Towards a Model of Design Tensions for Creating an Accessible Makerspace in the Caribbean

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As technology-rich maker and DIY practices proliferate globally, we need to understand how to capture and articulate the complex and sometimes conflicting factors involved in enabling and supporting them in different contexts. In this paper, we describe a study investigating the design tensions, priorities, and considerations of creating an accessible public-facing makerspace in the Caribbean. We organized two workshops with local and non-local experts to discuss cultural, contextual, practical, and pedagogical factors involved in creating a site for technology-rich informal learning. Based on our findings, we propose a model for systematically articulating and considering design tensions involved in creating public-facing makerspaces that prioritize accessibility and community engagement. Additionally, we offer insights into the possibilities of future accessible making and DIY practices in the Caribbean, taking into account local cultural, historical, and infrastructural characteristics.

CCS Concepts: • **Human-centered computing** → **Accessibility**.

Additional Key Words and Phrases: Technology-rich learning, accessibility, makerspaces, co-design, disability

1 INTRODUCTION AND BACKGROUND

Public-facing makerspaces, such as those in libraries, schools, museums, and other sites, offer opportunities for hands-on, technology-rich learning and self-expression [5, 17, 63]. In recent years, research has demonstrated how these spaces can be sites of inclusive technology-rich learning for people with disabilities [11, 12], innovations resulting in the design of customized assistive technologies (DIY-ATs) [33, 37], and productive spaces for discussions and activities that bring together issues of social justice, community engagement, and accessibility [3, 32, 34]. Recognizing this potential, recent studies have also explored the possibilities of creating accessible maker tools, processes, and spaces to include more people with disabilities in making [3]. The majority of this previous research is situated in the Global North and is necessarily shaped by the infrastructural, cultural, and contextual factors present there. The significant impact of differences between contexts in the Global North and South on issues of accessibility and inclusion as they pertain to technology is explored by previous research [45, 46, 57]. A small number of studies have further shown that when it comes to making and DIY-AT, long-term and persistent inequities present challenges in creating homegrown and contextually valid approaches [27, 29]. While these studies have highlighted the need to build local capacity to explore how maker practices can be appropriated, translated, and localized to effectively engage communities in Global South contexts, more research is needed to understand how to identify design tensions involved in localized projects, and balance specific factors involved in such endeavors.

To investigate these questions, we have initiated a longitudinal Action Research [21, 31] project that uses the planning, design, implementation, and eventual impact evaluation of an accessible public-facing makerspace as its primary mode of investigation. The Anonymized Center will be located at a site of historical and scientific importance (details removed for anonymized review) in the Caribbean and is in the vicinity of several other facilities, including a science museum, which has historically been used for natural science research and public engagement with STEM. One of the key objectives of the Anonymized Center is to house an accessible and public-facing makerspace that is collocated with the museum site to provide opportunities for engaging with STEM topics for both local community members and visitors to the site. This paper is focused on the initial design of the makerspace, which involves the identification and exploration of priorities and considerations in the creation of the makerspace, before moving on to implementation. We expect to build on the outcomes reported in this paper in the future to demonstrate how they can be operationalized and used in the implementation of the center and what their impact would be on members of the public and the communities surrounding the center.

Our study site is located on a Caribbean island with a rich history with multiple waves of Spanish and American colonialism, and ongoing postcolonial struggle. (Author's note: we will include more details and citations about the study site after anonymized review.) While a deep discussion of its history and social dynamics is outside of the scope of the current paper, we would like to mention a few key characteristics that are particularly relevant. A key characteristic is an ongoing struggle for the development and recognition of a distinct identity from those of historical colonial powers. While this struggle is expressed clearly through language, music, and art practices, it is complicated by the existence of a large and vibrant diaspora, and the prevalence of significant cultural diversity within the island's population. These have led recent efforts to recognize the existence of multiple parallel struggles with hybrid local and global identities. Another important characteristic is that the similar to other Caribbean islands, our context has a long history of ongoing infrastructural inequities, exacerbated by frequent natural disasters that have resulted in a spirit of resilience and awareness of the dangers of technological dependence. Finally, with respect to accessibility, while the natural terrain of the island, with mountains, beaches, and roads of varying quality poses challenges, there have been efforts to support access for people with disabilities and their families. These factors, in addition to practical considerations, including our personal and professional connections to the island and the opportunity of exploring makerspace design in collaboration with the Anonymized Center and multiple local universities, motivate this project and make it a particularly rich context for research into design tensions.

In this paper, we report on our investigation of the design tensions and specific factors that should be considered in creating a makerspace that prioritizes accessibility and community engagement with STEM. To investigate these, we organized two workshops with local and external experts on accessibility, making, and learning to discuss the cultural, contextual, practical, and pedagogical factors to consider in the design of the makerspace. During the first workshop, we conducted a co-design session using the World Cafe [52] format to elicit ideas and feedback from participants, and in the second we used a focus group to ask for feedback on initial synthesized findings from the first workshop. Our research questions are:

(RQ1) What design tensions are involved in creating a public-facing accessible makerspace to facilitate community engagement and STEM learning?

(RQ2) What factors should be taken into account in the design of a public-facing accessible makerspace in the Global South?

By answering these questions, we make two contributions: first, we contribute an empirically-grounded investigation of how to surface and navigate design tensions and tradeoffs involved in the creation of informal learning spaces that

prioritize community values and assets while being guided by accessibility and community engagement as guiding principles. Second, we contribute insights into the cultural, contextual, practical, and pedagogical aspects of makerspace design in a Global South context that can inform the future creation of similar spaces elsewhere. Collectively, these contributions expand the current understanding of accessible making and DIY practices by investigating what these practices entail in contexts with distinct cultural, historical, and infrastructural characteristics. To our knowledge, this is the first paper that studies the design tensions involved in creating an accessible makerspace in the Caribbean by centering accessibility and community engagement as key goals from the outset (i.e., before the makerspace is created).

The remaining structure of the paper is as follows: the next section provides a brief overview of the existing research on accessible making and makerspaces and the opportunities they offer for including people with disabilities in technology-rich activities, including the creation of Do-It-Yourself Assistive Technologies (DIY-ATs). Further sections present our methods for conducting a co-design workshop on envisioning a future public-facing accessible makerspace in the Caribbean, findings from the workshop that answer our research questions and present a model of thinking through design tensions. We conclude with a discussion of the implications of these findings and resulting insights and recommendations.

2 RELATED WORK

Our work builds on the existing body of research that has explored best practices for creating accessible and inclusive makerspaces, and designing relevant technology-rich activities for makers with disabilities. In this section, we provide an overview of this previous research and identify the research gap that our work responds to.

