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SONAR SCREEN: MICROCONTROLLER PROTOTYPING FOR SUSTAINABILITY

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ABSTRACT

The paper presents a detailed account of "Sonar Screen", an interactive architecture prototype developed by faculty members and students of the Department of Architecture at COMSATS University Islamabad, Lahore Campus (DACUI) for the IAPEX 2020 Expo organized by the Institute of Architects Pakistan Lahore Chapter (IAP-LC) in January 2020. The project was sponsored by IAP-LC and showcased as part of the exhibit titled "Architect's Corner". The purpose of the project was to utilize the microcontroller platform Arduino, to explore the application of parametric design in response to climate change. While conventional training of architecture means that students and faculty lack the necessary skills of programming and circuit design, the popularity of Arduino as an open-source platform also meant that project members could benefit from freely available online resources for learning. By designing the prototype as an installation, the project was deployed in a public event space to initiate discourse regarding climate change and the role of innovative architectural technologies for a sustainable future. The paper explains the challenges met during development, its impact regarding public engagement, and the potential of low-cost computing platforms for future design research at an undergraduate level.

Keywords: Parametric Design, Public Installation, Interactive Architecture, Arduino, Pedagogy

INTRODUCTION

Sustainable Interactive Architecture

Interactive design as a methodology was first popularized in visual arts and media due to increasing usage of computers and digital systems. By programming logic and responses, interactive systems can respond to physical environments or external stimuli. Following World War II, research into cybernetics opened new avenues for architects to understand the environment as a system in equilibrium. This led to new possibilities for integrating digital systems create responsive architectural forms (Steenson, 2017; Mcmahon, 2013). Buildings, spaces, and cities could be regulated in response to individual needs and external forces.

With time, improvements in sensing technologies have allowed us to quantify changes within our environment thereby altering our understanding of ecology and our complex lived realities (Alexander, 1964). Awareness regarding climate change and resource scarcity with an ever-increasing human population has made it crucial for architecture to be integrated with information to create a dynamic landscape that can minimize our impact in a sustainable manner.

Computational Thinking for Design

Digital tools and applications are developed by writing algorithms as sequential set of instructions for computers to execute. Computational Thinking (CT) as defined by

Wing (2006) therefore requires breaking down of a complex problem into clear set of causal relations between distinct factors and systems. Meanwhile, Senske (2014) relates this constructivist form of problem-solving to architectural design processes in which various factors, constraints, conditions and relations are used to create spatial solutions that are appropriate for specific contexts and user requirements. As Alexander (1964) also demonstrated through his seminal thesis, a complex design process can be broken down into more manageable sub-processes by using an algorithmic approach. Since then, digital technologies and CT have helped transform architectural design and construction industries by increased productivity and lowered risks. It has also led to exploration of material configurations through generative processes leading to tectonic expressions that were not possible before (Hauck et al., 2017). However, in countries like Pakistan, digital innovation in architecture is an uphill battle. While digital design systems such as Building Information Modelling (BIM) are used in many parts of the world to streamline design and construction processes, adoption rates in Pakistan are slow due to economic, social, and cultural factors (Farooq et al., 2020; Akdag and Maqsood, 2020).

Parametric Design Pedagogy in Comsats Lahore

To train students of architecture for better integration of emerging technologies using CT, DACUI initiated an advance course for digital tools focusing on parametric design in 2017. Parametric design in architecture refers to a systems-approach of abstracting a design process to create generative algorithms of spatial design. With advancements in software reducing the learning threshold, it is not necessary for designers to write code for designing interactive architecture. With parametric design tools, architects can employ CT to solve complex design problems (Loukissas, 2012).

One of the most popular tools for parametric design in recent years is the Grasshopper plugin for Rhino3D modelling application which provides a visual interface to create algorithms (or scripts) by connecting wires between diverse sets of components (inputs, outputs, and functions). By using this tool, architects can link spatial elements explicitly to environmental factors. Any change in context such as climate, movement, or material constraints dynamically affects the design outcome through such a script. Furthermore, it also allows architects to use the outputs directly for construction and fabrication in a seamless manner, thereby creating more efficient and sustainable forms of architecture (Hauck et al., 2017). While Grasshopper is not a programming language itself, it allows non-coders to use CT to create forms of architecture integrated with the environment.

IAPEX as a Platform for Public Engagement

The Institute of Architects Pakistan (IAP) was established in 1957 as a social group by architects of Pakistan to promote architectural design at a regional level predating official recognition of architects in Pakistan (Lari, 2008). Since inception, IAP has been actively engaging with not just professionals but also academics across Pakistan for improving public understanding of architects' role in developing the built environment.

In 2004, IAP organized the first IAPEX event in the city Karachi for connecting research activities with the wider public (Business Recorder, 2004). Now an annual architecture expo organized in each of the major cities of Pakistan, IAPEX is a multi-day exhibit usually featuring academic seminars, talks by prominent practitioners, student discussion panels, and exhibits for innovative building materials. As a major public event in major cities of Pakistan, IAPEX provides the opportunity to directly engage with the wider public regarding architecture and its role in sustainability. For the Lahore edition of IAPEX of 2020, the organizing committee IAP-LC planned a public exhibit to showcase prototypes developed by architects known as "The Architect's Corner". The expo was planned to run from 31st January 2020 till 3rd February 2020 at the Expo Centre Lahore in Johar Town. To diversify the experiments for the proposed exhibit, faculty members of DACUI were invited to participate and design an installation. As a significant public event, the exhibit offered not only a public platform for climate change awareness but also a chance for students to explore innovative approaches to parametric design and fabrication in a hands-on manner.

