Infotropism: Living and Robotic Plants as Interactive Displays

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Abstract

Designers often borrow from the natural world to achieve pleasing, unobtrusive designs. We have extended this practice by combining living plants with sensors and lights in an interactive display, and by creating a robotic analogue that mimics phototropic behavior. In this paper, we document our design process and report the results of a 2-week field study. We put our living plant display, and its robotic counterpart, in a cafeteria between pairs of trash and recycling containers. Contributions of recyclables or trash triggered directional bursts of light that gradually induced the plant displays to lean toward the more active container. In interviews, people offered explanations for the displays and spoke of caring for the plants. A marginally significant increase in recycling behavior (p=.08) occurred at the display with living plants. Apparent increases also occurred at the robotic display and a unit with only lights. Our findings indicate value in exploring the use of living material and biomimetic forms in displays, and in using lightweight robotics to deliver simple rewards.

Categories & Subject Descriptors: H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *evaluation/methodology, prototyping, user-centered design*

General Terms: Design, Experimentation.

Keywords: plants, robots, ambient displays, recycling, interactive displays, biomimetics.

INTRODUCTION

Motivation

Borrowing materials or metaphors from the nonliving part of the natural world, such as water or wind, is now an established practice in the design of interactive displays [1,2]. Some designers draw more deeply upon the living part of nature, imitating biological forms and behaviors with artificial materials and techniques (biomimetics) [3,4,5]. We have extended these practices by combining living organisms with electronic components in an interactive display.

Figure 1. A group of living plants displaying information.

We decided to use plants in our initial exploration of this design space. We were inspired by the observation that plants are naturally informative. Plants are constantly accumulating and displaying the effect of stimuli over time in a form that humans can interpret. For example, houseplants generally point toward the primary source of light in a room, and an accumulations of moss on a tree trunk indicates the direction North. Both of these examples showcase the ambient quality of plants as well as their legibility and simplicity. They also suggest that plants could be most appropriately used in a display of local information aggregated over time.

Since plant behavior is constrained in familiar ways, we thought that plants could contribute to a unique legibility in an interactive display. In discussing the design of tangible interfaces, Ishii et al. describe gains realized from respecting users' prior understanding of physical principles: "People know what to expect of a flashlight, know what to expect of lenses." [2] We thought this reasoning might be extended to biology. People know what to expect of plants.

We also thought the aliveness of plants could contribute to a compelling and engaging emotional quality in our design. If people's affinity for other living things were to translate into a receptivity to living things used as displays, we would expect such displays to be engaging and compelling. People might alter their behavior more, or for longer, in light of relevant information presented by a living or lifelike display. In certain contexts the effect could be measurable.

Related Work

A number of related works have used plants and plant forms to fill functional, aesthetic, and conceptual roles. Some feature artificial plant forms enhanced with interactive capabilities. LaughingLily is an artificial flower augmented with microphones and electromagnets that make the petals respons to the volume of nearby conversation [3]. Office Plant #1 actuates aluminum plant-like structures in response to a user's email activity, and "fills the same social and emotional niche as an office plant." [4] CyberFlora is a commissioned exhibit for the Cooper-Hewitt Smithsonian Museum featuring 20 robotic flowers sensitive to temperature, infrared light, and capacitance [5].

Artists have used living plants as media and environmental probes. Ackroyd and Harvey imprinted complex images and patterns on live seedling grass, using varying levels of light intensity [6]. Jeremijenko created the OneTree project, which used plants as distributed sensors and recording devices [7]. Pehrson connected a Yucca plant to a stock trading program via electrodes, giving the plant water in return for successful trades [8]. Goldberg's Telegarden connects human gardeners to a remote garden via a web-interfaced robotic arm [9].

Our living plant display contributes to this design space in a new way by combining living plants with local interactivity. Our robotic plant is the first to imitate a phototropic response in order to convey infomation. Both of these artifacts embody and exemplify a changing relationship between the living and the artificial.