2.1 Creating Accessible and Inclusive Makerspaces

Research has begun to explore best practices for intentionally creating accessible makerspaces and suggestions include enabling members of makerspaces to create adaptive technologies for the space, fostering belonging by building relationships with the disability community, and ensuring that individuals with disabilities are leaders in creating the experiences housed within the space [3, 56]. Importantly, in their study of identifying and overcoming barriers to participation in making for people with disabilities, Allen et al. identified making the physical space and information needed to participate accessible, allowing makers with disabilities to create adaptive technologies for the space, and, importantly, fostering a sense of belonging to counter historical inequities [3]. Other research on facilitating accessible, hands-on maker activities for people with disabilities has shown the importance of adaptability, the empowering role of technology in enabling creative expression, and the crucial work of facilitators helping out with activities [11, 22, 43]. Importantly, in these spaces, individuals with disabilities often have intersectional identities regarding their race and socioeconomic background. To fully participate in making and makerspace learning, it has been shown that a maker's full identity must be respected and considered [13]. Overall, however, there is limited work on how to include individuals with disabilities in project based making environments [50]. This work states that it is imperative that these populations are not excluded and suggest that using contextualized participatory practices can work to develop programs to better include individuals with disabilities in making practices [50]. Some work has specifically focused on designing inclusive making opportunities for individuals with disabilities and found that multimodal instructions and means for interacting and small class sizes to encourage one-on-one attention were helpful tactics [10, 55, 58]. It was also shown that having neurodiverse, inclusive classrooms made individuals with disabilities more comfortable and dispelled misconceptions for those without disabilities [10, 47, 55, 58]. Overall, more work needs to be done to ensure the co-creation of making

activities that are accessible for individuals with disabilities to participate in the same capacity as individuals without a disability.

More recent work has focused on how to facilitate maker-based approaches in community settings where priorities include reflecting the values and needs of the communities surrounding and using makerspaces [35, 36]. Research has also identified challenges to engagement in these settings. For example, in community settings, individuals with intersectional identities can be hesitant to ask for assistive technologies or accommodations to be included [15]. It has also been shown that simply opening spaces to individuals with disabilities is often not enough to ensure inclusion because a history of marginalization can lead to positions of inferior cultural knowledge, expertise, or social capital [56]. One study identified strategies for including older adults in community makerspace settings and found that an adaptive staffing approach that could withstand constant personnel shifts and shortages, structured activities to draw interest and overcome challenges associated with learning to use the machines, and reference materials to support individuals in independent usage of the space were key to creating an inclusive space [42].

While most of the research on creating accessible makerspaces is situated in the Global North, a few studies have explored the possibilities of making, with a focus on creating DIY-ATs in the Global South [26, 27, 29, 69]. For example, in a project focused on developing DIY-ATs in Kenya, Hamidi et al. explored the technical, infrastructural, and social aspects of creating a low-cost, customizable communication board [27]. They found that while many opportunities for innovation existed, inequitable infrastructural conditions also limited reliable access to computational materials needed to repair and sustain the system and identified a need for creating homegrown, localized capacity for supporting these practices [29]. Furthermore, they found that access to interactive technologies for people with disabilities in this context can create valuable learning and social inclusion experiences [26]. In another study, Savage et al., interviewed stakeholders in multiple countries, including those in Central and South America, who were involved in ecosystems of 3D printed assistive technology production [60]. They identified several factors that contribute to the sustainability of these ecosystems, chief among them the establishing of follow-up practices that include formal agreements and compensations, both monetary and otherwise, for participation. Among other recommendations, the authors identified opportunities for developing tools to support multistakeholder collaborations within and across ecosystems.

The brief review above shows that while research has explored the possibilities of creating accessible and inclusive makerspaces and practices, mostly in Global North contexts, there is a gap in understanding the design and implementation of accessible makerspaces in Global South contexts where issues of cultural and infrastructural differences may pose significant challenges and opportunities. The distinct setting of our study demands careful implementation of the mentioned practices to ensure that the envisioned makerspace can be welcoming to and inclusive of diverse visitors' intersectional identities and create a physical space where the experiences and creativity of individuals with disabilities are not just included but centered.

2.2 Makerspaces as Sites of DIY-AT Development

A key motivation for creating accessible makerspaces is enabling the creation of DIY-AT, as previous research has shown that consumer-grade fabrication methods (e.g., 3D printing) can be leveraged to create customized assistive technologies (ATs) [10, 25, 28, 33, 39–41, 49, 53, 54, 61]. Ecosystems of makers, clinical professionals, and people with disabilities have been shown to be well suited share knowledge towards the creation of ATs [39, 61], mitigate risk [49], and create AT that respond to intersectional elements of an individual's identity (e.g., race and disability by printing AT with specific skin tones [34, 40]). However, research studies have also indicated that current fabrication tools and processes are not inclusive of people without prior technical expertise and important challenges in integrating these techniques

into therapy and medicine remain [10, 33, 43, 53]. Researchers have also studied DIY-AT design outside of the medical context [6, 16, 37, 38, 59]. It is shown that the creation of DIY-AT through makerspace practices supports end user self-expression [6, 59], works to expand the definition of "assistive" technology and accelerate innovation [7], shows the importance of diverse and inclusive materiality for prototyping and design [16, 38], and highlights conversations around collaboration and how labor is valued [16]. In addition, two recent studies have analyzed community-led DIY-AT programs and how these initiatives can serve as an exemplar of how community-led design more effectively dismantles the compounding constraints experienced by diverse and intersectional communities [32, 37].

Universities have also attempted to create ecosystems for the production of DIY-AT. Some studies investigated utilizing the expertise of physical therapy students to create custom 3D printed solutions [20, 54]. While they successfully created ATs, these efforts showed that it is difficult to adequately teach PT students the CAD skills required to create DIY-AT devices. To remove the burden of learning a new skills from PTs, a follow-up study connected PT students, makers in the community, and people with disabilities to create custom DIY-AT within the context of a PT classroom [33]. This study allowed for the leveraging of the skills of each group to reduce the amount of knowledge needed outside of their own domain and interests. This allowed the PT students to focus on designing functional and safe devices, while makers supported the fabrication process. While also successful, the iterative nature of digital fabrication was difficult to implement within a medical context, which led to end users not providing as much feedback as would be expected when co-designing custom AT. The asynchronous nature of the collaboration and reliance on email communication between makers and PT students led to communication challenges through the process and lack of a development of a deep understanding of each other's expertise, as well [33].

Creating DIY-AT on campuses is one of the identified ways that university students in technical programs (e.g., computer science, information systems, etc.) can learn about accessibility and assistive technologies as part of their education [4, 70]. Previous research has shown that to truly increase students' understanding of designing for people with disabilities, their courses must include co-design sessions with people with disabilities alongside individuals who do not identify as having a disability (e.g., [12]). This has been shown to improve student learning of accessible design processes and increase their understanding that people with the same disabilities can have different needs while people without disabilities might have the same needs as people with disabilities [64]. Furthermore, they can help with educating students about the importance of considering social aspects of assistive technology and accessibility design [65]. These recommendations are in line with Ladner's call for making user empowerment a priority in these contexts [48]. Ladner emphasized the importance of designers working with people with disabilities in order to achieve usable and relevant designs [48]. Furthermore, he stresses that it is even better to empower people with disabilities to design and build the technologies themselves, and identifies two important features that allow for this: self-determination and technical expertise [48]. To achieve these goals, efforts require creating accessible design and fabrication tools and processes to ensure that people with disabilities, including students, can participate in designing technologies both at the university setting and beyond [12, 24, 44, 68].

This previous research shows the need for creating accessible digital fabrication tools and makerspace programs. In this project, we build on this work by exploring what is needed to facilitate the co-design of an inclusive and accessible makerspace to encourage the creation of custom ATs. Discussing accessibility and community engagement as organizing principles before a makerspace is created offers us the opportunity to understand how expert stakeholders situate this goal within the broader conversation of space and activity design in our particular context. Previous research, including that related to maker practices (i.e., creating DIY-ATs) in the Global South, has not focused on investigating how to think through design tensions involved in creating an accessible public-facing makerspace.

