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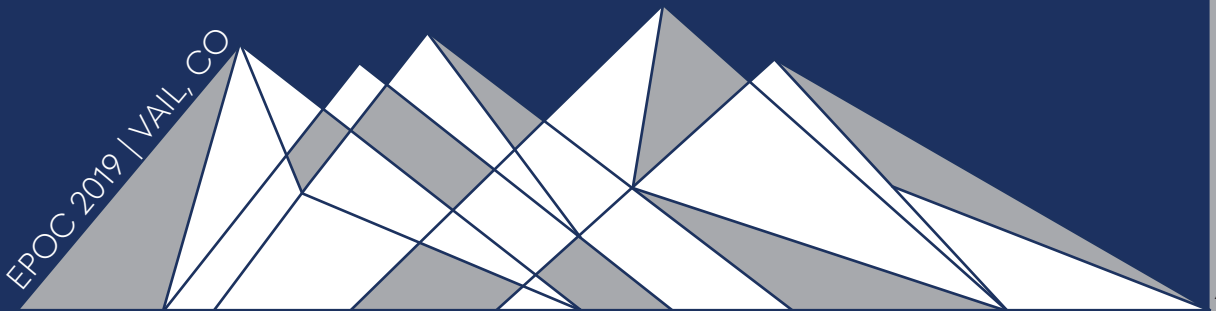

The Power of Prototyping Public Infrastructure: An Approach to Gain Feedback and Deliver More User-Centered Design Solutions

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ABSTRACT

Prototyping is a feedback mechanism that enriches the design process by emphasizing user experience and removing designers' fear of failure. Yet, this critical step is often absent during design of physical large-scale infrastructure (e.g. transportation systems, water systems), in part, because of the size and complexity of these socio-technical systems. This research aims to understand how design prototyping can be adopted for large-scale and complex urban infrastructure systems and how prototyping influence design cognition among infrastructure stakeholder groups. To measure the effect of physical prototypes on users and designers, more than twenty interviews were conducted with community members, business owners, civil designers, planners, city officials, and city engineers in two prototyped projects: a road network in Macon, Georgia and a re-designed city block in Akron, Ohio. The interviews were coded for evidence of how prototyping enhanced citizen engagement and how designers learned about users' priorities. Improved understanding of prototyping as a design methodology for infrastructure can lead to more user-centered and innovative solutions. This research provides tools to better manage design decisions in engineering and urban planning, and new approaches for urban infrastructure problem-solving. Future research can compare how this process may inform design if the prototyping is done with immersive virtual experiences compared to these real-world installments.

INTRODUCTION

The pace to design and construct infrastructure world-wide is more than ever before in history (Biswas, 2018). Over one trillion dollars is spent worldwide just in transportation systems (Leipziger & Lefevre, 2014). According to the UN, by 2030 the world will see the construction of infrastructure for 10 new megacities (Biswas, 2018). Despite these massive investments, the large demands for infrastructure are still not met. Moreover, the infrastructure that is built does not meet the needs and preferences of end-users. For instance, functional obsolescence, not physical failure, is the most common reason for demolition and replacing buildings and industrial facilities (Thomsen & Flier, 2011). Better meeting user needs is critical for more efficient and long-lasting infrastructure.

A prominent example of an infrastructure system that did not meet user needs was the Embarcadero freeway in San Francisco, California. When the Loma Prieta earthquake damaged the freeway in 1989, the city decided not to fix it. Instead, the city tore it down and transformed the space into miles of public paths with new transit routes (Cervero et al., 2009). Not only can physical infrastructure systems, like the Embarcadero Freeway, under perform to satisfy user needs but how users' interface with these systems is critical to consider for their success. With poor user interface, the tram in Melbourne, Australia experienced a decrease in ridership. The idea for a paperless ticketing system was innovative, but users felt confused on how to use it. Neglecting to considering the ticketing system from the users' perspective cost the city time, money and ridership (Holden & Scerri, 2013). Unfortunately, similar cases in which infrastructure is underused, or underperforming to meet user needs, are more common to our daily lives than engineers who designed these systems would like to admit. Neighborhoods with vacant buildings or empty lots, streets with bike lanes that end abruptly, and large parking lots occupied by few cars are the norm in communities across the United States.