DESIGN PROCESS

Ideation Phase

Our design process began with the idea of using living plants to convey infomation about human activity. We had two initial goals: (1) to make an interesting, relevant display; and (2) to use plants in a novel yet appropriate way. We explored these initial goals through a series of concepts.

Plant Manipulations

We initially researched altematives based on plant responses to a variety of stimuli. Plants are sensitive to touch (thigmonasty), orientation (negative gravitotropism), and water sources (hydrotropism). (Figure 2) We also considered changing the health of plants by giving and withholding nutrition. An undesirable state of affairs could be communicated by an unhealthy plant, and vice versa.

We focused on the idea of manipulating plants with light, because of its simplicity. Light can influence the health of plants, but it can also change their shape and direction of growth. (Figure 3) For example, low pressure sodium light results in thick stems, multiple side shoots, and deep green foliage, while incandescent light results in elongated stems, suppression of side shoots, and paling of foliage [10]. We realized that by using light to bend plants from left to right, in a vertical plane, we could produce a form similar to a needle gauge. (Figure 4) This would be less ambiguous than other manipulations. Although it would limit us to presenting ordinal data, this worked well with our subject matter.

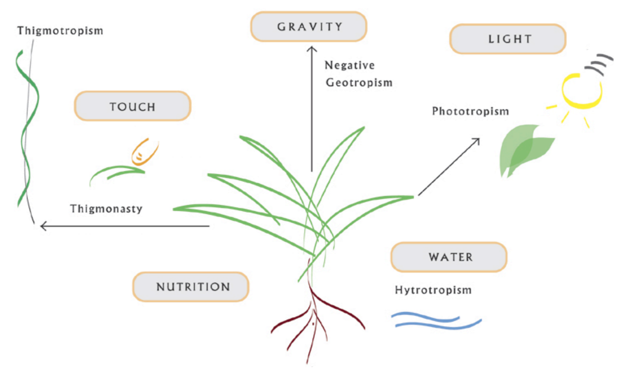

Figure 2. Concept sketch of possible manipulations.

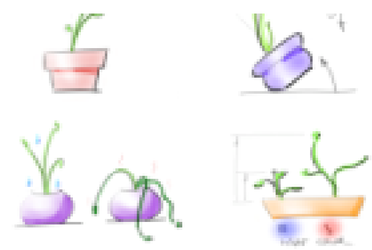

Figure 3. Clockwise, from upper left: (1) bending plants toward light, (2) tilting container while plant grows upward, (3) influencing health with nutrition, (4) using light to control side shoots, budding, and/or height.

Figure 4. "Needle gauge" design for ordinal information.

Recycling as a Subject Matter

We chose recycling as a subject matter while considering a cafeteria as a space for a public display. People could anonymously interact with such a display, but it would still deliver interesting, personally relevant infomation. Recycling is dispersed over time, but localized in space, as are the stimuli to which plants usually respond. Also, recycling is a practice in which individuals often feel their actions have no effect, and yet aggregate behavior has a very real effect.

We decided to map contributions of recyclables and trash into bursts of directional light, directed toward either side of a group of plants. If the trash side received more light than the recycling side, the plants would eventually lean toward the trash. This would communicate a very simple idea, which is that people throw away more than they recycle.

Biomimetic Robot Plant Concept

While generating concepts for our living plant display, we realized this was an opportunity to exhibit a robotic analogue in tandem with a living display. We began developing prototypes in parallel, cultivating living plants while sketching and constructing robotic plant components.

Prototyping Phase

Living Plant Display

We consulted with local horticulturalists and greenhouse workers to determine what varieties of plants would be suitable for our design. While some mature plant varieties are highly responsive (sunflowers, for example, follow the sun precisely), vegetable seedlings are very responsive in general. After testing and rejecting beans, peas, radishes, carrots, and mimosae obtained from gardening supply stores, we settled on corn seedlings. These offered the advantages of a pleasing, easily imitable form and dramatic growth over a 1-week period. We planted the seeds 1” apart in aluminum bowls filled with Miracle-Gro® AquaCoir™ soil, keeping duplicate bowls growing in case of accidental damage.

