3D SAMPLING: HAPTIC AND OPTICALLY PERFORMATIVE TEXTURES REMIXED FROM 3D SCANS

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ABSTRACT

3D Sampling is presented as a new method for comprehensive rearrangement and composition of 3D scan data, allowing multi-scale manipulation of surface texturing and subsequent fabrication and re-evaluation using 3D printing. Analogous to sample-based music, 3D Sampling contributes new frameworks, tools, and compositional strategies for the digital remixing, hacking, and appropriating of material qualities, performances, and behaviours directly from physical samples to produce new designs. Case studies are presented which demonstrate *3DJ*: a prototype 3D modelling tool for synthesizing haptic and optically performing textures from 3D scan-generated source material, which can be applied in the context of other 3D modelling techniques.

Keywords: 3D scanning, photogrammetry, sampling, textural synthesis, point-clouds

1. INTRODUCTION

3D Sampling is part of a revolution in sensibilities in the field of design modelling. For the first time, hand-held 3D scanning technologies, such as photogrammetry, enable anyone with a smart-phone to digitally capture real world objects as point-cloud data. In the near future, a treasure trove of 3D materials sampled from real world objects and environments will be available to designers. Presently, the rules of computer modelling software precede and constrain the form of the objects generated. However, 3D scans allow a designer to reverse this methodology, making detailed digital replicas of physical objects the starting point for design (Figure 1). By contributing methods to interject and collide the complex or structural irregular geometries of 3D scans deliberately into playfield of digital design, 3D Sampling facilitates a new solution space that would otherwise be inconceivable through conventional optimized, rule-based, parametric, or procedural modelling practices. In contrast with approaches taking inspiration from observed phenomena to infer design strategies, such as bio-mimicry and material computation (Oxman, 2009), 3D Sampling allows designers to appropriate, hack, and remix the material behaviour of macro-scale texture geometry such as structural corrugation, water shedding, grip, acoustics, optics, and camouflage (Gage, 2013). This paper presents the conceptual framework and technological implementation of 3D Sampling, demonstrated through case studies presenting designs for architectural surfaces textures.

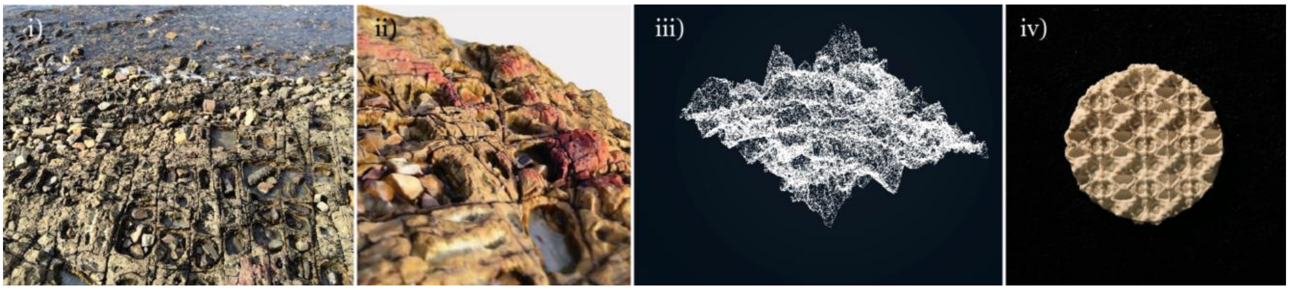


Figure 1: 3D Sampling overview: i.) Photograph, rock formation with convex surface features ii.) Detail, photogrammetric model generated using AutoDesk 123d catch. iii.) 3DJ: prototype design tool for textured synthesis from 3D scan samples iii.) 3D printed texture sample

2. RELATED WORK

Akin to sample-based music, 3D Sampling combines existing modelling tools and methods with concepts and practices drawn from external examples. This section describes: (1) How sampling provides the conceptual inspiration for applying 3D scanners as design generators; (2) Recent work in 3D mesh sculpting and cut and paste interfaces; (3) The technological opportunities and challenges related to 3D scanning; (4) Research efforts in the computer graphics community exploring texture synthesis techniques; and (5) The functional and cultural significance of texture design in contemporary architectural practice.

2.1 Sampling

In music, sampling is the act of taking a portion of a sound or recording and reusing it to create original compositions. Walker (2008) provides a comprehensive overview of the field of sample-based music; its motivations, compositional strategies, and history. Some of the central manipulations applied by artists in this field, including digital signal processing, convolution, algorithmic filtering, looping, and mixing, serve as compelling metaphors for 3D Sampling. In architecture, 3D scanning (Sheil, 2013) and textural sampling (Gage et al., 2013) have garnered recent attention; however, hybrid applications, as proposed in this paper are scarce.

2.2 Personal 3D Scanning

3D scanners are instruments that collect data about the geometry of physical objects, outputting lists of geo-spatial coordinates called point-clouds. Photogrammetry is one such 3D scanning technology that generates textured 3D meshes from photographs. However, because of computational requirements, there is a significant time lag between scanning and model generation. In contrast, low-cost, real-time scanning can be achieved through depth camera technology. KinectFusion applies this technology to 'paint' 3D reconstructions through the motion of Kinect device (Azadi, et al., 2011). One current disadvantage of this technology is the trade-off between the resolution of reconstructions and the immediacy of the interaction. As discussed in the literature (Boulassai et al., 2009; Arachchige, Perera, 2014; Truong-Hong, Laefer, 2011), a fast and reliable method for real-time segmentation and conversion of point-clouds into discrete 3D surfaces for computer modelling remains in absentia.