We look to physical prototyping to address these issues of not including the users' needs and preferences in the design process. However, most civil engineers and designers have not yet adopted a formal physical prototyping approach (Kumar et al., 2016) to develop civil infrastructure designs, probably due to the nature of such socio-technical systems (Miguel Andres Guerra & Shealy, 2018b).

In this paper, we look at the design process of a bike line network in Macon, Georgia and a neighborhood revitalization in Akron, Ohio, where prototyping and testing were informally used to involve the users in the design process and to reduce designers' perceived risk of breaking from the status quo to include users' needs and preferences in the final design.

BACKGROUND

We look to prototyping under the lens of design thinking (Beckman & Barry, 2007; Buchanan, 1992), which is an iterative design approach that starts with an empathizing phase to understand the users' needs and preferences, followed by

problem definition and solution ideation phases, and ending with design prototyping and testing phases (Kumar et al., 2016)

Although some of the first design thinking steps are not unfamiliar to infrastructure design, there is still no clear consensus on the methodology to be used to involve users and stakeholders in the design process. Moreover, prototyping and testing are phases that are not being used to design infrastructure, perhaps due to the scale and size of the artifacts being engineered and the financial cost to build them.

Prototyping is a feedback mechanisms that enrich the design process by emphasizing user experience (Coutts & Pugsley, 2018). Prototyping promotes the process of gathering feedback from the users who are experiencing the design features in order to obtain more information about which aspects of the solution need modifications and which ones do not (Miguel Andres Guerra & Shealy, 2018a). The process of prototyping also incentivizes designers to think out of the box, because having negative feedback from the users' experience of the design is a step towards building the right design and reducing the fear of failure (Kelley & Kelley, 2006).

Finally, prototyping also enhances innovative solutions in the convergence of balancing the users' desirability of needs or preferences, the viability of accessible resources, and the required technical feasibility (Brown & Wyatt, 2010). Prototyping accelerates the process of innovation by contrasting and balancing the ideas between these constraints in the search for solutions that address users' desirability (Johansson-Sköldberg, Woodilla, & Çetinkaya, 2013). Users' desirability refers to that which users need and prefer under their specific context. The required technical feasibility refers to what is possible to accomplish using the current available technology. The viability of accessible resources refers to whether the resources needed to implement the design proposed are accessible. Prototyping stands on navigating through these three constraints to deliver user-centered innovation (Brown, 2009; Johansson-Sköldberg et al., 2013).

Relationship to the Grand Challenges

Prototyping infrastructure relates to three of the EPOS Grand Challenges: (GC1) The New Project Manager, (GC4) Systems Integration, and (GC5) Lifecycle Value & Governance. Prototyping design is a decision-making tool that allows "The New Project Manager" to balance the short- and long-term performance. For instance, prototyping helps to test the (long term) service of a project by observing the users interacting with the proposed project design features (short term).

Second, prototyping infrastructure brings most actors of the project in early during the design. This early interaction facilitates a decentralized decision-making process to plan and shape the project design where all stakeholder voices are considered and more focus is given to the users. Prototyping also promotes considerations of social value dimensions in the project organization and design such as the users' culture, skills, and assets. Designers' and managers' intentions are to include the community strengths in the design, which are particular to every project and its context.

Lastly, prototyping is an effective mechanism that facilitates future users to manage trade-offs across their needs and preferences, considering a project's long-term service versus the immediate user preferences. In addition, the purpose of many prototypes is to challenge current norms and regulations that govern the design and may be outdated or can be improved.

OBJECTIVES

This research aims to understand how design prototyping can be adopted for large-scale and complex urban infrastructure systems and how prototyping influences design cognition among infrastructure stakeholder groups. Particularly, the aim is to understand how prototyping increases designers' considerations of users' needs and preferences into the design.

METHODOLOGY

The study uses a qualitative multiple case study methodology by Taylor et al. (2010) and Yin (2013) to measure design cognition among stakeholder groups. In total, twenty-one interviews were conducted with users, designers, planners, city officials and engineers in two prototypes about a city block and an urban biking network that occurred in 2015 and 2016 in Akron, Ohio and Macon, Georgia, respectively. The design team was the same for both prototypes, and the stakeholder groups of users, project promoters, and the city official were different for each prototype. Similarities for both projects are the prototypes timeline that both lasted less than a week, the projects were community led, both funded by local associations and private grants, and the design team for both prototypes was the same. The main differences of the projects are they respond to different jurisdictions, the context of where the projects took place, and the diversity of the users.