We also tested various lights, including fluorescent, incandescent, and halogen bulbs, in conjunction with the growing plants. Timing the plants’ response, we found that a visible lean resulted from 8 hrs/day exposure to 100W Sylvania “Daylight” bulbs in only 3-4 days. We used these bulbs in our final design.

Biomimetic Robot Plant Display

As we explored different species of living plants, we generated multiple sculptural forms, materials, and leaning behaviors for a robotic analogue. (Figure 5)

We started by considering ways to mimic the colors, textures, and shapes of living plants. Purchasing silk plants was one option, but silk plants generally imitate slow-growth species. We opted for designs focused on mimicking phototropic behavior. In the end we settled on Calder-like [11] planes of color in the shape of living corn sprouts. (Figure 7)

We considered making the electromechanical plants modular, and equipping them with individual photosensors. (Figure 5) We simplified this by driving a group of plants and making them “infotropic” instead. Here, we incorporated a stamp microprocessor (Figure 6) and implemented a custom serial communication protocol. The robotic plants responded by turning left or right as a group, in 5-degree increments.

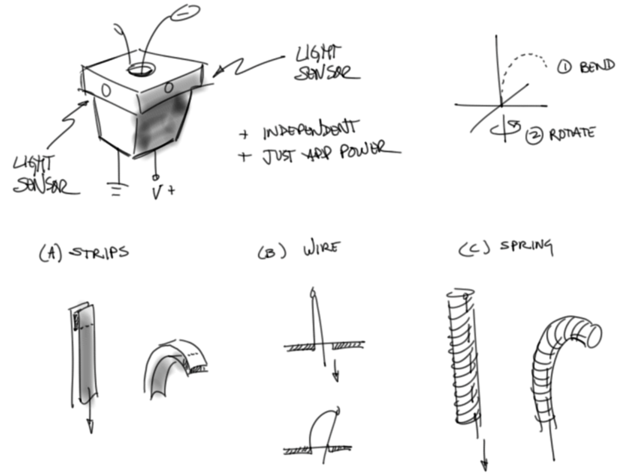

Figure 5. Concept sketches for robotic plant behavior mimicking natural phototropism.

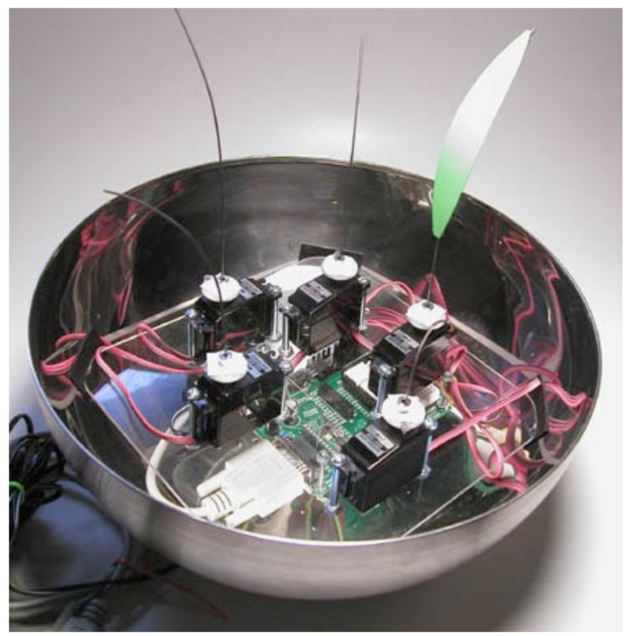

Figure 6. Inner workings of robotic plant display, showing basic stamp, servos, and wireform sprouts.