3   METHODS

We used a co-design approach in this project with the overarching goal of creating mutual learning among stakeholders about the factors that need to be considered when designing a public-facing accessible makerspace in our Global South context. Using a participatory approach allowed us to adopt an inclusive and transdisciplinary approach [8] that focused on the overarching societal goal of achieving accessibility, inclusion, and engagement in the design by drawing on multiple disciplines and sources of knowledge. To achieve this goal, we created two in-person workshops that brought together local and non-local participants. We decided to include both local and non-local participants to reflect the public-facing nature of the makerspace that would eventually serve both local and non-local visitors.

While several participants with disabilities took part in both workshops, we decided not to include representatives from all local groups that may visit the future makerspace, including learners with disabilities and families, during this phase of design because of several reasons: first, we took into account that the early stage ideation about the project before finalizing the makerspace site or having concrete example activities and tools are too abstract for non-expert participants to provide feedback on. Furthermore, we wanted to minimize of participation on the families and learners with disabilities, and therefore, decided to postpone including them in discussion to a later stage where we had concrete initial ideas as a starting point.

In the following subsections, we first describe the participants. Then, we describe our data collection methods, including a description of the sites visited prior to the workshops. We conclude with a description of our data analysis methods.

3.1   Participants

We collaborated with a total of twenty-seven local and non-local participants throughout the study (see Table 1). Participants' ages ranged between 20-60, and 20 female, 6 male, and one non-binary participants took part. We recruited two groups of participants: 17 participants were local (i.e., lived or worked primarily on the island), and others were non-local and based in the US. We selected non-local participants for their expertise with accessibility and making. To recruit participants, we shared an open call with a community of practice based in the US that has members with expertise in accessibility and assistive technology. Potential participants sent their availability and details about their expertise. Members of the research team reviewed applications and sent out invitations via email to those with relevant expertise and availability to join in person. The non-local participants who had been sent out invitations for the first workshop but could not make it, were able to attend the second workshop. Of the ten non-local participants, two indicated having a disability, including ADHD and autism. For the local participants, we included both those who were already involved with the Anonymized Center in some capacity and those with relevant expertise and experience in making accessibility and informal STEM learning. Of the seventeen local participants, six indicated having a disability, including psychological/psychiatric condition, ADHD, mobility-related disability, systematic health/medical condition, autism, and blindness. These included four participants in the first workshop, and six in the second workshop, with some attending both.

3.2   Local Site Visits

To prepare participants to discuss issues of accessibility and equity, we asked them to read three papers that our team identified as foundational in this space. These focused on understanding how to make makerspaces more accessible [2, 3], and identifying and navigating issues of equity and social justice when engaging in making [66].

ID	Ethnicity	Local/Non-Local	Role/Expertise
P1	Chinese	Non-Local	Ph.D. Student (Human-Centered Computing)
P2	Asian	Non-Local	Ph.D. Student (Human-Centered Computing)
P3**	Hispanic	Local	Associate Program Manager, Computer Science
P4**	White/Latino	Local	University FabLab Director
P5	Latina	Local	University Online Division Director
P6	Caucasian	Non-Local	Incoming Ph.D. Student
P7	White	Non-Local	Professional Woodworker and Owner
P8	Hispanic/White	Non-Local	University Faculty (HCI, Wearable Computing, Ubiquitous Computing)
P9	Latin/White	Local	STEM Center Operations Director
P10	Hispanic	Local	STEM Center Lead Educator
P11	N/A	Local	University Director of Digital Transformation and Innovation
P12	N/A	Non-Local	University Faculty (Accessibility, Programming)
P13	N/A	Local	University Administrative Staff (Technology Support)
P14	Puerto Rican	Local	Ph.D. Student (Human-Centered Computing)
P15*	Native American/White	Non-Local	Ph.D. Student (Human-Robot Interaction)
P16*	White	Non-Local	STEM Academy Director
P17*	Latina	Local	Ph.D. Student (Curriculum and Teaching)
P18*	Hispanic/Latino	Local	Ph.D. Student (Curriculum and Teaching)
P19*	Hispanic American	Local	Master's Student (Architecture)
P20*	Hispanic	Local	Undergraduate Student
P21*	Black	Local	University Faculty (Assistive Technology)
P22*	Caucasian	Non-Local	STEM Outreach Program Director
P23*	White	Non-Local	Engineering Projects Consultant
P24*	Hispanic	Local	Undergraduate Student and Pre-School Teacher
P25*	Hispanic	Local	Undergraduate Student
P26*	N/A	Local	University Faculty (Education)
P27*	N/A	Local	Graduate Student

Table 1. Participant information. P1-P14 took part in the first workshop, and P15-P27 (designated by a single *) took part in the second workshop. Participants with double ** attended both workshops.

During the first day of the first workshop, the non-local participants, along with the research team, visited four different locations on the island to better understand the sociotechnical ecosystem of relevant organizations that exist locally. Each visit lasted between 60 and 90 minutes, with the exception of the third visit, which because of time constraints, only lasted 15 minutes. Due to time constraints, non-local participants who attended the second workshop were only able to visit the second and fourth locations described below. The sites were selected and prioritized by the research team to reflect the diversity of relevant organizations that exist in local contexts and are connected in different capacities with the project. In this subsection, we describe these sites with some detail as they provide information about the current relevant practices on the island.

The first site was a university FabLab located in the architecture department and used by students, faculty, and staff to work on prototypes, designs, and skill training activities. The lab leader, who is trained in architecture and industrial design and also teaches classes and workshops in the space, gave our group a tour, which consisted of visiting multiple classrooms and studios dedicated to various fabrication activities, including 3D printing, woodworking, laser cutting, recycling plastic filament, among others. Participants looked at physical prototypes, which included objects for use as temporary shelters from organic light-weight mycelium-based materials, and 3D printed objects created with clay. The lab director mentioned priorities such as material sustainability and the ability to respond to power blackouts and challenges in getting spare parts for fabrication equipment as key issues involved in running the space.

The second visit was a coworking space that is connected with local and international organizations and partially funded by industry and government agencies. The organization is also currently the largest local technology-focused co-working and technology business incubation space and is known for being welcoming and accessible to the local community. At the time of our visit with the first non-local group, a youth hackathon focused on a fictional space travel game was in action, and groups of youth were working together to create imaginary technologies for future space exploration. The director and founder of the space gave a tour to our participants and provided examples of the center's projects, including a robotic system for automating future agricultural implementation for use both in local agriculture and for potential experiments with crops in outer space, and a project to 3D print coral reef structures to repopulate the local oceanic areas that are impacted by erosion. These projects were also highlighted during the second workshop's non-local participants visit. In addition to housing these projects, the center also has infrastructure for a data center and provisions for emergency planning, such as advanced drone technology. The tours included several buildings, including those created from repurposed shipping containers that are common to access and repurpose in the island that has a sizable shipping economy. Two details stood out during the tours, the use of bright colors for the coral reef structures that were described as being necessary to attract fish, and the focus on both local and global projects with a view to the future (i.e., space exploration).

The third site was a community learning center located in a public housing complex in a town near the Anonymized Center site. This center provides computer literacy programs and training to local adult participants. Members of our research group have previously collaborated with this center to provide computer training on tasks of interest to the community, such as participating in remote work and managing email and online privacy. The teachers at the center mentioned running bi-weekly training sessions mainly attended by women with content tailored to reflect participants' specific interests.

Finally, participants visited and toured the site of the Anonymized Center, where the envisioned accessible makerspace will be established. The center is located on a mountain and in a forest setting. It currently houses several buildings, including a natural history museum focused on space exploration, several buildings that are planned to be turned into

physics and biology labs, administrative buildings, and the physical site of the future envisioned makerspace. At the time of the visits, the center was not open to the public.

