants in total), each group comprised of two to four designers. The first three groups were formed by undergraduate design majors at Cornell University, while the fourth group had one professional architect and one design-focused doctoral student. Members of the three groups of undergraduate designers granted us permission to conduct observations of and interviews on their design processes, and to record field notes, pictures and videos. Members of the fourth group—the design professional and the Ph.D. student—only permitted us to conduct interviews with them. We did a forty-minute in-depth interview with this one group. For each of the three undergraduate student groups, we observed each group's design process in their studio workspaces for no less than 1.5 hours and as many as 3 hours, and recorded their interactions using video cameras, digital cameras, and hand-written field notes. At the end of each session, we did a 15-minute interview with one member of each team.

Following the observations, we coded our field notes and digital photos, and transcribed the video recordings [29], analyzing the transcribed materials using Charmaz's grounded theory coding techniques (i.e. "initial coding" and "focused coding") [8]. Given this paper's focus on a design-research framework, and given the paper's page-limit, we present here in Table 2 (found on the previous page) only the coding results and their associations with what we learned from the most relevant literatures.

Mapping Human-Human Interactions to Human-Environment Interactions

From the coding results and insights, we identified four distinct human-human interaction patterns as a means to validate our design-research framework:

- *Arm Gestures* are a means of pointing and communicating shape, size, directionality, and other forms of communication produced by the upper limbs.
- *Positive Social Cues* express enthusiasm, encouragement, or agreement.
- *Inspirational Cues* include storytelling and sharing abstract ideas.
- *Place-based Cues* reference remote places, including their histories, cultures, local living styles, policies, etc.

Arm Gestures are interaction patterns involving physical movements of the arms. For Arm Gestures, we used Direct Mapping, given that these physical gestures can be transferred directly to the physical trajectories of the space agents.

Positive Social Cues such as those communicating enthusiasm are difficult to directly map to the Space Agent. Thus, we use Conveyed Mapping to convey the same messages by creating new forms of interaction that can be achieved via the Space Agents. For instance, a Space Agent might express enthusiasm through its animated movements and flashing rainbow colors produced by embedded LEDs.

Inspirational Cues are the stories and shared experiences people tell each other to get inspired. There are many ways a room might tell a story. Direct Mapping could, for instance, suggest having the room and human designer "exchange" stories with the use of a whiteboard: the human designer can use the whiteboard to post ideas, and the room's intelligent system then uses this input to search the internet for relevant stories (news reports, documentaries, fictional accounts etc.) based on the keywords of the post. This information can be presented on a display embedded in the Space Agent or on the wall or ceiling, and the Space Agent might move and emit color and audio to bring attention to the story and even capture the atmosphere of it (as our lab has done previously with the LIT ROOM [28]).

Place-based Cues might communicate information about a remote place that is relevant and informative to the work at hand. While the human designer may use only words and nonverbal communication such as hand gestures to describe a remote place, Indirect Mapping might make full use of the Space Agents with its embedded lighting and audio to evoke the site environment and its atmosphere, rendering the whole of the environment a "portal" to somewhere else [12]. This use of ambient media is partly inspired by Ishii's ambientROOM [18] cited earlier, which communicates information more in the background than the foreground of our attention. However, for our case-study design, we imagine ambient media also being, when appropriate, in the *foreground* of our attention, depending on the context.

For our case study (at least), a key contribution of the Space Agent robot surface is its capacity to bring an element of surprise to the creative process that, for Cross [10] and Maher [25], offers that "impetus for framing and reframing the problem, thereby avoiding routine," [10] rather unproductive behavior in the designer.

In the design activity, one should recognize that the application of either Direct Mapping, Conveyed Mapping, or Indirect Mapping is a design decision made by design researchers. Similarly, even with the same mapping method, different designers might arrive at different design outcomes because of the creative nature of implementing the pattern-based framework. The three mapping strategies of our pattern-based framework—Direct and Conveyed Mapping, and Space Agency—are intended to generate inspired design solutions rather than rigid or formulaic outcomes.

FROM HUMAN-ENVIRONMENT INTERACTIONS TO DESIGN PATTERNS

In this section, we explore how the human-environment interaction patterns of our case study might generate "design patterns" for a collaborative environment supporting and even augmenting design activity. Helpful to us in this translation was the "Creative Workplace" literature, for instance, in suggesting the use of "fluid shapes" in space [27] for fostering creativity. As follows, the Space Agents (of continuum robot technology [12]) allow for fluid rather than rigid motion and shape-making. Additionally, following Martens' suggestion[26] that workspaces provide users with some measure of control over their physical environment, we designed an environment that may be physically shaped by direct control of its human collaborators.

Table 3 illustrates the human-environment interaction patterns and the corresponding design patterns generated. We recognize that these patterns are neither the only patterns nor the best design patterns. Nonetheless, these patterns are reasonable and logical ones based on our human-environment interaction patterns and what we drew from the Creative Workplace literature. In Table 3, we present these patterns in the manner of *A Pattern Language*—as both diagrams and brief narratives.