Deleted: road

The unit of analysis of the study consisted of two phases: prototype design and prototype testing. In the prototype design phase, designers develop a design ready to be built for the user to experience. In the prototype testing phase, designers learn from the users experiencing and testing the built design.

The Akron prototype was developed in 2015 with the goal to transform a blighted neighborhood into a vibrant destination. The design team worked on a solution that consisted of introducing temporary rapid developed types of urban infrastructure such as buffered bike lanes, enhancing pedestrian infrastructure, creating two public plazas and a series of pop-up businesses.

The Macon prototype was developed in 2016 with the goal to find solutions to connect the downtown area of the city with its surrounding neighborhoods. The design team found that residents wanted alternative ways to connect with the downtown area, along with appropriate-interest stores for the residents. The design team put in place a five-mile bike network with seven different design of bike lanes, pedestrian walkable infrastructure, and public spaces.

The interviews were recorded, transcribed, and coded for evidence of how this type of design process enhanced citizen engagement, how designers learned what users valued, and how designers were willing to adopt unconventional designs after the prototyping and testing process. The transcribed interviews were coded for content analysis approach by Yin (2013) and Saldana (2015), having both a-priori and emerging codes that were identified throughout the coding process of both case studies. The codes were clustered around overarching themes relating the designers design process and the influence of the users' feedback on the final design choices of the designers.

RESULTS

In both prototypes, the users' feedback of experiencing a built design was a relevant milestone of the process. Naturally, this milestone encouraged the design team to learn more about the users' needs and preferences in order to increase the possibilities of design success. **This focus on learning about the users' needs and preferences is reflected on the designers' behavior throughout the entire process** of prototyping for design. Designers constantly work to help users make informed decisions, build community rapport, and develop cohesion among ideas that worked well during the design and testing phases and the final design. Designers were purposely open to listening to the users and searching for community assets (local skills, leaders, and physical spaces). **The design team used specific strategies to learn about the Akron and Macon users** such as site visits, observations to understand context, behavior and culture, and through surveys. During the testing process, designers create feedback mechanisms through surveys and "feedback stations". They gauge volunteer and community energy informally and formally. In both cases, the testing process ended with designers following up with the users to search for new information. The following subsections provide more context and detail about the results obtained from the interviews in Akron and Macon.

Designers highly value users' feedback

In both prototypes, the data analysis showed how prototyping shifted designers' mindset into increasing the value of users' feedback and the knowledge of users' needs and preferences in developing a user-centered design. When prototyping in Akron and Macon, member of the design team including engineers actively aimed to learn more about the users in order to translate this information into the final design.

The six ways designers value users' feedback and learned from users throughout the prototype process in Macon and Akron are, by helping users make informed decisions, help visualize needs, cohesion of ideas in the community, building trust, and making prototyping both an advocacy tool and an optimistic forum of ideas. Throughout both prototype phases, designers built rapport with the community in order to create communication bonds that allow designers to improve their designs accordingly to the users' feedback. For example, Jeremy, one of the

project promoters in Macon, said that prototyping was used to help users make more informed decisions. Jeremy said:

> "[In our community], most people had never been on a bike, most people who had been on our bike lanes had never been on a bike lane at all. They just didn't have any basis for making an informed decision. In our community, people don't even know their options, then [prototyping] can help them make an informed decision… It gave the designers a clear message about what type is good and what type is bad. And it really was a clear indictment [to be translated into the design]."