3.3 Data Collection

3.3.1 First Workshop. The first workshop consisted of a two-day engagement which brought together 14 local and non-local participants in an in-person workshop. The main data collection activity of the first workshop was a co-design workshop that was conducted the day after visiting the local community sites. The session was hosted in a large room with reconfigurable furniture at the architecture school of the local university. The workshop was three hours long and was preceded by a 20-minute preparation time where participants provided demographic information through a short survey and signed IRB (Institutional Review Board)-approved consent forms. Following preparation and introduction to the workshop, we engaged participants in a World Cafe activity [52], which consisted of having participants take part in small group discussions on tables around a specific prompt for a set time before moving on to the next tables. Each time a switch happened, one participant stayed behind from each group to review the previous discussion for the new group before they all started discussing the new prompt. Each round, a new person stayed back at a table to review the discussion. This method encourages participation and is known to generate a relatively large amount of data in a relatively short amount of time. We made a few provisions to facilitate discussion, including having multilingual prompts at each table and leaving large pieces of paper, colored pens and markers, and smaller sticky notes on each table so that multiple participants could write down or draw their thoughts during discussions.

We had four tables, each consisting of a prompt focusing on one of the cultural, contextual, practical, or pedagogical considerations for creating an accessible makerspace at the Anonymized Center. We divided participants into groups of 3-5 people at each table. Participants took about 20-25 minutes discussing a prompt together before moving on to the next table with a new prompt. To facilitate conversation, the research team ensured that there was at least one member of the research team at each table at all times. After four rounds of World Cafe discussions, where every participant had discussed every prompt, we engaged participants in a concluding focus group lasting about 60 minutes to discuss each question as a group. This conversation was facilitated by the last author, who actively sought to increase participation from different participants and noted disagreements or points of agreement.

3.3.2 Second Workshop. The second workshop, consisted of another three-day engagement about four months after the first workshop, bringing together 15 additional participants, including two researchers who attended the first workshop. In this workshop, the non-local participants also visited relevant sites on the island to gain an understanding of the local context. Local and non-local participants then engaged in three different focus group discussions: one discussion about the initial considerations explored in the first workshop, another discussion on the proposed design tensions model (to be discussed later), and a discussion about lesson planning activities for the center. In this paper, we focus on the first two focus groups.

Similar to the first workshop, our research team first facilitated a 30-minute preparation time where consent forms were signed and demographic information was collected. We then gave an overview of the workshop format and introduced the overall goals. Given that for this particular workshop we had monolingual participants (i.e., speaking only Spanish), the researchers ensured that all the information, including presentation slides, handouts, and verbal comments, was presented both in English and Spanish to include and value the perspectives of all.

To structure our discussion on the findings from the first workshop, especially the design tensions model, we first presented slides with an overview of each topic, and then asked participants to share their thoughts and feedback

in small group discussions lasting between 35-50 minutes. Participants were divided into three groups, each group consisting of five to ten people, and all groups were provided with hard copies of a summary of the key considerations from the first workshop and an explanation of the design tensions model. Materials for providing feedback included pens, markers, blank sheets of paper, and sticky notes. At least one member of the research team was present at each group at all times to help guide the conversation and offer any clarifications on the discussion topics. We then held final discussions asking representatives from each group to summarize the highlights discussed on each topic, which also lasted between 35 and 50 minutes.

3.4 Data analysis

For the first workshop, our collected data consisted of audio recordings of the focus group discussion, discussions at three of the four tables (one of our recording devices did not record the discussion at one of the tables), annotations, comments, and drawings made by participants on the large paper pads and sticky notes provided at each table, and photos of the resulting annotated papers on each table for the first workshop during the two-day engagement. In total, we analyzed approximately 5 hours of audio recordings, and 289 distinct annotations and notes from the tables. For the second workshop, we also collected audio recordings of one of the small groups and the larger group discussions, and photos of annotations made on paper and sticky notes. The analysis of the data on the design tensions model included 85 minutes of audio recordings and 32 different annotations.

To analyze the data, we transcribed the audio recordings and analyzed them along with the content of the photographs using a thematic analysis approach [9] to construct and clarify recurring themes in the discussions. We used a combination of inductive and deductive approaches in the analysis, where we first used the predefined categories of factors used to query the participants for their input (i.e., cultural, contextual, practical, and pedagogical), as well as the six tensions, to identify codes corresponding to the factors, tensions, and the relationships among them before analyzing them across categories into refined themes. The first round of analysis was conducted by the first and last authors, each of whom independently worked on identifying factors along the four categories mentioned above and the model of design tensions, respectively. During the second round of analysis, they shared their analysis and provided feedback and refinements on each other's work. During the third round, they shared the initial findings with the second and third authors, who reviewed all themes and discussed and clarified points of contention with the first and last author.

3.5 Research team positionality

While our research team is currently situated in the US, most team members are originally from the Global South, including Central and Latin America, and the Middle East, and have first-hand experience with the educational programs there. One of our research team members has years of professional experience working at a local university at the Caribbean site where the project is located. None of the research team members are disabled. We would like to note that in recognition of the current use of both people-first and identity-first language when writing about disability [62], we will use them interchangeably in this paper.

4 FINDINGS

Our findings consisted of considerations, factors, and tensions among them that participants identified in relation to envisioning and creating a public-facing makerspace at the site. We present these along the four axis of practical factors (Section 4.1), cultural factors (Section 4.2), contextual factors (Section 4.3), and pedagogical factors (Section 4.4). We then present additional analysis that resulted in a design tensions model that captures the tradeoffs facing the project

creators and stakeholders (Section 4.5). We conclude with presenting the preliminary feedback we received from the second workshop participants about the developed model (Section 4.6).

4.1 Practical Considerations in Designing the Accessible Makerspace

4.1.1 Prioritizing Safety and Accessibility. Safety emerged as a key recommendation when discussing the practical considerations for designing an accessible makerspace. On the one hand, participants described the need for ensuring that the physical space, especially the equipment in the envisioned makerspace, remained safe. Examples from the annotations included: *"What about safety measures for people who are blind?"*, and a longer note about the deaf community,

> "Don't forget accessibility for the deaf. Machines have alarms. Safety has to be considered. We rely on noise (hearing people) so we have to work with the deaf community to understand needs for makerspace."

Other annotations such as *"organization, safety issues, where things are"* connected safety to having an organizational system for the community to access items in the makerspace in a safe manner.

On the other hand, participants emphasized the importance of establishing rules and procedures in the makerspace to inform the community about safety practices. P5 commented,

> "If I am using a machine, I have to be looking at the machine. I can't leave to do anything else."

P14 added that *"The laser cutter can catch fire, you have to be there,"* highlighting the potential risks of using equipment in a makerspace and the need to inform the community about best practices, such as continuous presence, to interact with the technology. As for having accessible instructions and information, P13, a local participant who verbally confirmed he is blind, demonstrated interest in having accessible equipment by stating,

> "I would love to learn how to work with the machines, 3D printing, but any means that would be accessible for people... That has to be OCR [optical character recognition] so if I go to a [makerspace] that the instructions can have some sort of text so I don't bother the next person."

