TACTILE OCEANS

Enabling Inclusive Access to Ocean Pools for Blind and Low Vision Communities

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Abstract. This research explores implementing computation to enhance access to ocean pool and marine landscapes for the inclusion of people who are blind or have low vision (BLV). Constructing reliable representations, explanations and descriptions can support interactions with objects and participation in activities, particularly in these ocean environments. We discuss the adoption of a series of computational design strategies to leverage the impact of recent scanning technologies in information transfer. The paper introduces a background to touch access and universal design. It presents a case study of aerial photogrammetry for an ocean pool in NSW, Australia, and presents multi-scalar workflows and processes across computational design and advanced fabrication methods, including a) photogrammetry through drone-flight on a macro-scale and 3D-scanning to establish data-sets; b) parametric design and scale adaptations; and c) 3D printing and robotic milling for touch access.

Keywords. Blind; Universal Design; Touch Access; Photogrammetry; 3D Printing; SDG 3; SDG 10; SDG 14.

1. Introduction

There are well over half a million people in Australia with vision loss, including over 65,000 who are blind (Vision 2020 Australia, 2010). With most vision loss related to age and an ageing population (Tong et al., 2015), the number of Australians who are blind or have low vision (BLV) is expected to grow rapidly in the coming years (Taylor et al., 2005). Blindness and low vision encompass a wide range of abilities and experiences, from total blindness to some usable vision; congenital blindness (from birth) compared with acquired blindness after gaining some visual experiences; photosensitivity versus the need for bright lighting; and tunnel vision versus peripheral vision. The commonalities are the barriers faced in accessing visual media, and

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specifically any environment, including public and open places, spaces and landscapes.

Marine coastlines hold strong significance and value in many cultures, and a celebration of iconic beaches and landscapes lies at the heart of Australia's national beach culture. The coastal beaches, bays, rockpools and man-made ocean pools are natural resources and community assets that provide for individual recreation and health, and collective inhabitation and interaction (figure 1). However, environmental conditions such as temperatures, wind and tides, topographical changes, uneven walkways and other site-specific characteristics can make coastal landscapes and foreshores difficult to navigate for people with varying sets of abilities, including children or older adults. Specifically, BLV audiences require a different set of communication through braille and relief diagrams, which are rare in open public or natural environments. With better access description, equitable access to the open ocean could be provided. We argue that readily available computational data capture and digital fabrication methods enable multi-scale prototypes that provide information and narratives for diverse audiences. This aims to support integration and inclusion, and increasing knowledge for the dynamic coastal environments, in alignment with the UN Sustainable Development Goals (SDGs) for education (SDG 3), reduced inequality (SDG 10) and understanding of oceans (SDG 14).

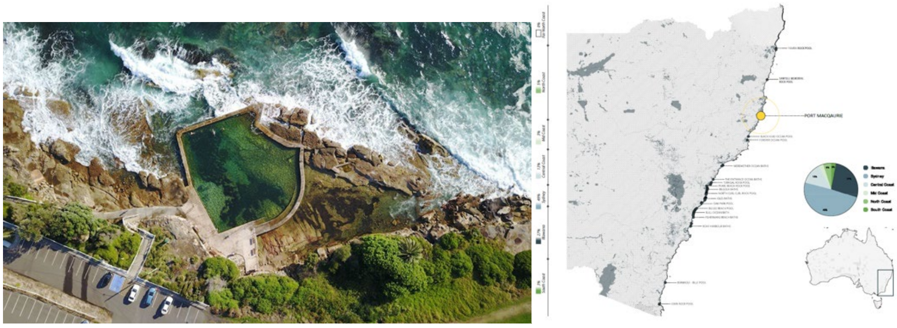

Figure 1. An aerial view of Malabar, NSW (left) and geographical distribution of ocean pools (right).

Constructing reliable representations, explanations and descriptions can support interactions with objects and participating in activities (Holloway, Butler and Marriott, 2018; Reinhardt, Sonne-Frederiksen & Christensen, 2019). Consequently, this research proposes an approach of multi-scalar methods to ocean pools for touch access and inclusion of BLV people and as engagement for all others. Based on a background to universal design, ocean pools and touch access, this paper provides a case study with development of workflows and processes across computational methods, including a) photogrammetry through drone-flight on a macro-scale and 3D-scanning to establish datasets; b) parametric and digital design; and c) 3D printing and robotic milling. The paper discusses results and concludes with an outlook towards future research.