Having the opportunity to experience what a bike lane is and what does it feel to be riding on one helped the users in Macon to have a more **informed decision-making** process. Similarly, user Julia, who later on started the Exchange House, a community business that was envisioned during the Akron prototype, says:

> The pop-up businesses in the vacant buildings was like super cool because I, again, I never been inside them, so I thought that was a need. Um, and then also like just having exposure to the different cultures, like, you know, sharing their arts and stuff like on the stage and then the main sort of area. I pretty much thought like every aspect of it was needed and necessary for the neighborhood. I say that now, especially since I've been here for four years, but like at the time I didn't know what [the neighborhood] needed but the [prototype] helped me see what the neighborhood needed and I still remember having this experience of like being super excited and just like 'this is so great'. (Julia)

Julia stated that the experiencing the prototype helped her visualize needs and preferences of which she had not been aware, such as restoring the vacant buildings or highlighting the diverse nature of the neighborhood. Furthermore, Akron project promoter Ashton concurs with this idea that experiencing transforms. The community can visualize how they want a place to be and raise their voice in the planning and designing processes:

> It is hard to get people to imagine that it could be any different unless they experience it. You know, if renderings, or just telling people what it could be worked. Then the neighborhoods would have come back. But experiencing your neighborhood transform, going to have a cup of coffee in a building that has been dormant or going to see an art gallery in a vacant lot. And also having the neighborhood of doing the work of activating its vacant space is really, really powerful. (Ashton)

During the prototype designing phase, designers consciously listened to users, scouted for leaders, searched for spaces with potential, and searched for community skills. Kyle, a project promoter in Akron, stated that the vision for the neighborhood should come from the community:

> We want the neighborhood to say, this is what we want. This is what we think our place could be and for the neighborhood leadership to help build that vision. (Kyle)

A member from the design team in Akron supports Kyle's vision when highlighting the role that community feedback has on a design:

> [Users feedback] was an important part of the process, …, and in any good neighborhood project, listening has to be a key component and not just for the neighborhood leadership but you also have powerful messages from the community. (Kyle)

> [The designers] have done a good job of listening to all those different groups and coming back with a project that incorporated all of their feedback. Not at all of it entirely, but pieces of all of the different stakeholders. (Kyle)

Prototyping helped shift designers' mindset into increasing the value of incorporating users' feedback and knowledge about the users' needs and references on a successful design.

Strategies designers used to actively learn about the users

Designers in Macon and Akron used specific strategies according to the prototype design or testing phase to learn about the users. During the prototype design phase, designers used strategies such as predesign site visits, community interactive activities, community meetings, observation of the users, and user surveying to learn more about the users, their context, and community skills. In Macon for example, the design team proposed over nineteen interactive activities, surveys, and community meetings in order to learn more about the users' skills and context. Mary, a member of the design team in Macon, stated that before starting to develop ideas for solutions, the design team proposed a festival of ideas with multiple activities aimed to gather information from many types of users:

> [The design team] came to [the community] for a few days and built nineteen events throughout the city. Questioning people about how do you feel about biking or walking improvements, and where would you like to see it, and what type of infrastructure, and why? And where? And all those questions. (Mary)

Helen, a user who participated in the Macon prototype design process supported Mary's statement, saying:

> Before they actually constructed the pop-up bike lanes, they did an idea's festival, called the "Macon's Connect Idea's Festival", two months before the construction of the [prototype]. (Helen)

Later, during the prototype testing phase, designers learned how users perceived their design and what users felt during the experience. They learned what features were well received and what could be improved. To get users' feedback about their experience, designers opened communication by facilitating both casual feedback and also formal feedback in predetermined "feedback stations" in the prototype space. For example, in the Macon prototype there were special booths to provide assistance about activities, locations, and event information, but they also were strategically located to collect responses from users about the bicycle lanes at critical locations

such as intersections or transitions of the bicycle lane design. Mary, a Macon design team member, describes the feedback received at the feedback station that was strategically located next to the bi-directional bicycle lane, saying:

> The median centered bi-directional bike line was a bad idea. People were confused on how to proceed at the intersections. The surveys also showed they felt unsafe when riding through this particular bike lane type. (Mary)

A couple of days after the prototype was over, designers followed up with business and property owners to learn what things worked and what things did not work during the prototype of the urban design features. For example, Mary describes a follow-up done to learn how the bicycle lanes affected the car drivers:

> We did a follow-up online user feedback to measure, "Did it make driving better or worse?" or "How comfortable was it?" We wanted to ask other questions, too, like "Did you notice any new stores while using the bike lane?" For those who did so, it was just basic bike counting and user feedback. (Mary)

The follow-up extended to many groups of stakeholders. Christine, a business owner in Macon, described that the design team approached her a few days after the prototype to inquire about the pros and cons of her experience:

> [The design team] came up with me because I was a business owner. [They] wanted my personal opinion, [they] wanted to know what I thought about the prototype... I'm sure he did with other businesses too. But he specifically asked about [design features affecting business] because I was a business owner. I definitely gave him lots of feedback. (Christine)

Christine's description shows that prototyping opens multiple communication opportunities between users and the design team, which is reflected on the final design.