RESEARCH QUESTIONS

- How does the use of open-source platforms like Arduino reduce cost barriers for researching climate responsive architecture in developing countries facing digital divide?
- Can parametric design knowledge and CT be effectively translated into rapid prototyping and programming for training students of architecture for exploring computational design?
- How can interactive architectural installations foster public engagement regarding climate challenges and the role that architecture can play in creating sustainable built environments?

Considering the context and opportunity to deploy an experimental structure within the public sphere, following research questions were outlined by members of DACUI to investigate during and after deployment of the project:

DEVELOPMENT

The following section presents a detailed account of the project, experiences, challenges, and outcomes in a chronological manner along with findings by various members of the faculty and student body who participated in this project. The project was initiated by faculty of the DACUI in December 2019 a month before the start of IAPEX Lahore 2020. IAP-LC in collaboration with DACUI provided all materials, funding, and resources for this project.

Project Planning and Collaboration

Interactive design and parametric design both involve generating dynamic systems that adapt to varying inputs. To showcase this, the exhibit focused on the application of parametric design in a real-world scenario. The project had a faculty lead (author) and co-led who were subject experts Professor Juliane Eick Aziz. Several faculty members and students interested in exploring parametric design also took part due to the complexity of the project in various capacities during planning, design, and execution stages.

Arduino Platform

For the hardware and software platform, Arduino microcontrollers were chosen to create real-time interactive systems. Arduino is an electronics platform developed primarily as a low-cost prototyping kit for academic environments (Kushner, 2011). The Arduino platform consists of small, printed circuit boards (PCB) with integrated microcontrollers, input and output pins, and power circuits that can be used for diverse purposes. Unlike computers, microcontrollers can only handle simple instructions based on inputs (sensors or pre-defined variables) and can provide signals to control other systems as output. Furthermore, microcontrollers cannot run applications or store an operating system (OS) but contain enough memory to store the source code. This makes microcontrollers cheaper and easier to use for prototyping projects. The small form factor and low power requirement allows the microcontroller to be embedded into various smart devices and products. The language used to write instructions for the microcontroller is based on the more conventional C++ programming language. Different programming tools can be used to write code, test it on another computer (with Arduino plugged into the USB port), and upload the code to the microcontroller so that it would keep on executing instructions when powered on. During development of the original Arduino platform, the inventors decided to make the entire platform (hardware and software) open source, allowing organizations and individuals to develop their own variants of the microcontroller or a compatible sensor. Because of its low cost and open-source knowledge base, the Arduino platform quickly became a popular Do-It-Yourself (DIY) and educational tool around the world. In Pakistan, major institutions teaching courses for robotics or electrical engineering make use of Arduino to teach students about programming, remote sensing, robotics, or Internet of Things (IoT) (University of Engineering and Technology Taxila, 2017; Mehran University of Engineering & Technology, 2024). However architectural education usually does not include similar skills. In the last few decades, an increasing number of architects have been acquiring programming skills with more schools offering programming courses (Loukissas, 2012). Project members decided that relying on open-source and online resources in combination with existing parametric design knowledge would be a more effective approach for acquiring skills in Arduino programming.

Foreseeable Limitations

During early discussions regarding the objectives, scope of research, and logistics, several challenges were brought to light. Some of these limitations determined the hardware used for developing prototypes and the final installation, whereas other limitations were simply due to shortage of time. Some of the challenges identified early on were as follows:

Lack of Existing Expertise

Members of faculty and students of DACUI did not possess any skills in terms of programming. This meant that developing and testing algorithms for the Sonar Screen would be challenging and time-consuming. Fortunately, parametric design knowledge helps using CT to think of systems in architecture and how they can interact with one another. Moreover, as a popular open-source platform, project members could easily rely on publicly available learning resources including the official Arduino website, YouTube videos explaining various prototypes, and plethora of online forums for troubleshooting.

Autonomous Functioning in a Public Space

The intended site for deploying the installation was a public space during a multi-day event. Ideally, the installation needed to run for the entire duration of the event with minimal supervision. This meant that the entire system had to be designed as an integrated system with its own power and processing capability. Arduino boards and software allows for quick prototyping by connecting the boards and sensors to any computer through USB. However, for sake of the public event it was decided to add separate power supplies and enough Arduino boards to eliminate any need for additional computers and supervision.

On-Site Assembly

For ease of assembly of the installation and its various components, it was decided to design and fabricate the support structure in a way that gave project members physical access to all the wiring and components without causing disturbance in the public space or interrupting foot traffic. This was crucial since the exhibition space was shared with other practitioners.

Cost of Fabrication and Assembly

To minimize costs while fabricating a large installation to engage the public, the facade system was designed in a modular manner. This allowed for quick assembly in a repetitive manner and helped in laser-cutting various parts needed in an economical manner. It also added redundancy in terms of circuit design as each module could run independently. In case a module failed, it could be easily replaced without affecting the entire installation.