1.1. UNIVERSAL ACCESS AND TOUCH ACCESS

In accordance with the UN Convention on the Rights for People with Disabilities (UN-DESA, 2006), the Australian Disability Discrimination Act states that 'a person with disability has a right to have access to places used by the public' (Australian Human Rights Commission (AHRC), n.d.) and failing to provide such desired access is unlawful. However, people with BLV often face barriers to enjoying these experiences in an equitable way. Access to information and independent travel are amongst their greatest challenges. They may be excluded due to a lack of information on physical access or indirectly excluded from public open spaces (Siu, 2013). In contrast, Universal Access includes access to services, information and premises to encompass a complete experience (AHRC, n.d.). In this context, multimodal socio-technical systems and environments that situate tactile media as a fundamental mode of presentation can help overcome experiential barriers.

BLV audiences experience the world primarily through touch and sound, a first-hand experience that is invaluable in building up concepts of the world (Sapp, 2017). This provides a much richer and engaging experience than description alone. In particular, access by touch is essential for an understanding of spatial relationships (Millar, 1994) and material properties. However, touch access is limited to that which is within reach, is of an appropriate scale, and can be handled safely. The BLV person must also know that the object is available and where to find it (Siu, 2013).

While in infancy and school, BLV children are supported in concept development and tactile literacy through provision of story boxes, tactile graphics (also known as raised line drawings), and a variety of other tactually rich experiences However, the same support is rarely extended to the workplace or public spaces. A notable exception is art galleries and museums, where new technologies are being harnessed to create tactile and multi-media artefacts for inclusion. As part of this work, researchers have created physical artefacts that are a suitable scale and safe to touch using new fabrication technologies such as 3D scanning, 3D printing, robotic milling and laser cutting (Reichinger et al., 2012; Scopignio et al., 2017). Similar strategies are required to provide accessibility by touch for other realms of culture and society, including the natural environment.

1.2. TACTILE MAPS AND 3D MEDIA

In providing accessibility measures for the natural environment, the ability to physically access the space is paramount. Tactile maps are of particular importance for independently building up a cognitive map of an area before visiting it, gaining an understanding of what is available, and where these features are located. Creation of 3D models is useful for tactile mapping, as 3D maps and maps with 3D icons have been found to be easier to understand than tactile graphics. Lastly, touch access begins to overcome the visual centricity that naturally exists while benefiting increased sensorial experiences for all users, including people who are fully sighted.

Meaningful touch access requires an appropriate scale that can be 'read' by a hand. Consequently, the research focuses on photogrammetry and 3D scanning for advanced manufacturing and fabrication, thus extending methods for image processing of landscapes (Arimaand Sato, 1994), photogrammetry for heritage (Datta 2005) and other public databases (Lowe et al 2011), or texture maps to reconstruct real-world geometry (Alawadhi and Yan, 2018). Our research focus tests data to output, with comparison of fabrication processes (3D printing/CNC and robotic milling), with future research investigating the details of the tools used in the research, libraries, image processing and scanning processes, and potential computing interfaces.

2. Methodology: Case Study, Ocean Pool and Coastline, NSW, Australia

Natural landscapes such as the NSW coastal line and ocean pools present environments that are complex and multi-layered. The research explores Malabar Ocean Pool as a case study using aerial photogrammetry. A prototype scale model is then created using computational design and fabrication for tactually communicating scale and spatial data and importantly, how to convey the rich and dynamic nature of coastal landscapes through touch.

2.1. LANDSCAPE SCALE: COASTAL TOPOGRAPHY

The geomorphology of coastal landscapes is shaped by natural processes and forces, often characterised by wandering rock platforms, spectacular headland formations and shifting sandy beaches. Tangible representations can provide effective information; however, this is not a matter of simple diagrams but requires mapping the landscape accurately and in a format that can be interpreted by designers, integrated in digital fabrication workflows, and reproduced through digital fabrication and manufacturing.