4.1.2 Creating a Makerspace that can Endure Natural Disasters. Multiple local participants noted that creating an accessible makerspace that is also *resilient* amid natural disasters in the area was a key practical consideration. For instance, some annotations focused on the current and future infrastructure needed for the space to operate and persist: "wi-fi, cellular data", "weather, humidity, hurricane, heat, ventilation, resilient, filters", "architectural considerations (climate control)." Furthermore, coupled with the discussion of having the necessary infrastructure were conversations for the makerspace to be an enabler of continued education. P13 described it as

> "In [the local context], we have storms, very strong storms, we lived it and we are still here, so the issue is how do we comply with the issue of continuing the education in whatever means."

Participants brainstormed alternatives for ensuring that students and families could continue learning at home. For instance, P4 introduced the idea of "*making miniature makerspaces...portable makerspaces people can safely take home with not a lot of expertise,*" highlighting the ability for the envisioned makerspace to have an impact on the community beyond its physical boundaries. The concern for continuing education even during natural disasters was introduced in the discussion of practical considerations; however, local participants also connected this concern to their cultural roots. P13 explained "*I know professors that went to homes physically so that the education would continue*" after a hurricane had impacted the island. Another participant, P8, who is a non-local, agreed that prolonged education and "*resilience that comes from building things that will last long*" was directly connected to the island's culture.

4.2 Cultural Considerations in Designing the Accessible Makerspace

4.2.1 Centering Art, Music, and Family. Art, music, and family were prevalent in our discussion about the cultural considerations for the space. When non-locals were asked what they had noticed regarding culture in visiting the local sites, P6 responded,

> "It seems like there's a lot of expression just in the way that the colors that are used on buildings and like the amount of murals and like what the murals usually represent."

Moreover, when sharing on behalf of the group, P12 commented that the group had "*talked about bringing in local artists and scientists to lead some of the workshops,*" suggesting that leveraging local talent and expertise would be beneficial for the accessible makerspace's cultural identity and growth. Discussions also pointed to the need of creating a makerspace where both accessibility and culture could flourish. P12 also said,

> "There is so much science to [music]. You can have people build their own cuatro [i.e., a Latin American instrument] but then you talk about the different thicknesses of the wire, and the different vibrations. Like the observatory as well right because the different size of your bowl is gonna make different sounds. So that could be like a cool maker project where you make your own instrument."

In thinking about activities that could incorporate the community's emphasis on family, one of the local participants, P10, who is also the center's lead educator, mentioned *" being able to [3D] print molecules, specific DNA proteins, that maybe people that are blind can feel,"* demonstrating a commitment to offering accessible STEM activities that also reflect aspects of the culture, such as family. Furthermore, there were multiple annotations about music being an integral part of the island's culture. P8 shared how the island's music "*talks about their history, where they came from, and what they face"* and that it could serve as a way to engage the community with a low entry barrier, "*connecting people regardless of their interest or expertise."*

Additional examples for making music and art accessible to people with disabilities emerged. P13 reflected on his personal experience creating graphical art as a blind person. His 3D tactile artwork included a video with closed captioning that narrated a cultural story that talks about "*discrimination, poverty, malnutrition, and even narcissism.*" Other local participants recalled the story and agreed that representing the local cultural context in the makerspace in accessible and interactive ways should be a key consideration.

4.2.2 A Focus on Collectivism and Bilingualism. In our discussion about culture, participants presented collectivism and bilingualism as cultural pillars in the community. According to P3, a local participant,

> "A lot of innovation happens in [the island]. We are collectivists, we process together, talk about things together, we serve each other. There is a lot of trying to help your community because of the challenges we face."

Participants agreed that relying on a collectivist approach rather than an individualistic approach for envisioning and developing the accessible makerspace would be critical, confirming that our participatory approach was preferred for the efforts involved in the imagining and creation of the space.

Another key recommendation for envisioning the creation of the accessible makerspace was keeping the prevalence of bilingualism in the island in mind. This was both evident during the workshop as well as multiple annotations made by the participants regarding language. For instance, in one table discussion composed of local participants, P14 observed that they were discussing in "*Espanglish*", signaling that speaking English and Spanish at the same time is seen as an integral linguistic activity that belongs to the community's cultural identity. In another instance, P4 asked the

local participants at his table if they preferred English or Spanish before beginning the table discussion. Moreover, both local and non-local participants made annotations regarding bilingualism which included *"language (work with dual language so we can communicate with other people)"*, *"adaptability (quickly change language)"*, *"narrate audio (spanish and english)"* indicating that bilingualism should be a key cultural consideration in the design of the accessible makerspace.

4.3 Contextual Considerations in Designing the Accessible Makerspace

4.3.1 A More Detailed Exploration of Accessibility. Participants engaged in deeper discussions about accessibility when discussing the contextual considerations in designing the accessible makerspace. Annotations about accessible tools and technology required included "adaptive tools, take home assistive technology, speech-to-text, voice components, descriptive audio, feedback-driven simulations, haptic feedback, screen readers, high-contrast designs, WCAG standards, wheelchair-friendly layouts, caption videos" and more. P11 commented that "*All devices nowadays, including computer or device, have the accessibility area, it has to be active,*" suggesting that all devices and equipment in the makerspace should have the accessibility features turned on beforehand and that continuous supervision to ensure this is done may be required. Participants also discussed accessibility of the internal and external space. For the internal space, participants noted that "adjustable tables, chairs, workbenches, and lights" would be needed. Additionally, lower-tech solutions were proposed as a way of prioritizing accessibility. One particular annotation read "adjustable height benches, etc. but low/no tech (so they don't require expensive or difficult fixes that may make something inaccessible for extensive periods)." P3 also added that "*There are things that we can do that are low-no-tech so that we're not dealing with those plan Bs as often,*" acknowledging that having contingency plans would be part of the process but suggesting that low-tech alternatives could help minimize the need for backup plans. Furthermore, participants expressed concern for the external accessibility of the center and the makerspace. As P7 recalled the tour of the center, she expressed that,

> "This is the biggest challenge, we think, is to get from those spaces [the different buildings in the center] up to the hill where it's what people are calling the museum. The museum itself is accessible there's an elevator that can get you to the floors but to get to the building is a challenge."

Even when you do have some accessible measures inside buildings such as elevators, "*these systems can fail,*" according to P7, and it is important to have the necessary resources to ensure accessibility is not compromised.

4.3.2 Understanding Financial Feasibility and Logistical Constraints . In our discussion about the contextual considerations, participants demonstrated concern and curiosity for the project budget. Participants agreed that having an understanding of the financial constraints would help guide conversations about the physical space, resources, equipment, staff, and sustainability of the accessible makerspace. When comparing the center's potential to the co-working/incubator visit, P7 argued,

> "I know like especially going to [the co-working space], it's like, you can see the potential... but also you got to remember that [the co-working space] is terrifically funded. [They] don't have to worry about money to make that look as amazing as it does."

Furthermore, through discussions about the center, P9, the center's operations director, revealed additional constraints that helped other participants have more context about the center's practices and regulations. Regarding accessing the grounds, P9 shared,

"Right now we are establishing that people can go in groups or separately and either way they can access the visitor center or the labs. For the labs they need reservation, the visitor center is going to be open [for all]."

This points to the need of informing participants about the logistical aspects surrounding the makerspace such as the center's hours of operation, services, communications, etc. which can help better structure conversations about envisionig such space together.

4.4 Pedagogical Considerations in Designing the Accessible Makerspace

4.4.1 Creating Meaningful Learning Experiences and Embracing Productive Struggle. Participants provided suggestions for how to create meaningful learning experiences in the makerspaces by connecting activities to the exhibits in the nearby museum. For example, they suggested that the makerspace can be used to prototype new exhibition ideas. For example, P12 said,

"We could bring in classes and each class builds something in the makerspace that becomes part of the museum."