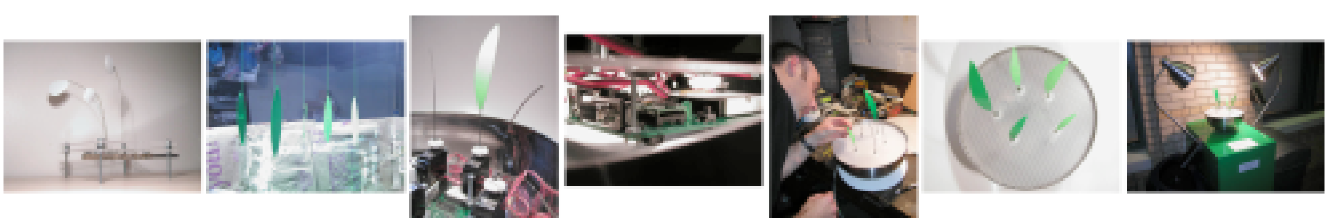

Figure 7. Robotic plant development, left to right: early mechanism; Calder-like sprout forms; servo and sprout connected by wire; Basic stamp controller; covering final assembly; view from above; final robotic display in public.

Figure 8. Final unit design with plant display in cafeteria.

We constrained the robotic display, like the living display, to movement in a single plane. This served two purposes. As previously discussed, it simplified information mapping, and increased the legibility of the display. Second, it simplified the mechanical tasks involved. Although the robotic sprouts rotated in a horizontal plane, while the living plants grew and tilted in a vertical plane, the general effect of "leaning this way or that" was realized in both.

Unit Assembly

We used lamp dimmers and Eagle Eye motion sensors from X10, a popular home-automation supplier [12]. Our trash and recycling canisters had narrow openings, forcing users to place rather than toss cans and bottles. The sensors would detect the presence of a hand at these openings. However, we had to restrict the sensors' peripheral vision, so they would not be overly responsive. We enclosed the sensors in triangular housings made of black foamcore, which had the drawback of making them more obvious. Sensors were networked using extension cords to a central computer housed inside one of the display stands. The computer turned lights on for 10 seconds when the sensors were triggered, and slowly dimmed them to darkness. We used several Linux-based freeware programs, including heyu and Xtend, to control the X10 modules and record events.

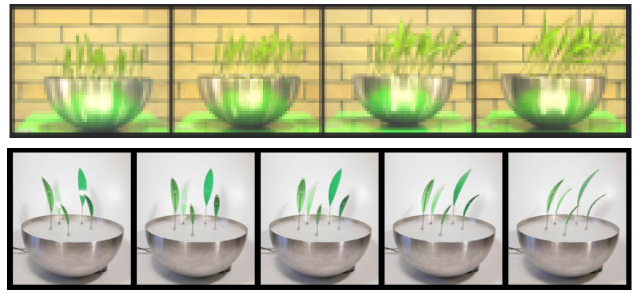

Figure 9. Progression of changes in both plant displays, indicating more trash disposed than recycling. The living plant is also exhibiting 4 days' growth.

EVALUATION

1.1 Setting

We evaluated our design with a two-week field study in our building's cafeteria. This cafeteria is frequented by faculty, students and research scientists of high technical expertise. Patrons are generally familiar with systematic methods of experimentation. They are about 2/3 male, and most are between 18-27 years of age.

We kept the normal pairing and arrangement of trash and recycling containers in the cafeteria. Research has shown the proximity and availability of recycling containers influences their use [13]. This meant we had 4 locations for our new units, equally spaced around the perimeter of the room. (Figure 10).

1.2 Procedure

Baseline (Week 1)

For the first week, we introduced only the display stands, trash and recycling containers, and sensors, without the lights and plant displays. This gave people time to become accustomed to our new designs. We began to weigh all trash as it left the cafeteria, four times daily. We also hand-counted, every night, the number of items recycled.