2.3 Procedural Texture Generation

Image-based texture synthesis is a topic of continued interest in the field of computer graphics, whereby 2D samples from photographic images can be used to synthesize novel textures to synthesize entire worlds (Efros and Freeman, 2001). Texture synthesis algorithms have two primary goals: to sample an existing texture to generate an unlimited amount of new image data that perceived to be the same to humans, and to transfer textures between objects. Texture synthesis works by extracting patches of an existing texture and applying the samples in consistent way. The literature provides a range of possible technical approaches to 2D textural synthesis (Ashikhmin, 2001, Ruiters et al., 2010; Efros and Leung, 1999; Wei and Levoy, 2000;). While applications of textural synthesis in computer graphics are typically guided by performance-driven criteria, 3D sampling applies textural synthesis as a new technique for design exploration.

2.4 Virtual Clay

Evocative of traditional practices of physical clay modelling, virtual clay has garnered recent attention as an alternative to conventional 3D modelling styles. A review of scholarly work reveals *3D Sculpting* (Dipen et al., 2013; Cit et al., 2013; Cingi and Oghan, 2012; Madugalla et al., 2013) and *Cut and Paste* modelling (Sharf et. al, 2006; Schmidt and Singh, 2006; Bierman et al., 2002) as two inter-related applications of virtual clay. This body of work has leveraged a variety of rapid mesh editing techniques to produce innovative new compositional operations for fusion of discrete parts and the transfer of surface features (Schmidt and Singh, 2006). Bringing together the processes of concept visualization and final design virtual clay offers a way to quickly explore a large space of alternative solutions by extending the functionality of existing 3D objects and simplifying user interaction and manual manipulation (Sharf et al., 2006). When used in conjunction with virtual clay, 3D Sampling provides a remixing operations which allow a designer extend and exploit a new range possibilities beyond the mere surface of an input 3D objects.

2.5 Textures, Patterns, Behaviours

Architects have always relied on textures and ornamentation as a compelling way of resolving the cultural and pragmatic requirements of building details (Figure 4a). Considering digital technologies and networks, the status of architectural texture and ornament has shifted in response to parametric tools, (e.g. Grasshopper or Maya); now designers can create highly complex and dynamic patterns predicated on relatively simple rules. The emerging interest in texture and ornament is discussed extensively in the literature (Mousavi, Kubo, 2010; Lynn, 2004; Picon, 2013, Gleinger, Vrachliotis 2009; Levi, 2008).

2.6 Research Question

The framework and tools presented here address some of the major limitations inherent in currently available computer modelling approaches—specifically, how to define the rules of a parametric system which produce a desired form or material behaviour. Without a clear understanding of the rules from the onset, parametric and procedural modelling approaches inefficiently reach acceptable solutions requiring significant iteration through trial and error. Demonstrating a new field of design and research inquiry, this paper explores several broadly defined questions: What advantages does 3D Sampling offer as a technique for design exploration? What are some possible applications? What is the relationship (if any) between the sampled material and the subsequent textures? How does one evaluate or analyze results? What are the boundaries of such an approach? We postulate that it is possible to 3D scan specific qualities of an object, remix the material digitally, and produce a range of new material qualities from the original scan.

a) b)

Figure 2: Performative Textures: a) Macabres, Alhambra (source: http://en.wikipedia.org/wiki/Alhambra#/media/File:Ceiling_in_Alhambra.JPG, user Liam 987) b) Haptic texture study, a range of surface textures were generated using the 3DJ modelling tool and CNC milled into a slab of Sapele wood.

3. METHODOLOGY

This section outlines the details of 3D Sampling, a novel technique for synthesizing textures with material qualities one or more 3D scans as the foundation. The function and rationale of the new 3DJ 3D Sampling software tool is elucidated.

3.1 Overview

Figure 3 outlines the six operations 3D Sampling contributes to traditional 3D modelling. Figure 4 explains conceptual framework of 3D Sampling. The key processes described are: 1. Scanning - the digitization of a physical sample. 2. Synthesis - remixing a digital sample using conventional (e.g. Rhino) and novel (3DJ) digital modelling. 3. Printing - physical materialization of a digital sample, and 4. Analysis - evaluating the behaviour or performance of a physical or digital sample. The framework also tracks the format of information as it translates mediums throughout the sampling process: 1. physical samples - physical objects; point-cloud samples - non-hierarchical lists of coordinates, and 3D mesh samples - hierarchical lists of coordinates.