Lack of Microclimatic Stimuli

Sonar Screen designed to use microcontrollers for creating an interactive installation, that could garner interest regarding the role of climate-responsive architecture for sustainable living. This would require using climatic stimulus such as sunlight, heat, or humidity as an input for the installation to respond accordingly. Because the exhibit was indoors, there were no possible inputs that could be used to drive the interactive components. Even if the installation could be placed outside (which was a consideration during early discussions), no climatic or environmental stimuli could help achieve a dynamic result to garner public interest due to the speed at which environmental factors change at a micro scale. The result would have been a seemingly static installation requiring frequent observations to notice any change. Since observers were expected to be constantly moving within the exhibition area, the team decided to use this to their advantage. By using pedestrian movement itself as a stimulus, rapid changes in interactive elements of the installation could be easier to notice. While this meant that the installation would not have been climate-responsive, from a pedagogical point of view it could effectively attract public attention leading to further discourse. With the limitations and challenges, the project leads initiated design and prototyping stage. Lead took on the role of experimenting with algorithms and sensors while co-lead prototyping the physical design of the modules that would move in response to sensor values and servo outcomes. As the project developed, groups were devised with students to distribute tasks and share learning outcomes from the initial stages. Student feedback was also crucial in exploring alternatives for both programming as well as physical prototyping.

Rapid Prototyping

Since the invention of the Arduino microcontroller platform, several different versions and iterations of microcontroller PCBs have been released. Each variant of Arduino offers similar processing capabilities but differs in terms of size, form, and connectivity. This allows users to find and select Arduino boards suitable for their projects (Arduino, 2021). In the case of Sonar Screen, Arduino Nano was selected as the most appropriate board. While significantly smaller to other boards such as Arduino Uno (which has integrated power and input/output connectors), the Arduino Nano microcontroller at the time was easier to buy in large quantities in Lahore. Furthermore, the Nano is smaller than Uno which made it ideal for a public installation as the smaller size allowed for more flexibility for attaching it to the physical structure even with added modules and sensors. To counter lack of dynamic environmental stimuli as mentioned earlier, early prototyping focused on experimenting with different kinds of stimuli that could be easily measured in an indoor space with random pedestrian movement. As Arduino platform is meant for ease of learning and rapid prototyping, several accompanying modules can be used to test various iterations without any need to solder connections. Breadboards, which are modular plastic bases with inbuilt connections can be combined with jump wires to design and test circuits in a plug and play manner. Developments in electrical engineering have made diverse kinds of sensors accessible at an economical cost which can allow architects to design interactive systems that take into account various aspects of the user and context (Cascone et al., 2017). For initial tests, two sensors were used: a light dependent resistor

(LDR) for measuring changes in light and a microphone-based sensor to measure amplitude of sound signals to test for suitability for the public installation (Figure 1). It was found that the sensitivity for both the light and sound sensor only allowed them to pick up changes in near proximity. For an interactive installation in a public space, variations in values and overall range of values were not enough to create a dynamic system. Further exploration made it clear that a more appropriate stimulus would be the changes in relative distances for individuals and groups. For this purpose, the ultrasound sensor was ideal as it uses sound signals to measure distances over a significant range. The sensor consists of both an emitter and a receiver. The sensor measures distance by first emitting a sound and measuring the time till the sound signal bounces back and is received by the sensor as shown in Figure 2. As a result, the sensor had a much better range and sensitivity to detect changes in a public space due to movement of users.

To transform the readings from the sonar sensor into facade articulation, values of the sensor were mapped to a range between 0 and 90. These values represented the opening and closing of each of the facade modules. With a microcontroller, absolute angular values can be used as input to instruct the servo, this opens a range of possibilities in terms of interactive facade prototyping. For the shading components, several prototypes were tested ranging from flexible carboard strips to origami inspired folds which could open and close using one pivot. However, the limiting factor was the small amount of torque offered by the servo module. The prototype which worked without issues was a ribbed pattern cut out of cardboard sheets to add flexibility and reduce mass (Figure 3). The scoring pattern allowed the servo to twist the entire panel and create openings depending on how close a person is in front of the ultrasonic sensor.

Design

Following the prototyping stage, the precut panel module was further iterated for stability and tested for longer periods of time to ensure that the sheet was flexible and thick enough to rotate multiple times without any permanent damage. The bleach board eventually selected was of 350 gsm (gram/sq. meter) with each opening size limited to 250 mm x 250 mm within an acrylic frame. To optimize for cost, each microcontroller was programmed to operate 3 openings in a single module (3 ultrasonic sensors and 3 servo motors). Due to limitations of on-board memory of the Arduino Nano microcontroller, 3 servos and sensors were the limit beyond which performance was not responsive enough for a public installation. The algorithm consisted of initializing sensors and a loop in which distance was determined using duration between ultrasonic signals transmitted and ultrasonic signals received. The constant loop allowed for continuous adjustment of servo angles to control the openings. For each module, three loops were programmed so that the