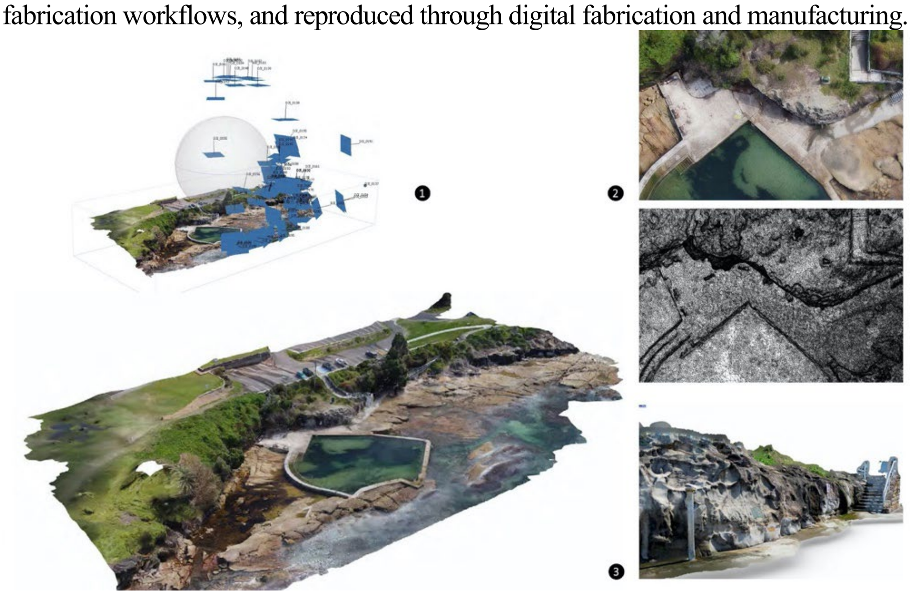

Figure 2. Data capture 2: Scans on environment-based scale. Aerial photogrammetry (drones, 1), overview of photo-based imagery and 3D mesh (2) and detail of rock surface (3).

Capturing such complex geometry through traditional, line of sight or laser-based survey methods would be challenging. This research therefore adopts aerial photogrammetry to efficiently retrieve data for a digital 3D model (figure 2) with photographs taken in a grid pattern, using UAV (DJI Mavic Pro) and software (Pix4D). Each image includes camera angle, GPS location and height, which supports triangulating points in space for mesh surface creation. While water movement and light reflections pose a challenge to photogrammetry methods as they disturb data capture, calm surface conditions and sun position (oblique angle) allow capture of the pool and surrounding seabed. The resulting data are geospatially located and map immediate survey areas while also locating within broader regions, thus enabling practitioners to understand spatial information at micro and macro scales. The method accuracy captures a high level of detail including rock platforms, cliff under-crofts headland, beach, or surrounding context. The data and geospatial coordinate system were shared as an open-source platform (The Wild Edge).

Initial 3D prints were made (figure 3) but due to maximum dimensions accommodated by the 3D printer, the size and scale of the models limited their ability to communicate sufficient information to users, as touch offers far less resolution than vision (Grunwald, 2008; Hatwell, Streri and Gentaz, 2003). The limitation on size imposed by 3D printers innately reduces the information that a tactile map can convey as deviations, bumps and changes in texture are reduced in scale and less evident to the touch.

Figure 3. Malabar Ocean Pool | CNC milled timber model with benches and 3D prints (PVC)

A second prototype was CNC milled in timber (figure 3), which enabled a wider range of achievable finishes based on cutting tools but more importantly, fabrication at larger scale and higher level of detail. A ‘stepped’ or benched cutting method was adopted to permit users to run their hands continuously along edges, like contours on a map. Areas of the tactile map with many benches signal steep areas. A scale bar was designed to allow BLV users to identify lengths to measure distances and lengths with their hands. Further improvements could be made by enabling scale associations with recognizable objects (such as a car) and introducing secondary materials to distinguish key features (balustrades, hazards and water surface) through material differentiation (metal, ceramic or resin).

2.2. OBJECT SCALE: GEOGRAPHICAL STRATA AND PLANT SPECIES

Consecutively, the research moved from aerial photogrammetry on environment scale to an object scale, using an EinScan 3D scanner with structured light technology that casts light patterns onto an object. By analysing the edges of each line in the pattern, the distance from the scanner to the object’s surface is registered as a digital representation of the physical object by combining single dimension scans that are captured at different angles. These scanning workflows and fabrication processes were shared with a group of designers for co-design of touch access objects and maps. In adopting 3D scanning and printing techniques, advanced CNC manufacturing and robotic fabrication for milled patterns and 3D upscaled prototypes, the research generated multi-scale prototypes, a tactile pattern archive and touch access objects including 3D objects, reliefs and mixed media tableaus that provide information and narratives for diverse audiences for inclusion and increasing awareness of the dynamic coastal environment.

Initially, different scripts enable a computational workflow from design data to manufacturing protocols. This included control over dot grids (as a braille translator); pixel grids and bitmap (for image conversion); and line tracing (for boundaries and shapes for direct use of scripted pattern description to tooling path) (figure 4). Different classes of scripts were developed in Grasshopper (GH, a visual scripting software) and robot programming in KUKA|prc (robot toolpath simulation) for a standard six-axis industrial robot arm. These supported the fabrication of test samples in beech, and the production of visual and tactile surfaces.