Participants also wrote "building a connection between makerspace and museum," and "prototyping experiences," on the shared boards during discussions.

Additionally, participants described how it is important to build a learning environment that embraces productive struggle. P3 described it as "*in a makerspace, there is a certain safety about [failure being] just part of the process*" which was echoed by P12 who stated that we should consider "*building a space where you can make mistakes.*" Participants mentioned that traditionally, makerspaces have been perceived as intimidating and unwelcoming spaces and that designing an accessible makerspace from the beginning was an opportunity for imagining a space that is inviting, welcoming, and that works for all.

4.4.2 Leveraging Existing Learning Theories and Approaches. The discussion around pedagogical considerations also focused on understanding the existing learning theories and methods and how to incorporate them for specific populations in the accessible makerspace. Participants suggested drawing from what is already available and evidence-based methods as opposed to reinventing the wheel. P4, for instance, emphasized the Montessori learning method (learning by doing) as he stated that,

"As an educator that is working in the FabLab and am giving classes on prototyping... I think that part of playing and enjoying the process of design is going to be really important in an accessible makerspace."

Others emphasized the Theory of Multiple Intelligences (P13), Universal Design for Learning (P3), and Metacognition (P5). Additional annotations on teaching and learning practices included: "multiple modalities, individualized learning, competence-based approach, design thinking, guided-inquiry leanring" and more. Ultimately, however, participants agreed that there is no perfect method and identifying and analyzing pedagogical approaches through iterative processes would be valuable for creating an accessible and inclusive makerspace. This discussion also brought up important questions such as who is the audience for the accessible makerspace as the planning and creation of the space from a pedagogical standpoint will vary according to the population it will be designed for.

4.5 Modeling the Design Tensions of Creating a Public-facing Accessible Makerspace

Our analysis from the first workshop pointed to a number of design considerations that we characterize as 6 design tensions for creating a public-facing accessible makerspace in our Global South context. This list is not meant to be exhaustive, and we anticipate that with more stakeholder participation, additional tensions or new aspects of the identified tensions may become clear. Our purpose in presenting them here is to illustrate the range of potential considerations and point to future directions for visualizing and thinking through them in the future. Furthermore, as we will outline below in the case of each tension, design decisions do not have to be one-dimensional, and often, the ideal situation could dictate that multiple goals are aimed for in each tension. However, in the presence of resource constraints and external priorities, it is important to articulate and consider all possibilities regarding tensions and their tradeoffs. Figure 1 presents a visualization of these tensions in relation to the three phases described briefly below.

Phases:

■ Initial Phase ■ Transforming Phase ■ Target Phase
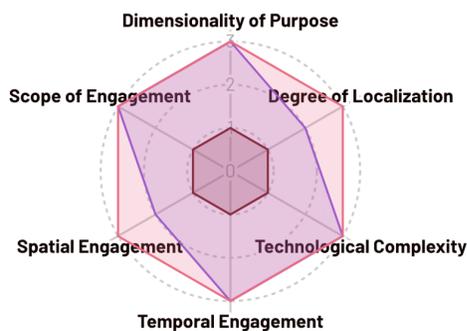
Design Tension	Guiding Question
Dimensionality of Purpose	To what end (i.e., why) are the maker learning experiences created?
Scope of Engagement	Who are the users/makers/audiences?
Spatial Engagement	Where do the maker learning experiences happen?
Temporal Engagement	When do the maker learning experiences happen?
Technological Complexity	How are the technology-rich aspects of the learning experiences facilitated?
Degree of Localization	To what degree is the design tailored to the local context?

Fig. 1. A model of 6 design tensions and 3 design phases to help with thinking through design tradeoffs at different stages of makerspace design and development. The spider graph shows the tensions in relation to each other, and the table summarizes the design tensions and a corresponding guiding question for each tension.

Scope of Engagement (Who?): The first design tension involves who the makerspace should aim to serve. Is the design going to serve a specific user group (e.g., local people with visual impairments), making the environment, activities, and engagement strategies specific to them, or is it going to take a more inclusive approach with the goal of serving as many people as possible? This tension was voiced during the discussions as participants questioned who the audience would be for the makerspace. For example, P13 emphasized that, *"who is your audience is important,"* and P4 suggested that *"we need to categorize into spaces"* each designed for different audiences with different needs who visit the makerspace. While at first, this question may seem trivial, closer examination shows that there are tradeoffs for each direction: focusing on a narrower population would enable more customized and optimized experiences for them, but may make it harder for other groups to engage. One annotation described the need for customized solutions as: *"for people who are blind, customized solutions, not all who are blind know braille,"* reflecting the experiences of P13, who shared that he had lost his sight a couple of years back as an adult and had not learned braille yet. On the contrary, creating a space that would accommodate as many people as possible, for example, using principles of Universal Design [1], would be more inviting for more groups of people but could potentially leave out fewer resources or opportunities

for deeper or more meaningful user engagement. Related to this issue is what aspects of identity should creating such a makerspace prioritize: should it aim to focus on one aspect of identity (i.e., disability), or multiple aspects of identity (i.e., being disabled and Latinx)? Given that intersectional aspects of identity result in distinct experiences [14, 15], design decisions regarding this tension can impact user experiences. An enticing possibility in exploring this tension could be to design the space to incorporate best practices in creating accessible learning spaces (e.g., [1]) that is generally accessible for most visitors, and also host special events, workshops, or activities for specific groups. An important practice is to keep updating the accessibility aspects of the space, both through input from the community and emerging best practices in research and industry.

Temporal aspects of Engagement (When?): Another tension that arises in the design of the makerspace relates to the length and frequency of user engagements. These temporal aspects of engagement should be taken into account to ensure proper facilities are created to support them. In discussions about the center logistics, P9 suggested "*I think the best way is if we have schedules for groups and for regular visitors*" pointing to the technical challenges surrounding timing for different activities. An enticing possibility in exploring this tension could be to design to facilitate both types of engagement. For example, run technology-rich learning summer camps and host shorter workshops during the school year. However, it is important to consider the additional resources (i.e., accommodations, transportation, planning, and activity facilitation, etc.) that supporting multiple modes would entail.

Spatial aspects of Engagement (Where?): Another design tension relates to the spatial aspects of engagement, meaning design decisions regarding where the engagement takes place. While the notion of a makerspace is often related to a specific physical location, it is important to consider how the activities and impact of a makerspace do not need to be limited to its physical site. For example, our participants had suggestions for how makerspace activities can be extended to reach visitors' homes through mail kits or hosting remote or hybrid activities. When discussing the importance of learning beyond the physical makerspace, P3 mentioned,

> "A lot of the work that we do in these spaces, it's not the inside that's important, it's the 'what can I take out? that matters the most."

These strategies can both overcome some of the logistical issues of reaching the physical site of the center and also generate more resilience if future disasters (i.e., pandemics, hurricanes, or political unrest) result in social distancing. Another way to navigate this tension is to think of the role that the makerspace can play in prototyping, refining, and evaluating activities that can be done offsite in the future.