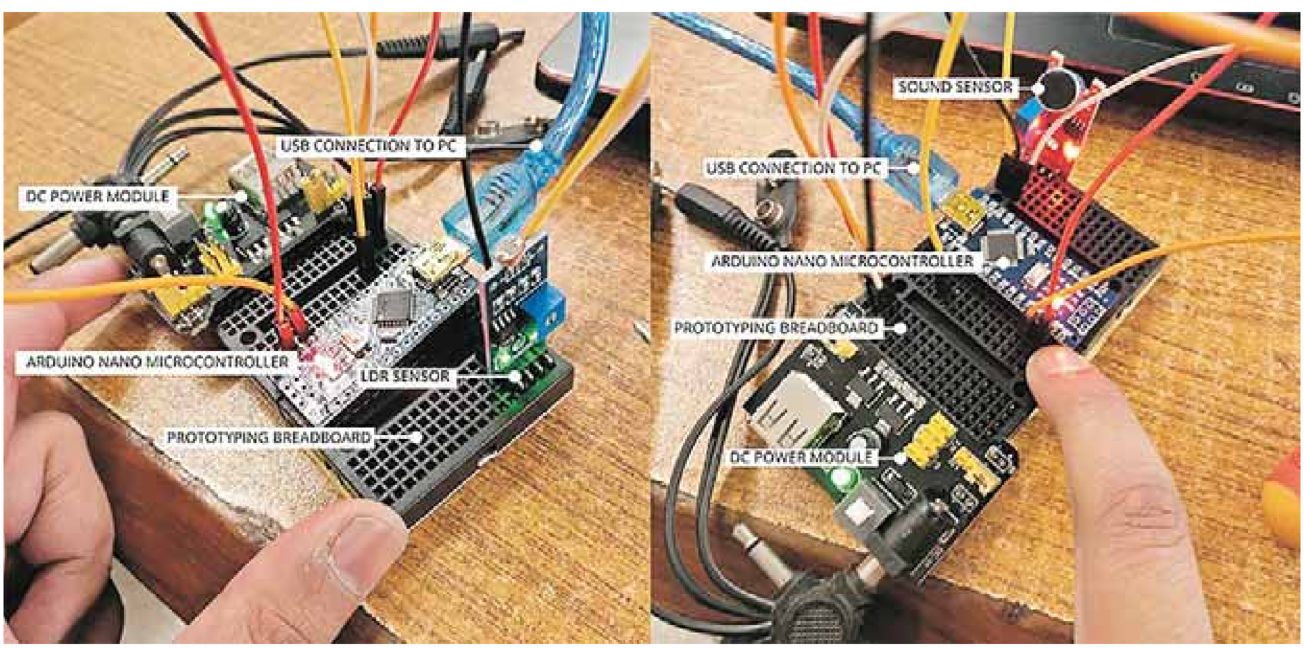

Figure-1: Breadboard Prototyping for Testing Various Sensors using Arduino Nano.

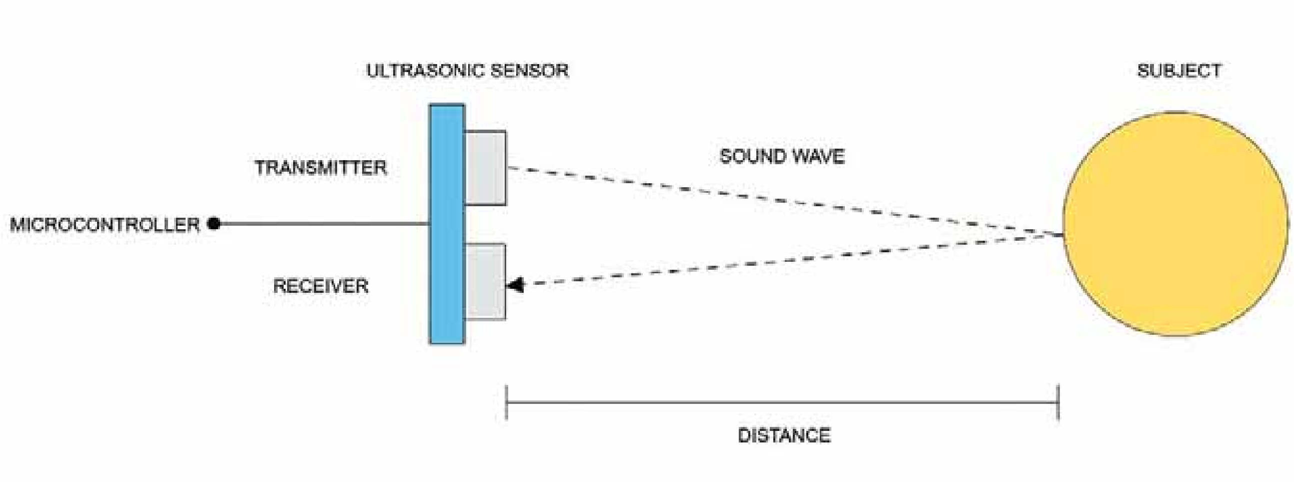

Figure-2: Distance Measurement Using Ultrasonic Signals.

microcontroller could cycle through each sensor and servo sequentially. The following diagram demonstrates the algorithmic logic and necessary variables required (Figure 4).

The output from the microcontroller determined the angular input for the servo motors attached to the bleach card panel, resulting in a twisting motion inside each opening as a person would move in front of the ultrasonic sensor attached on top of each panel as shown in Figure 5.

To provide sufficient power and facilitate assembly, each module's microcontroller was connected to an Input/Output (I/O) extension board. The I/O shield allowed for the same ease of use as the larger Arduino UNO while keeping costs relatively lower. To provide power from the mains supply at the venue, multiple I/O shields and controllers were grouped and connected to AC/DC variable power converters. In this manner, four panels (each with three panels, three sensors, three servos and a microcontroller) could be powered by a single power supply unit (PSU). This modular approach enabled a simplified assembly process by bolting each module onto the wooden structure with ample space in the back for assembly and troubleshooting (Figure 6).