As Alexander et al. reminds us, "no pattern is an isolated entity"—a pattern can only exist "supported by other patterns: the larger patterns in which it is embedded, the patterns of the same size that surround it, and the smaller patterns which are embedded in it" [4]. For the few patterns presented in this paper, each of these patterns can follow another one in time; and at one time, one pattern can be

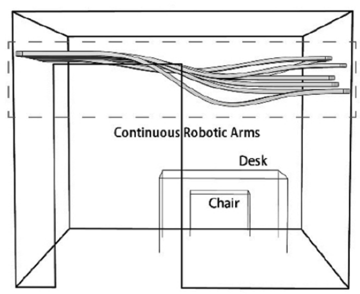
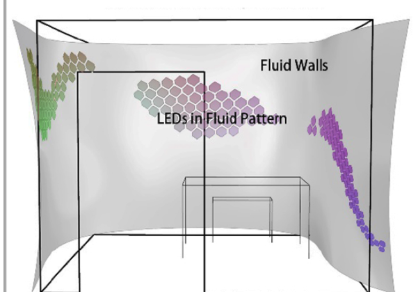
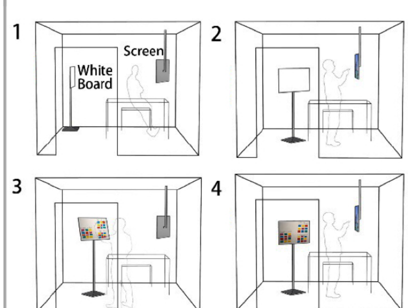
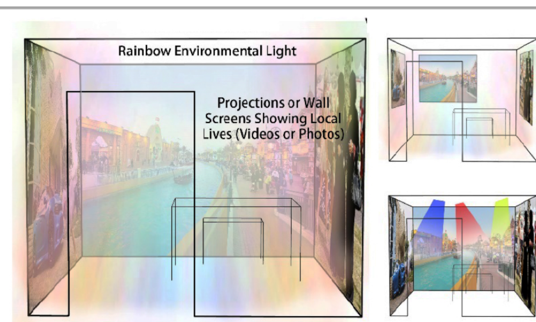
Human-Environment Interaction Pattern	**Design Pattern Diagram**	**Design Pattern Narrative**
Arm Gestures to Space Agents		Space agents (continuum robot surfaces) physically reconfigure to "point" and to convey shape, orientation, direction, and the like. These robot surfaces can be mounted on or embedded flush with ceiling and wall surfaces or, alternatively, be free-standing within the volume of the room.
Positive Social Cues to lighting effects		Lighting is one means to convey "positive social cues." Changes in color, intensity, patterning, and periodicity/duration may be perceived by the human collaborator as a form of encouragement. Such lighting may be combined with the movement of the space agents to further the impact.
Inspiration Cues (story-telling) to white board input by human designer and responsive content content identified by AI, presented on displays		The collaborative environment and human designer can "exchange" stories with use of a whiteboard: the human designer can use the whiteboard to post ideas, and the room's intelligent system then uses this input to search the internet for relevant stories based on the keywords on the posts. This information can then be presented on a display, embedded in the space agent, or projected on the wall or ceiling to capture the atmosphere of it.
Place-based Cues to multi-media display		Using images, video, audio, and lighting to evoke a remote place that might stimulate creative thinking. The space agents might work in concert with this audio-visual output, rendering the whole of the collaborative environment a "portal" to somewhere else.

Table 3. Five human-environment interaction patterns and their corresponding design patterns.

layered upon another one, which collectively constitute larger patterns. In Table 3, for instance, we see the design patterns not operating in isolation (e.g. only the Space Agent's impact, as presented in the uppermost row) but combined with the effects found in rows beneath it, so that the shape-making Space Agents operate in concert with the lighting effects and audio of the room to offer Place-based Cues [6].

Admittedly, each of the patterns presented in Table 3 require further investigations to ensure that human users understand the conveyance of the human-like interactions offered by the collaborative environment. Such experiments would undoubtedly alter the patterns of Table 3 and may yet generate additional patterns which would, as Alexander et al. offer, represent "more true (sic), more profound patterns" that over time become "a common language, which all of us can share" [4].

CONCLUSIONS AND FUTURE WORK

In this paper, we presented a pattern-based framework for designing interactive artifacts that are spatial and human-like, following (in part) from communication theory and related literature. In so doing, we have explored how human-human interaction can be studied, analyzed and translated to interactions of people and their cyber-physical surroundings—the latter we defined here as "collaborative environments." As part of our framework, we introduced three novel, translational strategies: *Direct Mapping*, *Conveyed Mapping*, and *Space Agency*. Our case study—the design of a collaborative environment for design activity—served as a means to elaborate and validate the framework. As prescribed by our pattern-based framework, the case study traced the following sequence of activities: ethnographic studies of human-human interactions, mapping human-human interactions to human-environment interactions, generating design patterns based on human-environment interaction patterns, and generating the collaborative environment design from these design patterns. Our future work involving human participants will (a) investigate if and how-well distinct patterns generated through the case study communicate (e.g. enthusiasm) to participants as we intended, and (b.) measure the impact of the Space Agents (i.e. robot surfaces) in their physical surroundings on a single human designer undertaking a design task, as comparted to a control in which two human designers partner on the same design task.

Increasingly, our physical surroundings are becoming interactive and intelligent by way of embedded system. The authors of this paper, by no means, contend that our pattern-based design framework is the only way to design interactive and intelligent artifacts. However, it is difficult to identify embedded artifacts that are without spatial implications, given their numbers, their networking, and their other, expanded behaviors. Furthermore, for such artifacts, we tend to expect from them behaviors that are natural and familiar to us—that are perceived by us as collaborative. And so, as design researchers strive for more human-human-like interactions between human beings and their cyber-physical surrounding, our framework holds particular promise.

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