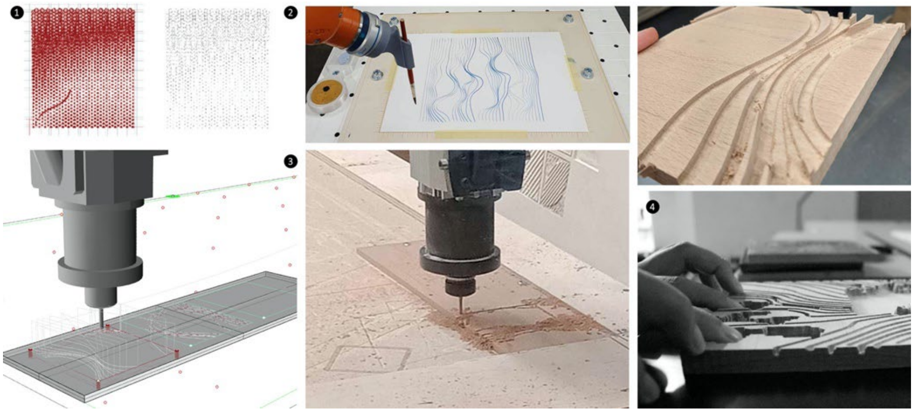

Figure 4. Script with pixilation for image conversion (1), trial of robotic milling path based on line codes through drawing (2) and transfer to milling (3), with manual testing of tactile proficiency (4).

A set of scripts controls the robotic toolpath, tool angle and standard industrial tools adopted for manufacturing (Dremel and router, with variability in tool dimension from 1.5-6-10mm drill bits). Codes are structured with sections pertaining to the generation of the robot targets, sections for creation and optimization of the robotic toolpath, and a final code section for export to robot fabrication and local database. Previous studies developed a pre-set scripts for the implementation of braille script into the robotic milling process (Reinhardt, Sonne-Frederiksen and Christensen, 2019), with a script translating braille text to uncontracted braille in accordance with Australian standards (Australian Braille Authority, 2020. The script integrated a common braille font into GH, so that text is directly translated into points that reference braille standards for cell and character, and a per line approach to situate words within a robotically milled surface with cavities where variable dimensions of ball bearings are inserted as raised braille dots. The workflow from scan to data to robotic fabrication was explored as a series of scripts that derive meshes from a 3D scan, and then zoom into topographical lines of the upscaled object to convert this to a robot milling path. Figure 5 shows the first approach with robotic milling for touch access, with variability of pattern orientation and geometries, pattern types (module or path), grading and densities subtractive fabrication. The preliminary testing of the tactile plates clearly indicated that plates were more successful depending on the following factors: a) fine line engravings are readable only when drill lines correspond to finger dimensions; b) the higher the percentage of milled surface, the better the experience of touch, where higher contrasts in densities and height are better, and larger areas are better; and c) combined 3D prints (additive) and robotic milled (subtractive) techniques work best, as these produce recognizable changes in material, higher contrast, more detail and increased depth of the plate.

Figure 5 Sample collection of patterned texture that communicate botanical, geographical or marine data for touch access, including hybrid objects (subtractive/additive manufacturing coupled).

In a second development, the research investigation focused on the scale-up of details and zones, as opposed to the aerial photography model where scale is decreased to make the vast landscape tangible (figure 6). Studies included geographical strata of the cliff face, marine specimen including shells and fish species, and botanical samples with a high degree of detail (Banksia). Areas within the scanned objects' geometry were selected, enlarged and 3D printed relative to a hand scale, with testing in various sizes and positive or negative surface. The most successful prototypes were a) adequate in dimension to the fingertip; b) positive instead of negative, as cavities could not always be fully explored, and c) distinct in pattern as a repetition or high contrast. A cross section of models was distributed in Thingiverse for open sharing.

The engraved, deep patterns, embedded objects and tactile objects deliver information beyond simplified diagrams or pictorials of images, but convey physical phenomena, growth processes and dynamic formations that are an integral part of the landscape and natural environment, and thus form a detailed counterpart to the landscape topography discussed in the previous section. 'Hyper-artifacts' (Fuller and Watkins, 2010) is a term used to describe the integration of touch with an interpretive information or underlying thematic. These hyper-artifacts are designed to be touched and handled by the audience and bring together people who are experts in vision (a common public) and experts in touch (BLV) so that they can together ‘decode’ or read data and information: as an inclusive design approach for multi-functional furniture that carries narratives in the form of images and text (braille), with the aim to provide shared objects for communities so that places we use become accessible and users with different abilities are comfortable, inspired and ‘feel’ a place that belongs to them.