Fabrication

Once the design was finalized, the rotating fin elements along with acrylic frames were fabricated using laser cutting for high precision since the electronic components had to be attached to the frames. For each module on the Sonar Screen, wiring lengths were calculated to prepare jumper connections for each of the I/O shields. Students from DACUI managed the wiring and testing process to ensure that every wire could be attached to respective components and PSUs on site.

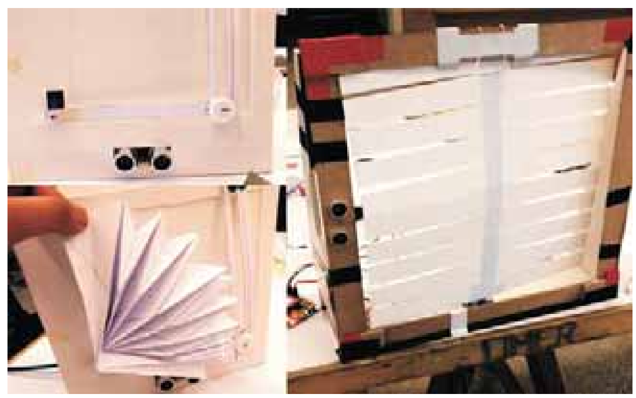

Figure-3: Shading Prototypes.

Simultaneously, a separate team of faculty and student volunteers led by co-lead helped plan, paint, and fabricate the support structure with the head of woodwork workshop.

SONAR SCREEN DEPLOYMENT AT IAPEX 2020 LAHORE

Once fabrication was completed and transported to the exhibition space, each of the modules were screwed to create a seamless facade grid. Using the dedicated space for maintenance, project members connected the necessary wiring from each of the modules to their respective microcontrollers and PSUs (Figure 7).

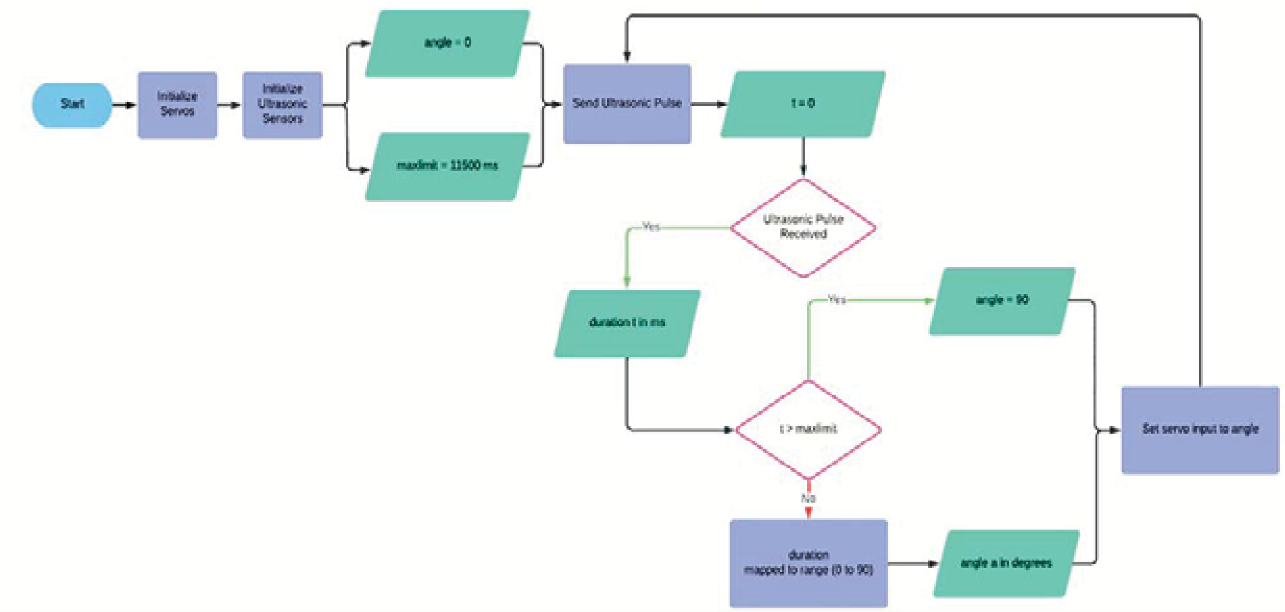

Figure-4: Process Flow Diagram for Algorithm

At the time of its first test, one of the power supply adapters failed to run. As it was not possible to obtain a new one, the team quickly re-wired the microcontrollers to use two adapters instead of three as originally planned. This turned out to be sufficient in terms of power requirements. One of the biggest advantages of using dedicated microcontrollers instead of a consumer PC is significantly lower power consumption: approximately 30 Watts for the entire facade prototype using Arduino microcontrollers, sensors, and servos as opposed to 50 Watts for an average consumer laptop alone.

Another issue that became apparent after running the complete assembly was sensor interference for the ultrasonic sensors. The size of the modules was limited by several factors including flexibility, ease of fabrication, and torque of the servo motors. This determined the placement of all the ultrasonic sensors along the facade prototype. However, any sound wave is spread outwards during transmission. This outward spread meant that all transmission waves were overlapping while bouncing off various users. Without any filter mechanism to distinguish one signal from another, various sensors were inadvertently detecting signals transmitted by the adjacent ultrasonic sensor. Due to this interference, the response from each frame was much more unpredictable and chaotic. This issue could have been solved by increasing the distance between each sensor, using fewer sensors per unit area of the facade prototype, using diverse range of sensors in tandem, or by adding a timed delay within the code to stagger the transmission signals hence reducing interference from neighbouring sensors. However, the issues listed above were not detrimental to the performance of the installation and the project successfully responded to movement within the space without any need for supervision, providing team members ample time and opportunities to interact with attendees, fellow participants, and members of the AEC industry to investigate the research aspects (Figure 8).