Technological Complexity (How?): Another design tension relates to the technological aspects of the makerspace: should there be an emphasis on the latest high-fidelity technologies, or especially given the history of our site and the challenges in acquiring and maintaining equipment there and in Global South contexts more generally, should there be a focus on low-fidelity but more sustainable alternatives? Multiple participants argued that taking a low-technology approach with both the equipment and the materials, would lead to more sustainable practices over time. Annotations on leveraging low-cost materials included: "*Legos, art supplies, clay, play-doh.*" Additionally, participants who were more familiar with the technology that is typically present in makerspaces touched on having varying levels of equipment complexity. As the director of a FabLab, P4 suggested that in the accessible makerspace,

> "There can be some really simple, straightforward 3D printers… maybe some more complex ones that are more sophisticated that also affects a lot because there's some that you have to have knowledge to operate them and they break and then you have to have knowledge to fix them."

revealing the hidden challenges of this technological tension. Again, it is possible to take a hybrid approach, where a combination of technologies is present at the makerspace, and part of the engagement focuses on reflecting on their possibilities and the tradeoffs involved in their use and non-use.

Degree of Localization (What?): Another design tension is the extent to which the makerspace and its activities are localized or tailored to the specific context in which it is situated. While it is well-known that incorporating relevant cultural assets can enrich and inform design decisions [67], in practice, applying this principle is often challenging, not least because of the heterogeneity of even small communities. Despite this challenge, understanding and centering the desires and needs of communities in our context to the extent that is possible at a given point in time is a central goal of the project. There were multiple annotations made about creating meaningful projects and activities that would "give back to the community." P6 suggested that the community members using the makerspace could engage by "*learning a task that they could take back to their community and that can benefit their community in some way.*" For instance, "*one person can teach other people in the community things like learn[ing] how to use a computer.*"

Another aspect of this tension is that it may be possible that by embracing the specific socio-historical aspects of the local context, the makerspace can paradoxically develop an identity that is both reflective of its context and echoing more global concerns. For example, while the emphasis on practices that support self-reliance and sustainability is shaped by the recent history of natural disasters and colonialism of our site, these themes resonate with many communities and contexts around the world, including in the Global North, and incorporating them can result in increased value and relevance.

Dimensionality of Purpose (Why?): Finally, a design tension arose in relation to the potential aims or purposes that the makerspace could serve. While many aspects of the project may be dictated by funders, by design, the fine-grained details of its implementation were left to be decided based on community feedback. A key question here was whether the makerspace should serve a small number of purposes (i.e., creating accessible learning experiences for visitors with disabilities), or combine multiple ones (i.e., serve as a learning space, and also help prototype experiences for the co-located science center). For example, P3 described that,

> "Actually, makerspaces for me are one of the things that are very important because they allow you to use the technology and all that, but much of the time spent in makerspaces is thinking, working with others, asking questions ... it is a lot of collaboration, not everything is about the machine."

Other participants also suggested a variety of purposes that the makerspace could serve such as letting communities "bring in outside projects for repairs (annotation), and "*how the makerspace can work as a hub for creating teaching instruments for different schools in the area,*" according to P4. Similar to the above tensions, while a combination of approaches could be interesting to explore, increased goals may increase the center's impact but also its cost of operation and need for resources.

Reflecting on Phases of Design: While developing the model, we anticipated a need for representing different phases of a project to facilitate reflection on priorities and tradeoffs. Thus, in addition to the tensions described above, we included three design phases, Initial Phase, Growth Phase, and Target Phase, to use in conjunction with the model. We envision that the makerspace design planning can move through from the Initial Phase, into several iterations of the Growth Phase, moving into a Target Phase, before iterating between the Growth and Target phases as priorities are evaluated over time.

4.6   Feedback on the Design Tensions Model

To receive initial feedback on the model and the tensions, we presented it to the second workshop participants and asked for their feedback. We presented each tension with its corresponding question. For instance, when thinking about the Scope of Engagement, we asked participants to discuss tensions about *who* the space would be meant for. We noted that simplifying each tension by following the 5W1H framework (aka Kipling Method) [51], which uses the six questions of What, Why, When, Where, and How to explore an issue, made it easier for participants to enter the discussion rather than using the names of tensions by themselves.

The participants generally had positive reactions to the model, and found it useful in thinking through and discussing tensions. Multiple participants also noted that the term "*tension*" itself was constructive, as it does not necessarily carry a negative connotation to it and also opens a discussion space where the trade-offs involved in the design of a public-facing accessible makerpace are acknowledged. In both the small group and final group discussions, we observed that participants began expressing their perspectives and concerns by using the word "*tension,*" indicating their awareness of the difficult decisions that would need to be made for the creation of the space. Speaking on behalf of the group, P15 indicated

> "We followed the model accidentally, like we used it to structure our discussion. And so, evidentially, the model is a really good model."

This quote suggests that the model acted as a tool to guide the group's thoughts. One of the annotations made regarding the model also read: "design tension model may be a good start," implying that the model can serve as a foundation for beginning collaborative and community-driven discussions about envisioned spaces.

Feedback on the design tensions model also included the phases in which the design tensions can exist (initial, growth, and target). While our initial concept of phases included the understanding that they are transitory and not mutually exclusive, P15 raised a key concern that situating the design tension model within the phases would still pose limitations and "make people think that we'll get to the end and be done." Instead, P15 recommended exploring the design tensions in terms of length of impact, saying,

> "[Perhaps you should think about] Is this a decision I'm making right now and we might reconsider it later, or is this a decision that I'm making that we're going to be stuck with and maybe we should put some more thought into that one."

This quote shows that the design tensions and time are greatly interrelated. Furthermore, that the Temporal Aspects of Engagement tension regarding length and frequency of engagement activities is not only applicable within the boundaries of activities, but also within the decision-making process. For example, this dimension should also consider how often design decisions are made and evaluated throughout the process, and how long would be the envisioned impact of a particular decision. Similarly, P16 said

> "We also talked about creating a space that could change. So what we would have made 15 years ago looks very different than probably today. So how do we make it so that it has adaptability within the space. And maybe the philosophy of education or philosophy of how we are inclusive will be different in the future. So how do we try to create space that could adapt to that."

Participants' feedback confirmed our hypothesis that in presenting the tensions, the model is not limited by binary decisions to resolve the tensions. In other words, it is possible to aim for achieve more than one aspect of a tension at a

given time. For example, when discussing whether the space should serve the immediate local community versus the researchers who are acquainted with the center, P15 stated,

> "It can be all of those things. There's a lot of space here and a lot of potential, as long as you keep them all in mind and that *they are in tension*, that any one of those will pull and could pull the whole project in that direction."

This was echoed by P9's recognition that "*we cannot get everything, but we could be adding stuff little by little.*" Participants also had suggestions for how to prioritize the questions. For example, in relating the questions, P15 said,

> "Who is it for is the most important part. Is it for uplifting the people in the community and making them feel like they belong in STEM, or is it for people who are already in STEM to collaborate with each other in this really cool space? Is it for both, and the mixing of those communities will need to be done very carefully and handled with a lot of caution and a lot of thought."

While this quote points to the importance of prioritizing the Scope of Engagement (Who), it also shows that the design tensions are not one-dimensional, and are multi-dimensional, frequently interacting with each other. For example, as we consider the Scope of Engagement, we must also consider the level of Dimensionality of Purpose (the *why*) that exists within the tension of who the center will serve. Identifying the specific communities that the makerspace will serve also requires an understanding and investigation of *why* specific communities would want to be in the space, whether it is belonging, collaboration, varying reasons that are difficult to identify, or all of the above. P26 also made reference to the multifaceted nature of the Technological Complexity and Scope of Engagement tensions by suggesting that value should be placed on *who* has already done the work on the type of equipment to be purchased:

> "Even when we buy the equipment, for example, the 3d printers, FabLabs or other labs have already made the research [on] what are the models that are accessible and what are the models that have, for example, physical buttons and not screens. So that's important, that the equipment we buy is accessible, but then other labs are already doing that research and can say this is the model that you must follow."