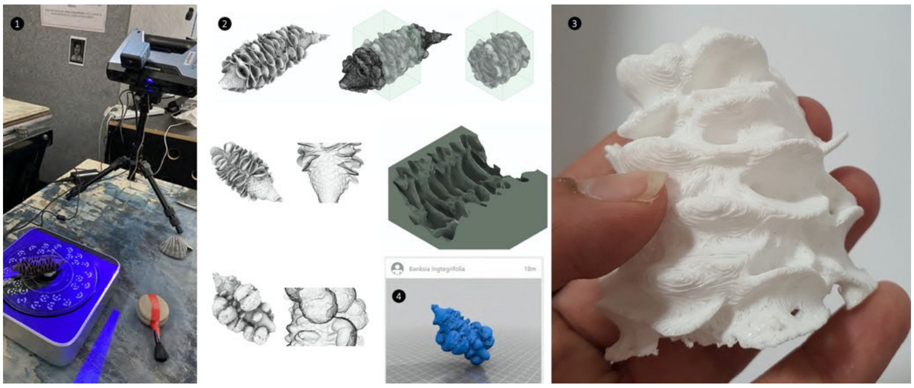

Figure 6. 3D scanning work process with botanical precedents (1), with conversion to pattern area selection and upscale (2), a 3D print of detailed area (3) and sharing the model in open platform (4)

3. Discussion

The prototypes discussed here highlight that 3D data can be successfully adopted across a range of subtractive and additive advanced manufacturing media (and combinations thereof) to provide tactile representations and information. The scalability of data is hereby of importance: as a readily available resource for designers to adapt prototypes to the size of a hand, making them tangible. As the case studies show, objects, signs and explanatory maps can be produced with relatively low effort, with commonly available media (3D print, CNC, robotic milling), in a direct workflow from aerial photogrammetry data or laser scan to fabrication. For this reason, designers used 3D data directly in McNeel Rhino, rather than image processing. Simplification via removal of redundant details is one of the basic design principles for effective tactile graphics (Edman, 1992). When using methods such as photogrammetry to produce 3D modelling, significant post-processing is required to remove 'noise' as a result of the modelling process and unwanted detail such as detailed vegetation on maps. As direct user feedback had been prevented by ongoing pandemic restrictions, future research will engage with BLV participants to further refine tactile content in the 3D objects.

With a focus on touch access, spatial mapping and access to environment, this work has been primarily aimed at people who are blind. While they may not use touch as their primary means of accessing information, people with low vision can also benefit from artefacts designed for touch access, as indeed can people who are fully sighted - this has been a common finding in studies of museums providing touch access. Nevertheless, future work should consider the addition of high contrast visual enhancements on the touch models for greater ease of use by people with low vision.

The research explores the UN SDGs across several dimensions. In providing access for people with BLV in desirable and unique Australian marine environments, it contributes to SDG3 - 'Ensuring healthy lives and promote well-being for all at all ages' and SDG10 - 'Reducing inequalities and ensuring no one is left behind'. And for a wider population, it equally contributes with information to a better understanding of the resources of the natural environment, thus addressing a mixture of SDG4 – Education and SDG14: Oceans, enhancing an understanding thereof.

4. Conclusion and Future Work

The main contribution of this research is the adoption of data capturing and advanced manufacturing methods to enable touch access for BLV communities, with inclusion in and access to natural environments. The research has reported on leveraging aerial photogrammetry and 3D scans for computational data collection, design and advanced and robotic fabrication. Multi-scalar data and tactile representations of pathways, boundaries, marine and botanical information and narratives for audience engagement enable BLV communities to better inhabit and understand the inter-tidal landscape, and thus promote inclusion and sustainability for all communities.

The provision of tactile graphics has remained a domain of transcribers using a limited number of specialised techniques such as swell paper and braille embossers. This project demonstrates the potential of new modelling and fabrication technologies to greatly expand the tactile offerings available for people who are BLV, both in terms of richer materials and models, and provision beyond the classroom and into the natural environment. This project has been the impetus for specialists in fabrication technologies, vision impairment and accessible formats to share knowledge and collaborate. Future research will further explore digital scan and fabrication methods for access to the environment for people who are BLV and expand and implement research findings in real world applications to make practical contributions to accessibility, well-being and appreciation of natural environments.

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