OUTCOMES

Cost Barrier for Open-Source Technologies

In many developing countries such as Pakistan, rate of adopting new technologies is slow in the AEC sector. Despite awareness of the productive output and improved capabilities of innovative digital tools, designers and engineers hesitate in changing their workflows because of any financial risks in the short term (Farooq et al., 2020). This phenomenon leads to only partial change of conventions methods of design, experimentation, and fabrication in architecture (Hauck et al., 2017).

In case of the Sonar Screen, the aim for working with open-source tools and hardware was to challenge such perceptions when using innovative tools for prototyping and problem-solving. Hardware platforms such as Arduino can reach a wider userbase around the world because the schematics

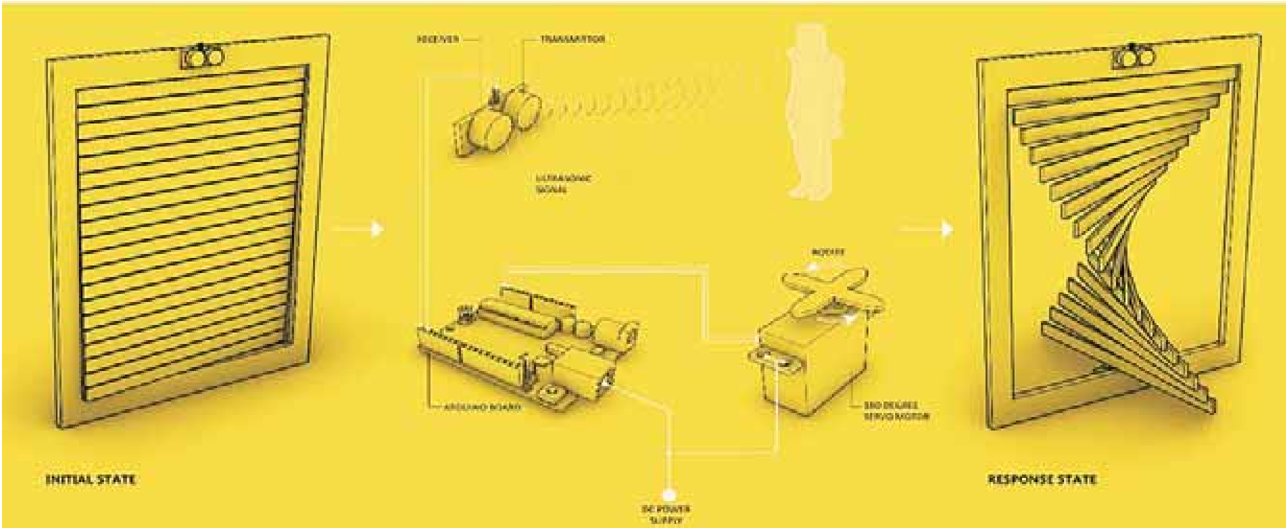

Figure-5: Twisting Facade Module Design
Source: Shahzeb Khan

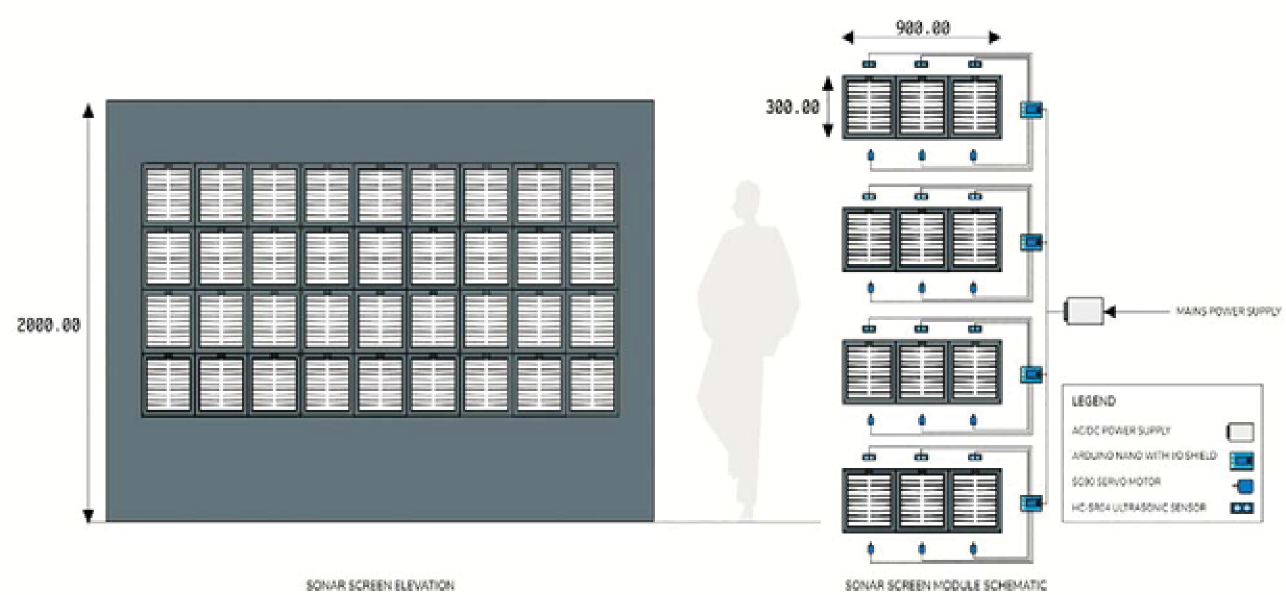

Figure-6: Sonar Screen Schematic

and knowledge associated is made publicly available. Arduino has numerous third-party variants that bring costs down by being manufactured in different parts of the world. Thus, making such systems ideal for quick deployment in developing countries like Pakistan, not only bridging the digital divide but also fostering architectural research and experimentation.