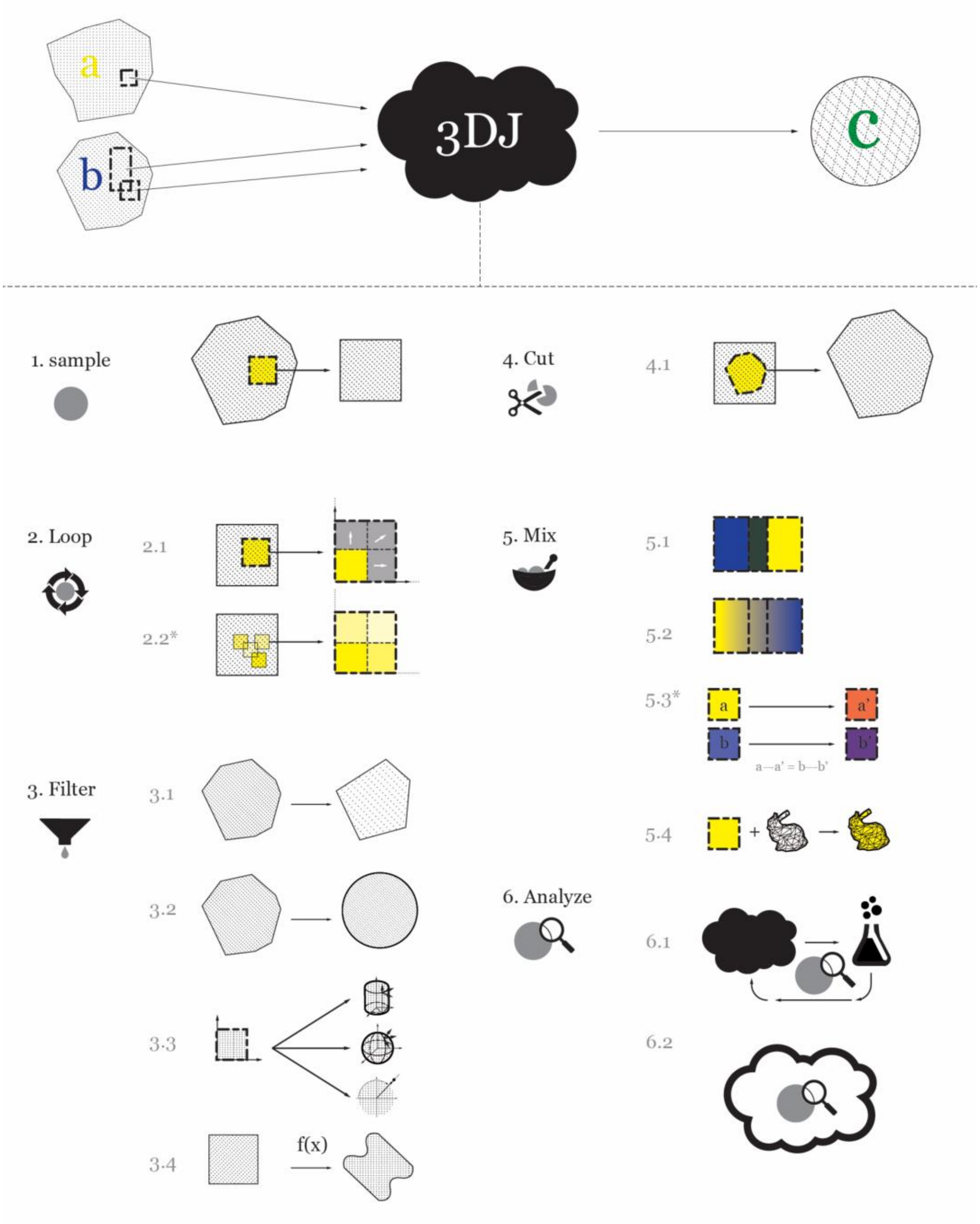


Figure 3: Breakdown of the main operations of 3DJ: (1) Sample – a set of point cloud data, (2) Cut – extracting a set of point cloud data, (3) Loop – repetition of geometric features, using a process of arraying tiles (3.1) or pixel quilting (3.2) as described in (Efros and Freeman, 2001), (4) textural blending, superposition, and juxtaposition. Techniques include superposition and averaging of samples (5.1), linear blending using distributed averaging of pixel positions (5.2), transforms using image analogies (Hertzmann et. al, 2001), and 3D mapping of textures using techniques such as projective texture mapping (Segal et. al, 1992), (6) Analysis –evaluation and identification of desirable features of a sample, either through empirical testing methods (6.1), or computational simulation (6.2).

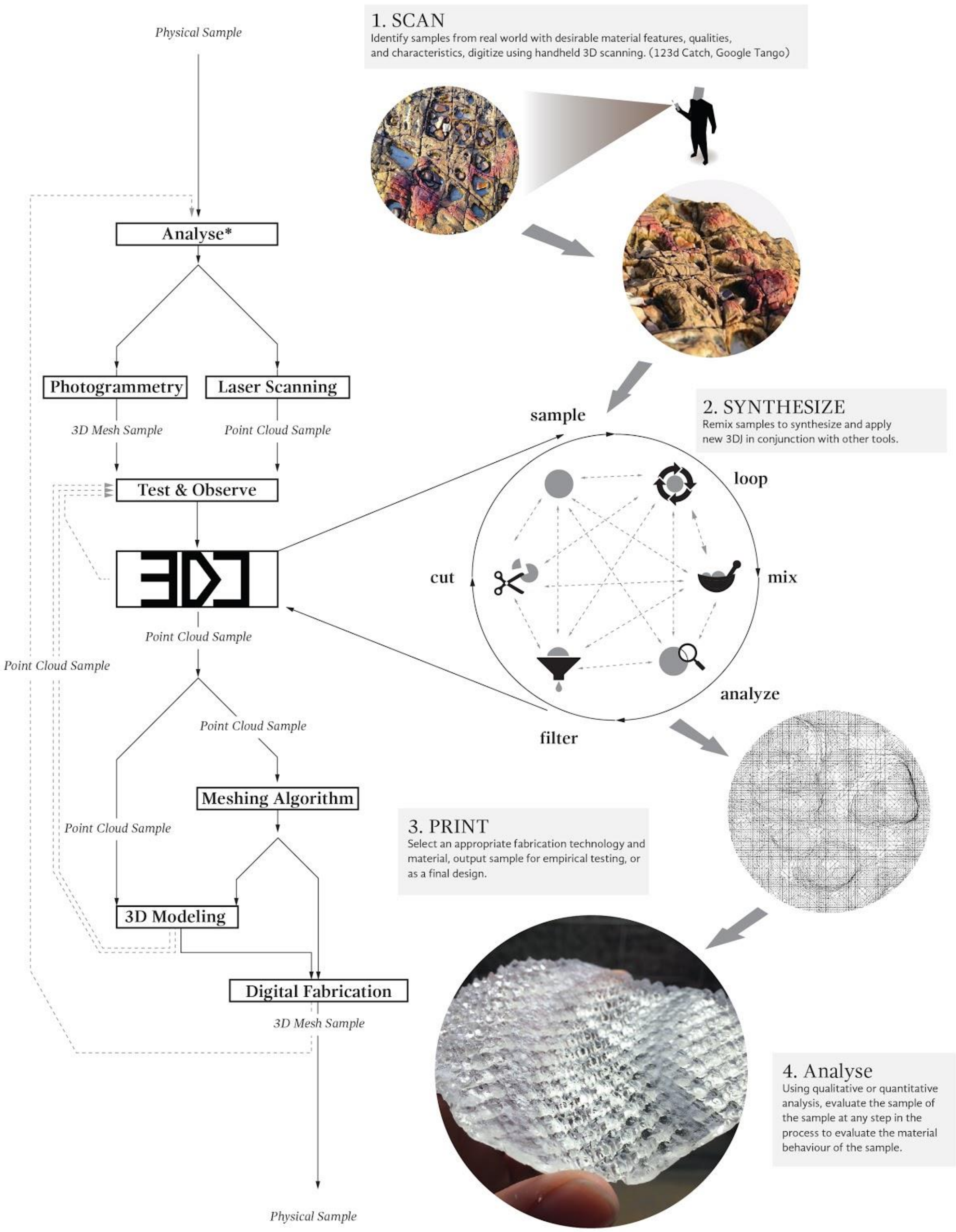


Figure 4. 3D Sampling network diagram: flows, processes and tools.