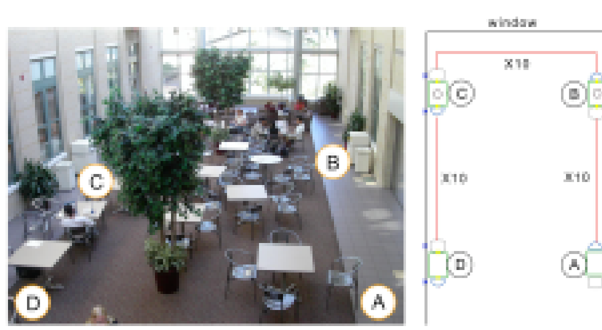

Figure 10. Arrangement of units in cafeteria. During Week 2 the initial conditions were: A=Control, B=Robot + Lights, C=Living + Lights, and D=Lights. Locations of Robot and Living displays were switched midweek.

Display Introduction (Week 2)
One week later, we created four display conditions: Control (no lights or displays), Robot + Lights, Living + Lights, and Lights. The locations of the plant displays were chosen as the two most equivalent in terms of waste-disposal activity, as indicated by the previous week's observations. On Wednesday night, we exchanged the locations of the two plant displays.

During the second week, we also conducted 13 10-minute interviews with people we observed talking about, pointing to, or interacting with at least one of the units featuring a plant display. Respondents gave informed consent and were asked a series of questions, about when they first noticed the units, what they thought they were for, if they elicited any feelings, and what effects the displays might be having.

When the study was over, we debriefed cafeteria patrons with an 11x17" poster explaining the nature, purpose, and results of our study. We affixed these to the walls where we had introduced each new unit.

FINDINGS

Short Interviews
Several themes emerged in the 13 interviews we carried out, including eco-consciousness, exploration, experimentation, appreciation, and interpretation.

Eco-consciousness. People reported first noticing the bright green color of the display units or the plants, and linked these to an "environmental" or "eco-conscious" theme.

Exploration. People described their attempts to understand the displays: in this case, the robot plants.

> "I don't know, but I think it moved. Did it move? [Interviewer: Do you think it moved?] Yeah, I think so, but… I don't want to be crazy. Maybe it didn't move. I went back and tested it, to see. I put some trash in. And then I put my hand underneath it. Did it?"

Three people related their attempts to "game the system" by waving their hands underneath the motion sensors. The slow motion of the displays was sometimes confusing: two people said the robot was "broken, because it's not moving."

Experimentation. Over half the respondents (8 of 13) were sensitive to the fact that a study was taking place, using words and phrases such as "experiment," "conditions," "testing human behavior," "collecting data," or "to see if" in describing what they saw. Four respondents guessed some part of our intention: either that we wanted to "determine the recycling-to-trash ratio, or "encourage recycling." One said,

> "I think this is an experiment, to see if people throw away more with fake plants. And then, with the real plants, will they recycle more. [Interviewer: That's interesting.] You're kind of killing two birds with one stone. Recycle a Coke, plant a tree."

Appreciation. Asked how the units made her feel, one said (pointing to the living plants):

> "I like them. They're so small. They look so dependent. I waved my hands underneath to give them some light. I didn't have a bottle. I like the bright green color. Green is very environmental. And I like the way the cabinets and the lights go together."

Another respondent declared,

> "They made my day! All of these people are staring at these things. I like to watch. They're giving the plant extra light"

Some people may not have noticed a difference between the plant displays. Three thought both were real, or both "fake". One person liked the robot plants best:

> There's a nice aesthetic sense to them. It's kinda cool to have robotic plants.

… while another said the living plants made more sense.

> I saw the plastic plants first. The others make more sense. [Interviewer: They make more sense?] If they're real plants. It's more clear.

Interpretation. Of the 13 people we interviewed, 5 described the mechanism of our invention in some way, e.g.,

> "The plants gauge whether there's more recycling than trash. If they were the same then the plants would be straight up."