After completion of the project, material costs were evaluated. The hardware and material costs for the Sonar Screen installation at the time was approximately $645 (Rs. 100,000 as per exchange rate in 2020) with most of the costs due to the structure itself as shown in Figure 9. Furthermore, the electrical components are reusable which meant that DACUI could set up a repository available to all faculty members and students motivated to explore further without incurring additional costs.

Public Engagement and Pedagogy

Public engagement through installation is not only crucial for demonstrating the role of architecture innovation but

Figure-7: Wiring and Assembly.

Figure-8: Sonar Screen Exhibit

also beneficial for architectural training since architectural practice is based on co-creation with diverse stakeholders. Differing and diverse subjective experiences can provide useful insights for contextually informing the design process. Within the academic studio, design projects are developed in a highly controlled environment without any public interaction. By co-designing prototypes with the wider public, students of architecture design can understand how cultural and social nuances can be integrated (Selcuk et al., 2024).

It was observed during the event that the ultrasonic sensors instantly responded to passersby stimulating curiosity which led to interesting questions and discussions regarding the role of architecture and technology to create sustainable spaces. Users intuitively understood the causal relation between their movements and the façade as they were able to control the installation with playful gestures and postures. Originally it was planned for Sonar Screen to be controlled by user movement rather than environmental stimuli. The installation also featured literature explaining the objectives of the Sonar Screen, as a demonstration of climate responsive architecture. However, this led to discussions on site exploring another purpose that was not considered initially but was proposed by several members of the public: to design adaptive screens that provided ample privacy without compromising natural lighting and ventilation. The code for the Sonar Screen explained earlier was designed so that standing closer to the screen resulted in modules opening. However, several users felt that if the angles were inversed (modules closing as users walked closer to the screen), the screen could block direct view from the other side of the screen. This inquiry and discussion meant that users were envisioning applications within their local context. In Pakistan, privacy is considered an integral spatial aspect for differentiating domestic from public spaces. Even within domestic spaces, individuals exercise privacy based on social structures, norms, and cultural sensibilities. This is also evident from the various types of intricate screens seen in traditional and vernacular architecture of Pakistan. However, limited visibility in screens also means limited natural light and ventilation. The fact that several users perceived Sonar Screen and application of computational design within their local context implied that the installation was effective in terms of public pedagogy. Public engagement through physical exhibitions not only helps in terms of pedagogy but also can provide useful and interesting feedback that can help with future technological developments (Claypool et al., 2020).

Computational Thinking for Design Pedagogy

From an academic perspective, this prototype was intended to demonstrate that rapid prototyping using open-source technologies is a viable method for employing CT for undergraduate architectural training. CT has been demonstrated as critical for teaching not only efficient application of digital technologies but also cognitive abilities to solve complex problems. As per Wing (2017), CT as an analytical and problem-solving strategy is fundamental for facing complex challenges any domain in the 21st century. Furthermore, several studies from developing countries categorized with immense digital divide demonstrate positive correlation between CT and problem-solving capabilities (Jehan and Akram, 2023; Kaleem et al., 2024).

Since the DACUI undergraduate architectural training program included parametric design as an essential skill in digital tools, students were already being trained to employ CT to solve complex problems. Working with open-source hardware platforms such as Arduino allowed faculty members and students of DACUI to further explore those skills for computational design. To understand the learning experience and opinion regarding computational design for sustainability,