3.2 Technical Framework and Implementation

This section describes the technical implementation of 3D sampling further.

3.2.1 3D Scanning

Figures 8-11 explain 3D scanning as it applies to the practice of 3D sampling. For the designs described in this paper, two samples were applied: a rock formation and oyster shell generated from photographs using the 123d catch application (Figure 8).

3.2 3D Synthesis

3D Synthesis involves the processes of sampling, modifying, and remixing digital samples using conventional and novel software approaches. This section describes *3DJ*, a custom DJ tool developed for manipulating 3D scan point-clouds in the course of this research.

3.2.1 3DJ

Inspired by music sampling tools and methods, 3DJ is a prototype computer modelling application developed by the authors for 3D Sampling (Figure 13). Written in Processing, the inputs and outputs of 3DJ are point-clouds. 3DJ provides an interface and additional features allowing designers to manipulate point-clouds in new ways. 3DJ recognizes the practices, methods, and procedures of design established in sample-based music, and organizes the experience of designing with 3D scans into six operations – sample, cut, mix, filter, analyze, and loop – to produce new texture variations The 3DJ interface allows a user to crop regions from imported 3D scan point-clouds or meshes (cut), and apply looping, mixing, or filtering operations to synthesize a new point-cloud texture which can is output as a PLY file. While more sophisticated textural synthesis algorithms can be incorporated in the future, the 'looping' operation involves a simple mirroring and tiling of sub-samples. 'Mixing' involves a simple linear blending algorithm to combine two or more scans (figure 5). The 'Filter' in this version of 3DJ involves operations which apply global mathematical distortions across the textural field, as well as mesh reduction algorithms; either involving a random re-sampling of the input point cloud within 3DJ, as well as the use of the built-in mesh reduction function in rhino prior to the import of a sample being imported into 3DJ. While future versions of 3DJ could include real-time mesh re-construction; efforts to do so using within 3DJ stalled the tool, undermining interaction rate; ultimately a Poisson surface reconstruction algorithm and the built-in Delaunay mesh triangulation were applied using Mesh Lab to produce satisfactory meshes for subsequent milling and 3D printing operations. While similar techniques could be achieved by employing a variety of existing software in concert, the aim of integrating these operations within a single tool was to facilitate greater design exploration by allowing the user to actively intervene within the process of guided textural synthesis.

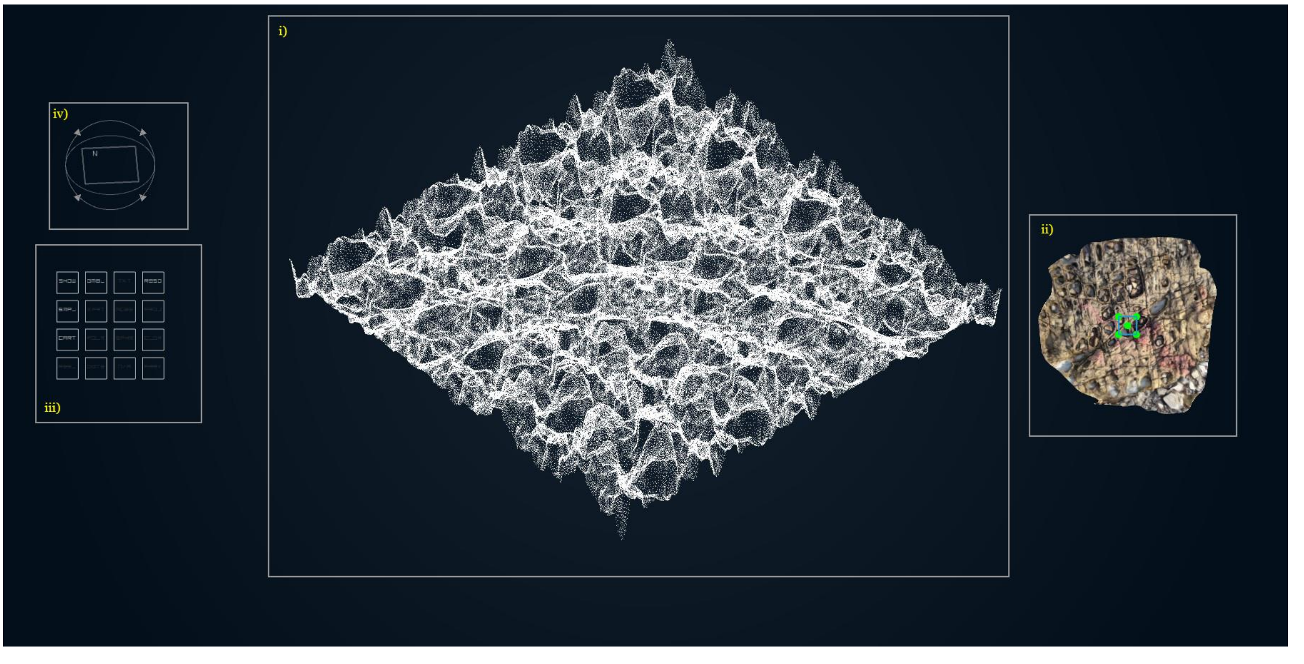


Figure 5: Screenshot of 3DJ interface: i.) 3D view port, ii.) 2D interface, here a user crops of a sub-sample from the input3D scan data, iii) customizable buttons for user manipulation, toggles a looping operation, mathematical filters, point cloud reduction and coordinate mapping iv) 3D view selector – top, bottom, left, right, axo – southwest, southeast, northwest, northeast