We initially overheard one respondent saying:

> "I get it! Whichever one you put it in, the light goes on. So be-

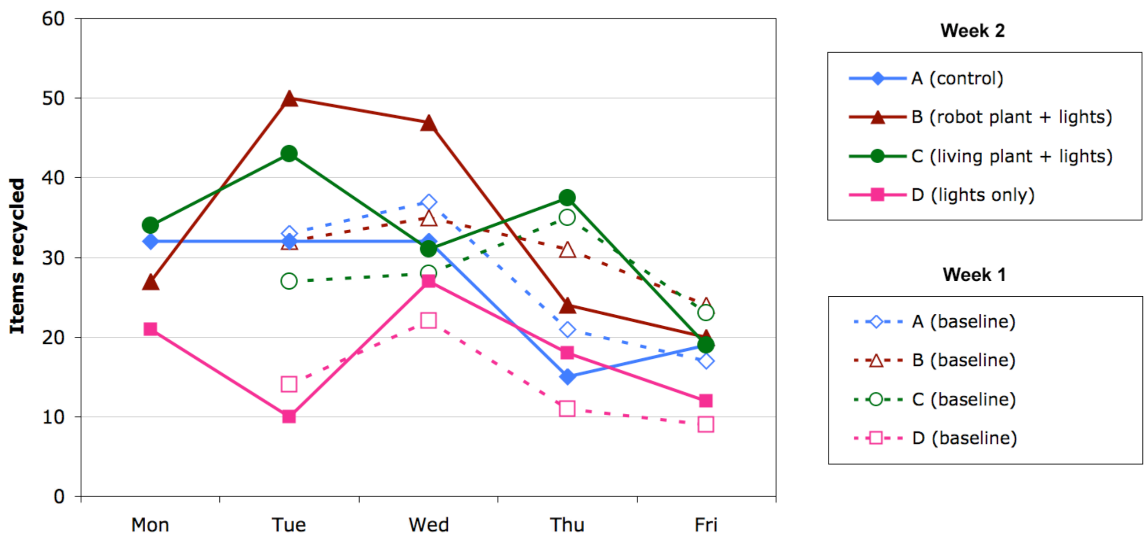

Figure 11. Changes in recycling during study. Dashed lines represent Week 1 (baseline). Solid lines represent Week 2 (conditions). Similar shapes represent the same condition across days. Recycling data are missing on Monday, Week 1.

> cause they're bending that way, people are throwing away more."

Three people characterized our design as artistic, or intending to send a message. One remarked on their reflective function:

> "There's no need for it that I can articulate. It's not being designed for a need, or a need like a lot of the stuff here is. It just fits into the environment. It's … making an awareness of a problem. It's giving people something, something that they can do what they want with … It has got people actually thinking. You know, 'hmm' [looks thoughtful], and also it gets a good reaction. People smile. There's a magic. You don't know what's going to happen, and then it goes, and there's a sense of, wonder, I guess."

Behavioral data

We generally observed an increase in recycling (Figure 11) and no change in trash across Weeks 1 and 2. Our study was only 2 weeks long, and we note that these increases were not statistically significant. We would have run a longer study, but Week 3 was our university's Thanksgiving holiday.

There is reason to take into account both measures (trash and recycling) simultaneously. After all, if trash had increased much more than recycling, we would certainly not consider that a positive change in behavior. After standardizing the trash and recycling scores, and combining them in a ratio, a MANOVA analysis indicates that the unit featuring living plants started out worst and ended up best. This effect was marginally significant, $F[3, 9] = 3.1$, $p = .08$. Though our other quantitative results did not approach significance, the effects were generally in the direction anticipated.

GENERAL DISCUSSION

Our design succeeded as an interactive display. Several people we interviewed were able to easily interpret the leaning behavior of the plants. People commented positively on the aesthetic quality of the displays.