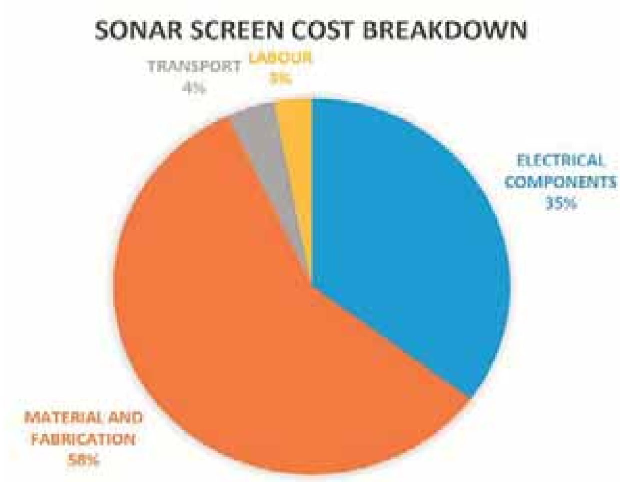

Figure-9: Cost Breakdown for Design and Fabrication

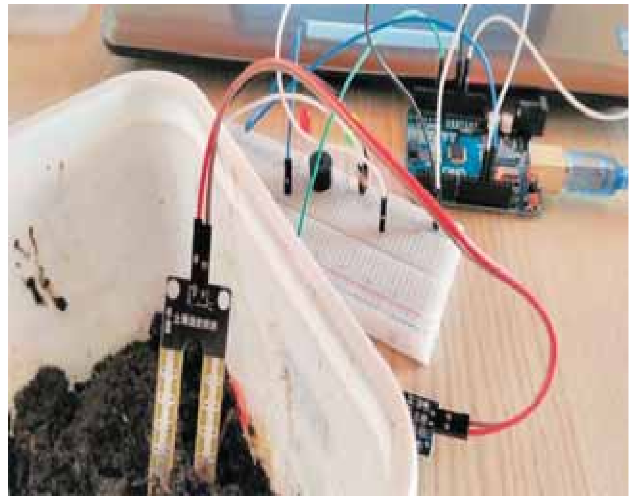

Figure-10: Bio Integrated Design Prototype

a qualitative survey using the Likert scale was conducted amongst students (n=60) at DACUI. Of the students who participated, 20 (33.33%) students were directly or indirectly involved in the Sonar Screen project, while 40 (66.66%) students were familiar with parametric design and CT based on their curriculum. The findings are shown in Table 1.

As seen, a strong consensus exists among students on the significance of these tools for the future of the profession. A majority (77%) rated computational tools as "Important" or "Very Important" for the future of architecture in Pakistan. Similarly, 90% agreed that interactive technologies can enhance public engagement in architecture. The educational value of open-source platforms like Arduino was also widely recognized, with 81% agreeing or strongly agreeing that such platforms benefit architectural education. The Sonar Screen project itself appeared to be an effective learning tool: 80% of students reported that it helped them understand how CT applies to architectural design. Additionally, 78% of participants felt they were able to apply their parametric design knowledge during the project. Looking ahead, 79% of the students agreed these tools can support sustainable architecture in developing countries. Notably, there was overwhelming support (90%) for interdisciplinary learning that combines design with coding and electronics, and an equal percentage recommended greater emphasis on computational tools within the architecture curriculum. Overall, the survey results demonstrate a clear student interest in and appreciation for integrating CT and interactive prototyping into architectural education and practice, affirming the relevance and impact of the Sonar Screen initiative.

Figure-11: Arduino Prototype for Bio Integrated Design Exploration.
Source: Ahmad Sohail and Mohammad Abubakar

After completion of the Sonar Screen project, further projects were initiated by faculty members and students to explore computational design. One example is the bio-architecture project led by DACUI faculty member, who along with a group of students, conducted several experiments for using computational design to explore organic materials for sustainable fabrication techniques using organic matter Figure 10.

Students who were directly or indirectly involved with the Sonar Screen project also incorporated computational design and interactive architecture in their own projects such as the thesis project titled "Pakistan Auto Odyssey, an Automotive Experience Centre". For this project, the student collavorated with peers to develop the necessary algorithms for facade prototyping as showing in Figure 11.

Table-1: DACUI Survey Results for CT and Sonar Screen.

Q1.	**How important do you think computational tools are for the future of architecture in Pakistan?**				
A1.	Not Important at All	Slightly Important	Moderately Important	Important	Very Important
Score	**2%**	**4%**	**17%**	**35%**	**42%**
Q2.	**Interactive technologies can improve public engagement in architecture.**				
A2,	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Score	**4%**	**0%**	**6%**	**27%**	**63%**
Q3.	**Open-Source platforms (Like Arduino) can benefit architectural education in Pakistan.**				
A3.	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Score	**4%**	**2%**	**13%**	**35%**	**46%**
Q4.	**Sonar screen helped me understand how computational thinking applies to architectural design.**				
A4.	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Score	**0%**	**5%**	**15%**	**20%**	**60%**
Q5.	**I was able to apply my knowledge of parametric design (e.g., Grasshopper) in this project.**				
A5.	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Score	**0%**	**0%**	**22%**	**22%**	**56%**
Q6.	**Computational tools can help create sustainable architecture in developing countries.**				
A6.	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Score	**4%**	**2%**	**15%**	**33%**	**46%**
Q7.	**Interdisciplinary learning (e.g., design + coding/electronics) is important for architects today.**				
A7.	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Score	**2%**	**2%**	**6%**	**25%**	**65%**
Q8.	**I would recommend more focus on computational tools in the architecture curriculum.**				
A8.	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Score	**4%**	**2%**	**8%**	**21%**	**65%**

The examples demonstrate the viability of open-source technologies to apply parametric design skills and CT for exploring interactive and sustainable architecture. Without a high-cost barrier, architecture schools in developing regions can incorporate applied computational design research within their curriculum to meet challenges of the future.

CONCLUSIONS

The Sonar Screen installation helped initiating discourse regarding architecture, climate change, and the potential for innovative technologies to create a more sustainable future within context of Pakistan. The project members not only learned programming skills for architectural design but also learned about the value of such installations for public engagement. Furthermore, the project proved as a valuable benchmark for using similar open-source technologies in a feasible manner specifically in context of developing countries such as Pakistan where technological development is constrained by limited access to emerging digital tools. Arduino and similar platforms can augment current educational programs in developing regions to foster problem-solving skills using CT. By integrating computational design skills with accessible prototyping, future professionals and researchers can help in developing robust architectural solutions that are adaptive to changing climatic conditions of Pakistan.

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