Figure 6: Variations created from prototype 3D texture design tool: a) Sample: a cropped extract of an oyster shell. b) Filter: a mesh-reduce operation and mesh smoothing operation c) Mix: a mathematical z-distortions applied to textures) Loop: tiling of sample textures achieves scalar-manipulations

3.3 Fabrication

Technological limitations currently constrain 3D sampling to macro-scale material properties, attributes and characteristics. For the initial tests, high definition starch-based powder 3D printing (Figure 8a) was used. However the brittle, water soluble, nature of this medium degraded performative qualities, thus other alternatives were explored. 3D printing mediums like resin-based stereo lithography (Figure 8b) and ABS allow optically and mechanically performative parts. However, economies of scale and material flexibility made CNC milling the desired fabrication medium here.

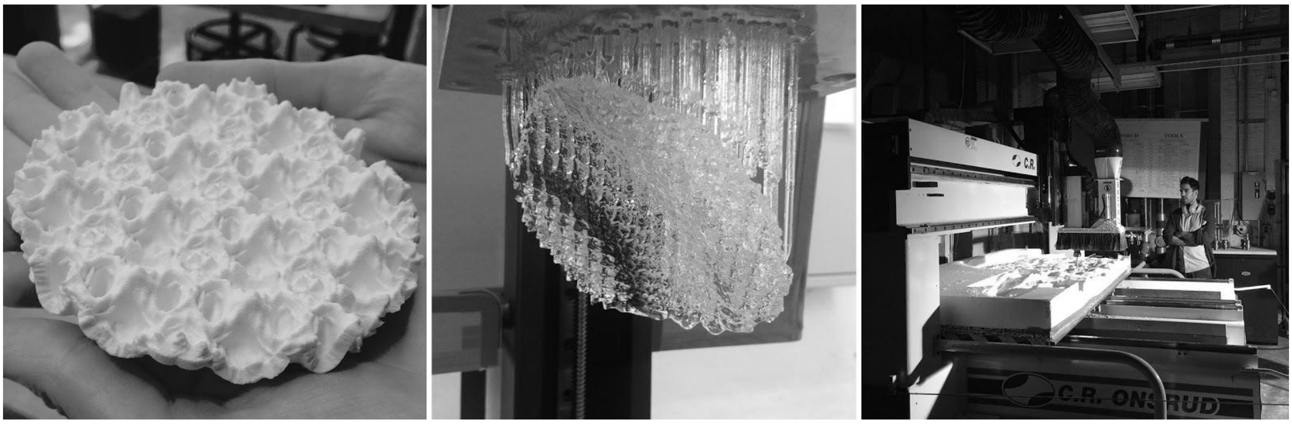


Figure 8: a) Additive manufacturing: powder printed models were brittle and did not have useful mechanical properties b) Additive manufacturing Optical qualities - resin stereo lithography on a Form-1 3D printer, c) CNC milling

3.4 Analysis

Analogous to how musicians must have the ability to listen to a progressing mix to properly judge their compositions, 3D Sampling requires feedback to evaluate how mixing operations manifest as the sample's physical characteristics. While the initial test applied qualitative analysis and evaluation in the production of texture design (Figure 17), other possible modes of empirical, and real-time digital analysis exist, including thermal, optical, and haptic performances, and tests quantifying surface qualities (e.g. aerodynamics, roughness, irradiance, etc.) add citations here. While the physical analysis methods provide immediate, tangible results and verification, real-time digital analysis methods within 3DJ would facilitate a stronger relationship between digital manipulations the final texture designs.

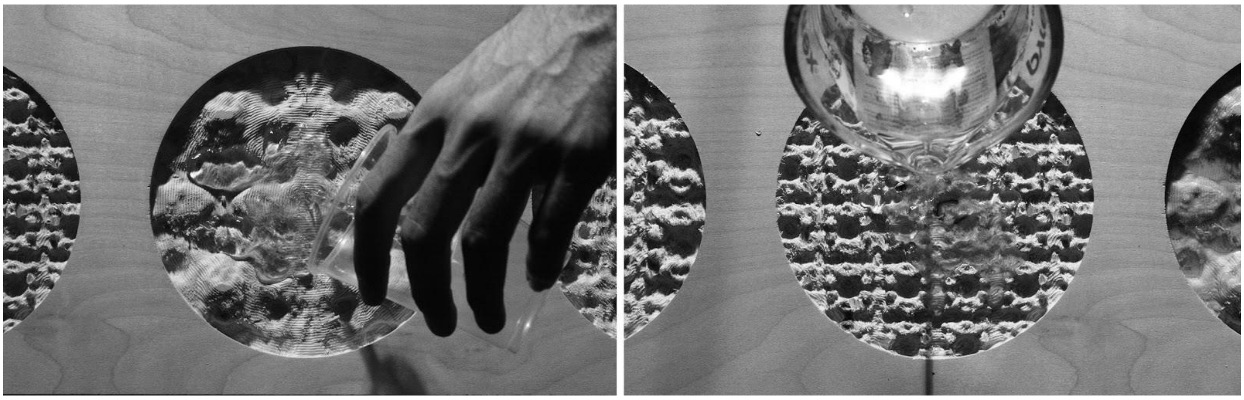


Figure 9: Initially analysis, exploring how texture designs affected the flow of water across them

4. CASE STUDIES

This section describes initial design experiments demonstrating the application of the 3D sampling framework to the design of camouflage, haptic, and optical, qualities using a single 3D scan.

4.1 Landscape and Camouflage Textures

Figures 13-15 describe the first design experiment. Imagining possible applications to landscape design, this test demonstrates how terrestrial features can be 3D scanned and blended at multiple scales of occupation, generating a landscape. Textures representing a range of scales using sampling and looping operations were synthesized in 3DJ and combined through a technique of superposition, to produce a hypothetical landscape providing numerous scales of human habitation. Considering the human body as a datum, we observe three scales in the model: A landscape scale, suggestive of a connection to a broader context, a proto-architectural scale, suggestive of more enclosed and intimate spaces, and finally a human-scale, suggestive of ways in which a person might directly engage the landscape.