DISCUSSION AND CONCLUSION

In both prototypes, the city and citizen-led groups used inexpensive materials to install temporary bike lanes, dieting of streets, structures for pedestrians, and public spaces in vacant lots. These temporary installments, lasting only one week, helped city planners and design engineers to try more user-centered features. For example, the city engineers in Macon were very skeptical of trying bike lanes throughout downtown, and even more when after meetings with community members for their feedback, the designers came up with a network that tested multiple different types of bike lanes. However, after experiencing the prototype, the Macon's Mayor requested the three-day prototype to run throughout the full week. Throughout the prototype, designers learned that the most popular bike lane design was not what the city engineers had anticipated. These one-week prototypes contributed to a less-than-conventional roadway design. These prototypes also increased designers' consideration and observation of user needs and provided insight into how the prototype met product (e.g. a road) and service (e.g. traffic reduction) design constraints.

The data analysis showed how prototyping shifts designers mindset into increasing the weight of users' feedback and the knowledge of users' needs and preferences in developing a successful design. When prototyping infrastructure, designers and engineers actively aimed to learn more about the users in order to translate this information into infrastructure design. Designers actively aimed to learn about users' needs and preferences during both phases of a prototyping. During the prototype designing phase, designers valued information about the user to include in the design. Designers consciously listened to users, scouted for leaders, and searched for spaces with potential and for community skills. Designers in the Macon and Akron prototypes used strategies such as predesign site visits, community engagement activities, community and kick-off meetings, observation of the users, and user surveying to learn more about the users, their context, and skills.

During the prototype testing phase, designers were interested in learning about the users' experience of the design in order to improve the prototyped design features. To get users' feedback of the experience, designers opened communication bridges with stakeholders by preparing and familiarizing users to experience an infrastructure design prototype, facilitating stakeholders to provide both casual feedback and also formal feedback in predetermined stations and surveys. For example, in the Macon prototype there were special booths to provide assistance about activities, locations, information, but they also were strategically located to collect information about the riders' experience of critical locations such as intersections or transitions of the bike lanes. Another way designers collected users' feedback of the experience is by validating the design with the users through follow-ups, making prototyping an optimistic forum of ideas, and using the volunteer energy as a barometer for user satisfaction. For example, a couple of days after the prototype was over, designers followed up business and property owners to learn what things worked and what things did not work during the prototype of the urban design features.

The interview results provide evidence of a process to better manage the design process when redesigning roadways, public spaces, bicycle lanes, and other types of public infrastructure. The evidence suggests that although the functionality and purpose of prototyping to increase design feedback through user observations is a game changer, prototyping has yet to become a formal process in design of civil infrastructure (Guerra & Shealy, 2018). Prototyping is a critical stage in which designers learn information about the users' context and culture through experiencing a temporary built project.

Improved understanding and a more formalized process of prototyping as a design methodology for infrastructure can lead to more user-centered and inherently more sustainable designs. This type and scale of prototyping enables more feedback than previous design approaches for infrastructure and at a fraction of the total cost of building the actual project. The results of this research provide practitioners with evidence-based tools to better manage design decisions and considerations on how users' feedback influences future infrastructure users. The research results can be directly integrated into engineering projects and urban planning requests for proposals, or new approaches for urban infrastructure problem-solving.

Those designing infrastructure can use prototyping to explore ways to incorporate feedback from users in order to develop infrastructure designs that are highly and efficiently used. When physical prototyping is not feasible, virtual prototyping may be a solution, including virtual reality from 2D and 3D to immersive experiences. Future research can compare how this process may inform design if the prototyping is done virtually using 2D, 3D, and immersive experiences and using these real-world installments. More research is needed to measure whether and how virtual prototypes can substitute the experience of real-world installments and how virtual prototyping influences design cognition among infrastructure stakeholders.

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