Our total design appeared to increase recycling behavior. The gains we saw are probably due to a combination of factors. First, the immediate feedback of a light turning on may have prompted people to recycle. Feedback is most effective if it is immediate, and immediate rewards can be a strong incentive to recycle [14, 15]. Second, gains in recycling could be attributable to a heightened eco-consciousness. Interviewees linked the bright green color of the display stands and the presence of the plants to an environmental theme. Third, gains in recycling may have resulted from a desire to help the plants. People realized that recycling was a way to give the plants light. Some people may have wanted to straighten the plants with light from the opposite side. Or, they may have realized that by recycling, as well as throwing away trash, they could give the plant twice as much light, without waiting for a light to turn off. Finally, gains may have resulted from deeper interpretations of the display. Most people who commented on the leaning behavior of the plants made a successful attempt to connect this with a larger message. This message was, of course, that people throw away more than they recycle. Realizing this, people may have been more likely to recycle something they would have otherwise thrown away. Although we cannot be certain this happened, we believe that for some people our display induced a change in awareness just at the point of throwing away a plastic bottle. This idea is supported by quantitative and qualitative evidence.

An increase in recycling achieved marginal statistical significance at the display featuring living plants. It may be that the aliveness of the living plant display contributed to a more engaging, more compelling interaction. This idea is supported by interviews with users, who talked about caring for the plants – giving them light, or feeling attached in some way. The robotic plant display enjoyed a strong initial interest that declined after 2 days. Qualities other than aliveness may explain different responses to the living and robotic plants. For example, the "leaning" behavior was not exactly the same.

We have considered augmenting our robotic design to promote more sustained interest. One advantage of a robotic design is that it can be precisely specified as well as precisely manipulated. Because the robotic display we created is "infotropic," rather than phototropic, it can be repurposed in interesting ways. We have used it to time a presentation, noting progress by the slow rotation of the plants. People other than the speaker were not aware of this until we told them, which demonstrates some value as a private display.

DESIGN IMPLICATIONS

Lightweight Robotics for Incenting Behavior

People respond to small degrees of interactivity, and may even enjoy lightweight interactions more than intensely focused interactions with complex robots. We need not wait for human, animal, or even insect-like intelligence to introduce simple robotics pleasantly and effectively into everyday environments. Artifacts made with lightweight sensors and actuators are more robust, and can be maintained for lower cost over longer periods of time. Our design is an example of lightweight robotics in a public setting, using simple sensors, processors, and actuators to deliver small yet effective rewards.

Plants as a Communicative Medium

Plants represent a uniquely appropriate medium for communicating long-term trends. The local character and familiar nature of plant behaviors offers additional advantages to the designer seeking to maximize interface legibility. Although we drew upon the natural and familiar behaviors of plants in both our living and robotic displays, there are many possible manipulations of plants that we did not implement in our design. We encourage designers to explore other applications of plants and plant forms in communicative, informative, and interactive contexts.

Combining Living and Electromechanical Components in a Hybrid Artifact

Interactions with hybrid artifacts, featuring both living and electromechanical components, may have a more engaging quality than interactions with purely robotic mechanisms. The addition of living materials may introduce an emotional quality absent from interactions with purely electromechanical systems. More research is needed to test this hypothesis. Biomimetic artifacts may also stimulate an affective response. We advocate a bidirectional perspective in the design of hybrid systems: as roboticists explore the qualities of robots that make them seem most alive, it seems natural to ask how we might profitably harness the quality of aliveness starting from biological material.

CONCLUSION

The purpose of our study was to observe and describe public reactions to our original usage of living and biomimetic plants in interactive displays. The designs appeared to be generating a pleasant experience overall – adding a small bit of wonder to an otherwise mundane ritual. We observed an increase in recycling activity with our living display and possible increases resulting from the use of a biomimetic display and even lights alone. These findings argue for the development and deployment of lightweight interactive artifacts to deliver simple rewards in appropriate contexts.

Showing, through systematic field study, that our original artifacts generated a public response was a significant step. Characterizing the nature of those reactions was a second step, one that paves the way for future studies in the design spaces of hybrid and biomimetic artifacts. Our documented designs stand as a contribution to research in the new spaces of hybrid artifacts, biomimetic design, and lightweight robotics, which we encourage others to explore as well.

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