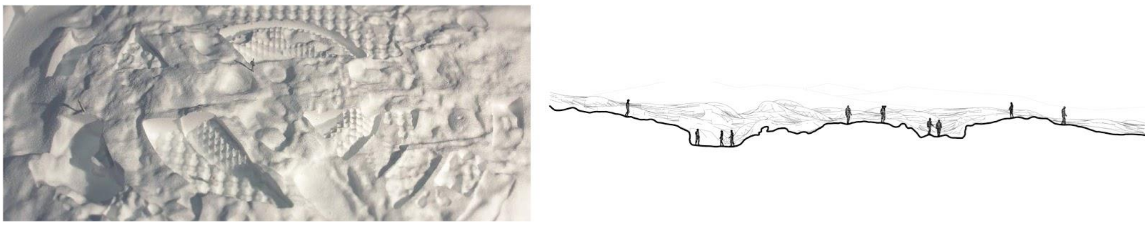


Figure 10: Landscape scale

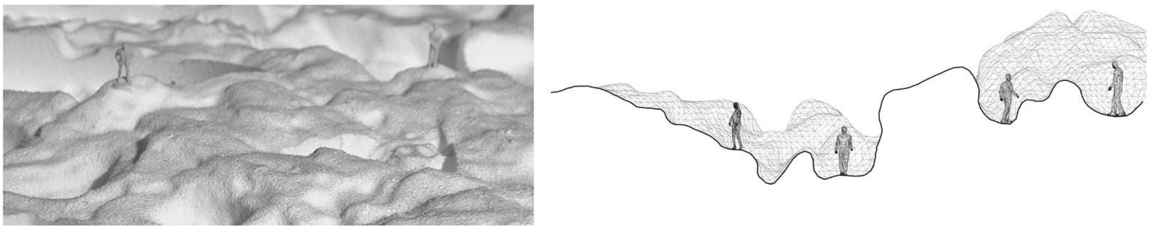


Figure 11: Proto-Architectural Scale

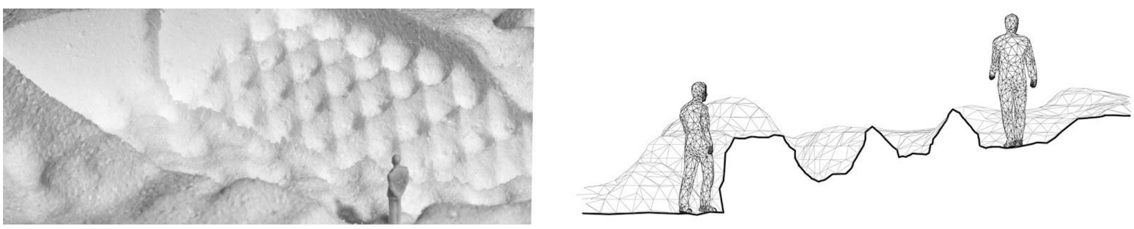


Figure 12: Human-Scale

4.2 Haptic Textures

The second series of experiments (Figures 20-21) explored applications at product design scale by demonstrating possibilities to synthesize textures with tactile qualities (e.g. grip, comfort ect.). Multiple sampling, looping, mixing, and filtering operations were applied using 3DJ to generate a wide range of material textures: from slippery, to sharp, to rough. A key finding, was how the material selection itself was a design operation, transforming the qualities of the raw 3D scan. For example, an otherwise un-altered geometry sampled from the 3D scan becomes smooth like a piece of cloth when milled into wood. However, applying a filter produces a jagged texture. Applying a loop increases the roughness of the sample. One compelling opportunity demonstrated in this case study is using 3D Sampling as a means to short-scale surface heterogeneity.