Furthermore, key conversations about financial feasibility also emerged during the design tensions model discussion, specifically regarding the long-term sustainability of the center. P22 suggested that maintaining relations with faculty members in nearby universities would be important as she stated that the center should connect with "*faculty partners at both of those campuses who can in their grants maybe see this as an outreach center that can help in terms of the longer term sustainability in addition to wanting to support the community.*" Annotations on financial feasibility included questions about the type of services the public-facing accessible makerspace would have "paying for services (specialized workshops) or free," and questions about funding key personnel such as "staff for fundraising."

In general, we interpreted the feedback regarding the design tensions model as positive, especially because participants agreed that acknowledging the existence of tensions and trade-offs was crucial in moving forward with envisioning the public-facing accessible makerspace. In particular, participants recognized that beyond the awareness of the design tensions, flexibility and adaptability would be needed throughout the envisioning and creation of the space.

5 DISCUSSION

Our findings illustrate the opportunities and challenges of identifying and balancing design tensions and tradeoffs in envisioning a culturally-situated, value-driven, and community-oriented space for technology-rich learning and innovation in the Caribbean. Beyond identifying specific factors that can inform the design of future makerspaces, our

study points to a new participatory approach in articulating and navigating design decisions, and adds to the literature on Participatory Design and other similar approaches that value the inclusion of diverse and sometimes contrasting perspectives and input in the design process [18, 19]. Our findings have implications in several areas that we will outline below.

First, our findings show that using accessibility and community-engagement organizing goals impacted the entangled design tensions involved in envisioning the makerspace from the outset. Our findings show that participants did not want to compromise on accessibility, but wanted to balance it with other contextual and practical tradeoffs. The design tension model shows that this is a complex but doable task, and one that is worth aiming for. For example, as we discussed, issues of sustainability and climate change were front and center in many of our discussions, and our findings show that in our particular context, with its ongoing post-colonial relationship with its neighbors, issues of independence and sovereignty weigh heavily in decision making and may be prioritized over acquiring the latest assistive technologies, or building infrastructure that offers the highest degree of safety. We don't view this as a weakness, but rather as a strength that invites us to consider low-tech and community-based, or grassroots, approaches to accessibility, as suggested in our findings. For example, if technology cannot be acquired to maximize the safety of specific equipment (e.g., a large laser cutter), alternative collaborative approaches that invite disabled and non-disabled makers to work together can be established. Second, given the volatile political and environmental aspects of our context, participants underlined the importance of responsive approaches that view accessible makerspace design as a process where tensions are not necessarily resolved but are managed over time, and as different factors impact access to the broader ecosystem that supports making.

Second, similar to previous work on creating accessible makerspaces [3, 34], our findings emphasize the importance of creating a sense of belonging while also considering practical and safety issues. While supporting belonging has been identified as a key factor in creating accessible makerspaces for people with disabilities [3], it's unclear how this is to be achieved. Our findings show that engaging the local culture, including art practices, combined with disability representation, is a promising direction. These strategies that are shown to be effective in other technology-rich learning contexts [36]. Interestingly, we saw much focus on environmental sustainability and an emphasis on building local capacity to sustain the technology used at the center. We posit that these factors were more pronounced in our exploration, given the environmental and political history of the site. Additionally, the proximity of the makerspace to the science museum offers exciting opportunities for using it as a site of customized assistive technology innovation aimed at making the museum accessible for disabled visitors. Suggestions included using it to create 3D printed maps of the site or other alternative interfaces (e.g., auditory or tactile) to experience museum exhibits on nature and space, directions we are excited to explore in the future. If realized, we expect that in addition to contributing to museum accessibility, these innovations can create a sense of belonging in disabled users makerspace users, both those who contributed to them, and those who may be inspired to learn that these innovations are made locally and by other disabled makers.

Third, in exploring the project's complex design space, we have found the notion of design tensions productive in facilitating discussion and elucidating the choices that face stakeholders in such tasks. While we plan to iterate on our model in the future and especially revisit the idea of phases and how they can be better communicated to stakeholders, we find that discussing tradeoffs in terms of tensions can open them up to be examined from community perspectives. With respect to phases, our current reflections are that articulating them can help prioritize decisions, and that our approach of discussing plans for transition and a "target phase" are in alignment with current research on non-profit project sustainability research that recommends planning for achievable long-term project end goals [23].

For example, during the Initial Phase, priorities may include limiting different aspects of engagement to overcome the practical challenges of getting the project off the ground. This priority can inform decisions in relation to all design tensions. For example, with respect to the Dimensionality of Purpose, only the most central goal (i.e., creating an accessible makerspace) should be pursued. Similarly, the most practical spatial and temporal aspects of engagement should be chosen, resulting in activities that take place at the makerspace and over a short period of time (i.e., a visit or a workshop). Moving on to the Growth and Target phases, the decision-making around design becomes more complex as there are more factors (practical, cultural, pedagogical, and technological) to consider. However, it is important to remember that all phases are transitory, and decisions can be adjusted in relation to evaluation and community feedback. Which brings us to perhaps the most promising aspect of this process: its potential to enable community participation in providing input into the design process at different stages of implementation. We expect that articulating design tensions and continuously soliciting community feedback on them can help guide design decisions in later phases of the project and help prioritize which tensions are in need of immediate adjustment and which ones can be left to future cycles.

Finally, our findings inform several recommendations on the methodological aspects of engaging stakeholders in the initial phases of designing value-driven makerspaces and other similar technology-rich learning sites. Our first recommendation is to embrace the complexity of perspectives and views by inviting diverse stakeholders to participatory engagements. We found that including language support, activities designed specifically to elicit participation (i.e., World Cafe), and site visits for non-local participants were helpful in inspiring rich and productive discussions. Beyond answering research questions, bringing together local and non-local stakeholders can also result in community building and new connections [30]. Second, while the design tension model is not final, we found it an effective way to facilitate discussion in the second workshop. In addition to helping with the discussion, the model communicated our intention to listen to participant perspectives and do the work of synthesizing complex and sometimes contrasting views to inform design. We plan to follow this work up by using a refined version of it to communicate about our design process to a larger group of local stakeholders.

6 LIMITATIONS AND FUTURE WORK

Our current paper has several limitations that we plan to address in the future. First, given the early stage of ideation, we did not include participants who would be representative of the general public that the future makerspace intends to serve. In the future, we plan to include members of the public, especially those with disabilities, in the design and evaluation of the makerspace. Second, the analysis of design tensions presented above has not been discussed in detail with stakeholders or experts outside of the particular group of workshop participants for feedback. Iterating multiple rounds on this data with previous and new participants can help confirm and refine findings and unearth new ones.

7 CONCLUSIONS

Our study has focused on investigating considerations needed in the design of a public-facing accessible makerspace for learning and community engagement in the Global South. Design tensions impacting stakeholders have been identified. We have illustrated potential considerations, and have identified that these can be helpful in facilitating discussion. These have provided an insight into the complexity of choices that stakeholders face. Finally, recommendations have been presented relating to the methodological aspects of engaging stakeholders in the initial phases of designing accessible makerspaces.

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