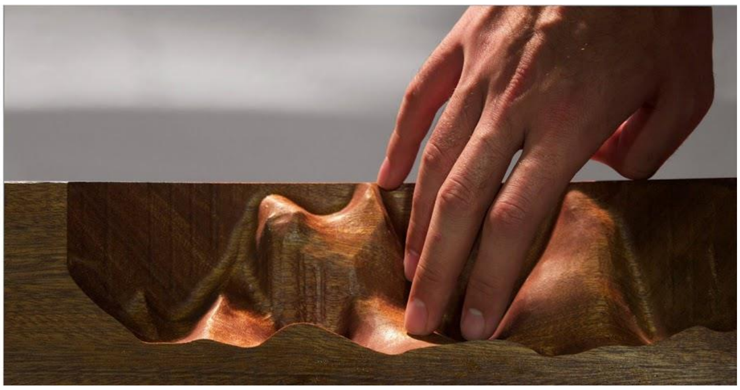
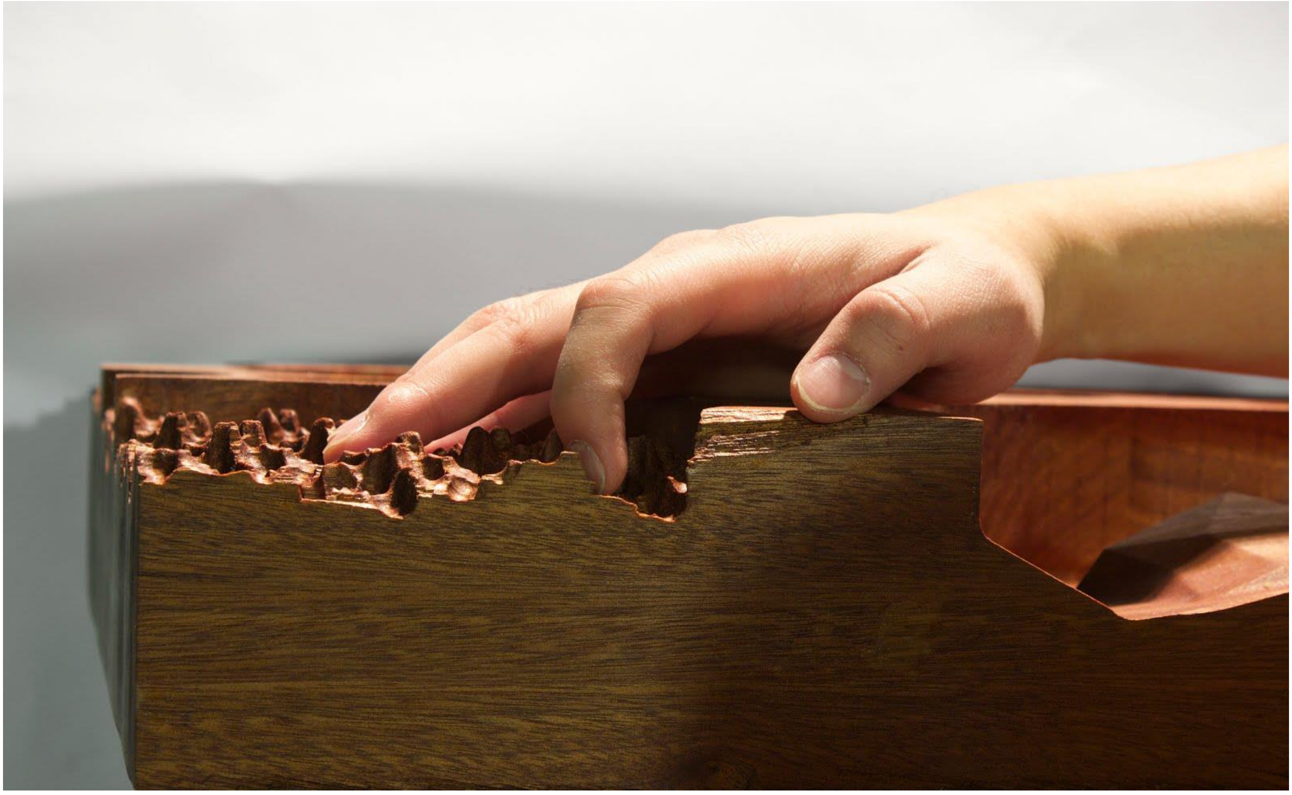


Figure 13: Haptic case study. Material selection translated from qualities wish to express from original 3D Sample.



Figures 14. Haptic case study. Material selection translated from qualities wish to express from original 3D Sample.

4.3 Optical Textures

Figures 22-24 highlight the third experiment, exploring the synthesis of optically performative textures at the building envelope scale. The methods were applied to demonstrate how material qualities related to light transmission across a CNC milled acrylic surface such as opacity, transparency, and reflectivity could be controlled using the 3DJ tool. From the preliminary results, it was observed that filtering, which removes redundant points, produces greater transparency (Figure 22), while looping, which increases point density creates a texture with greater diffusion and specular noise (Figure 23). The unaltered sample geometry (Figure 24), results in textural chimera.

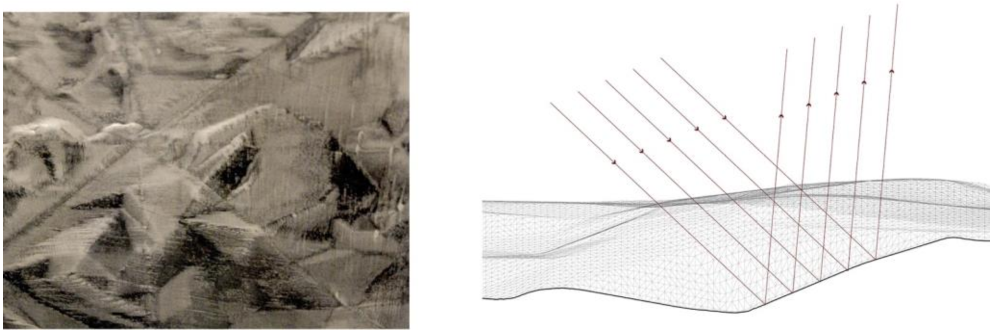


Figure 15: Optical example 1, filter achieves more directed light

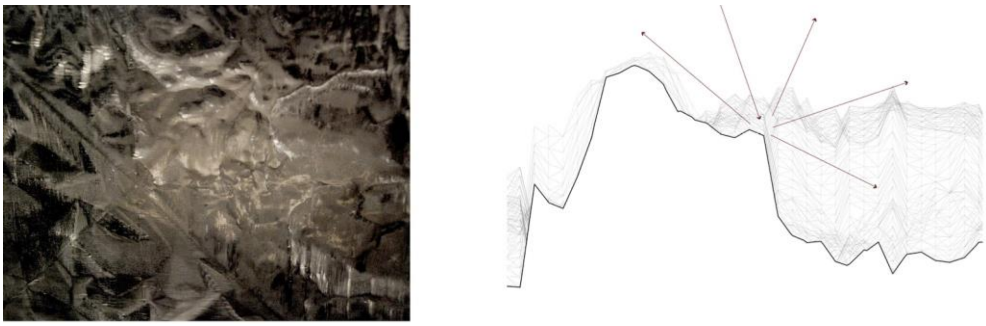


Figure 16: Looping texture produces more dispersed light and opaqueness

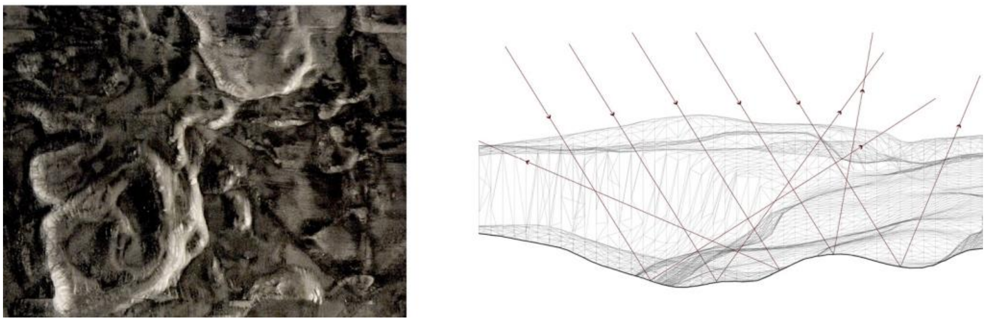


Figure 17: Unaltered geometry

5. DISCUSSION AND FUTURE WORK

The motivation for the case studies was to demonstrate morphogenic potentials of sampled material. Part of this involved the development of syntax to link operations of the tool and the resultant material performances and behaviours produced. Figures 25-27 summarize the application of 3D Sampling operations, and compositional strategies used to generate performative textures. The case studies provide initial results, demonstrating a single iteration of the 3D Sampling framework.

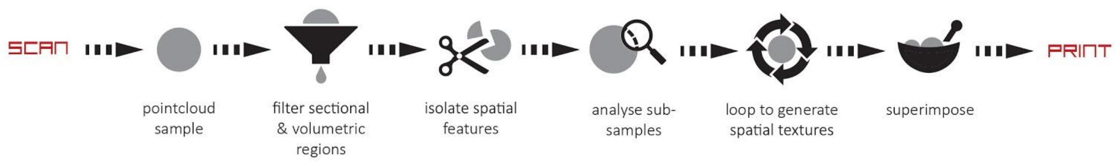


Figure 18. Camouflage case study

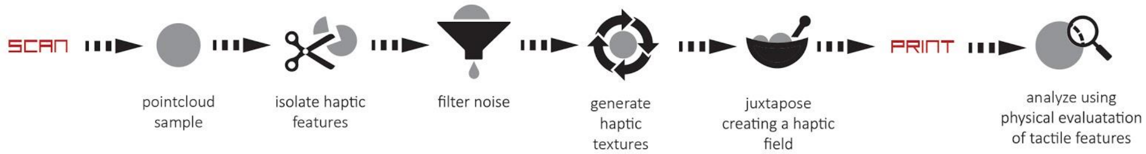


Figure 19. Haptic case study

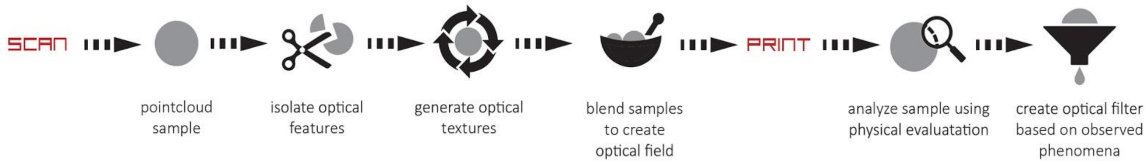


Figure 20. Optical case study

5. CONCLUSION

5.1 Summary

3D Sampling imagines a future where a designer could instantly sample and remix the geometry and material qualities of objects from the real world, producing new designs. The research presented in this paper contributes: (1) The concept of 3D Sampling as a creative process; (2) A definition for conceptual and technical framework for 3D Sampling; (3) 3DJ, a 3D modelling software tool allowing users to generate new 3D textures from 3D scans; and (4) Three case studies the implementation of the framework, and provided initial results and evaluation. The speculative tools, frameworks, and experiments presented and assessed in the paper, represent first steps which exemplify the potential future of a new design and research field which re-contextualizes 3D scanning, once conceived as a process of measurement, as a method for creative production.

5.2 Potential Impact

While the solutions developed within the three case studies—spatial, haptic, and optical—were framed within an architectural discourse of texture, the implications of this work reach far outside the discipline. Considering how sample-based music practices have made music creation accessible to a wider audience, 3D sampling could potentially offer a simplified and more intuitive way for non-experts to edit, manipulate, and create 3D objects. Future 3D textural synthesis tools, suggested by the 3DJ prototype software, imply a wide range of possible applications in light of different users. For instance a product designer could apply these methods to design ergonomic, tactile, qualities such as grip, comfort, water shedding, around the sense of touch, while a landscape or urban designer might sample of natural features to integrate a structure into a landscape through camouflage. Conversely, a materials engineer could use 3D Sampling to apply a texture with desirable properties but poorly understood principles such as gecko's feet to a develop and analyze solutions directly through empirically testing, contrasting to parametric modelling processes which would require the development of a conceptual model of a gecko's foot prior to application within a design space.

5.3 Future Work

To further explore the connection between the operations and performance, future work may incorporate additional iterations between synthesis and analysis in order to further knowledge. Quantitative analysis and experimental data would buttress this. Greater interrogation and classification of the initial samples, as well the combination of multiple samples would expand on this initial exploration, such as the possibility of creating material hybrids (e.g. mixing gecko's feet with fur). A promising avenue to advance methods regarding mixing within 3DJ would be to adapt seminal work on 2D texture synthesis in computer graphics (Efros and Freeman, 2001; Ruiters et. al, 2011; Hertzmann et. al, 2001) as a way to conceive of new mixing, looping, and filtering operations. Bump mapping techniques could provide a quick way to test how these techniques for 2D textural synthesis translate to

3D point-clouds. Another possible topic for exploration is the mapping process to 3D textures to be applied irregular surfaces, and resulting affect on textural performance.

5.4 Concluding Remarks

Within architectural practice, the use of external design precedents, research, and first-hand observations as forms of knowledge are often considered more efficient strategies in developing designs than initiating projects from a tabula rasa (Zarzar, 2003). 3D scanning generates a wealth of new digital data that architects can access freely to produce new material, spatial, and even cultural qualities, properties, and effects. By re-framing 3D scanning as a mode of creative production and operationalizing this mode through novel software demonstrations, this paper explores the ability to transcend subjective or experiential qualities of physical reality, and empowers designers with new tools to experience and remix the world.

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