

Rethinking Prototyping: Scan to Production

Designing with heterogeneous materials

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Abstract. *This paper examines how digital scanning techniques can be utilised in the digital fabrication of hybrid materials. It explores how ‘imperfections’ discovered in natural materials can inform unique design solutions. In the first part of this paper, the technical scan-to-production process is explained. Secondly, the paper discusses this new production model against current standardised production processes. Third, the paper introduces ways in which the proposed research method can be incorporated into emerging design practices through three realised projects – Digitized Grain, STP @ Milano Design Week, and Timber X-Ray Scanning; Finally, an assessment of the Research through Design Production over the course of these projects details the key changes in each stage of the STP process.*

Keywords. *Digital fabrication; material production; scanning.*

INTRODUCTION

Material production reflects the technology of the times. An important motivation in material design and construction within architecture is to establish relationships and elicit response through the use of materials. Modern material production places importance on efficiently producing uniform, homogeneous artefacts from natural, irregular materials. With the aid of contemporary design techniques however, it is now possible to have material design make use of, and even feature explicitly, the imperfections of natural materials with minimal impact on production efficiency. The Scan-To-Production (STP) process, through the use of digital scanning and robotic fabrication, proposes to take material irregularities as design input, to distinguish and create meaningful order from material ‘noise’.

SCAN-TO-PRODUCTION (STP)

What if fabrication machines could flexibly adapt to irregular, heterogeneous material properties? It is now possible for designers to make use of real-time sensing and complex modelling algorithms through inexpensive devices and computing power. Willis et al. (2011) combine these algorithms with CNC machines, resulting in “interactive fabrication”. The aim of STP is not necessarily to perform real-time, interactive fabrication, but instead prioritises capturing a higher resolution of scanning data over real-time interaction. Moreover, STP focuses on the post processing of scanned data and its translation into fabrication processes, using this data as crucial design attributes instead of dismissing these characteristics as material defects. STP considers these as attributes that can intelligently inform the design process

– material uniqueness exploited to its full design potential.

SCAN-TO-PRODUCTION – TECHNICAL PROCESS

The technical process of STP is as follows: A natural material with heterogeneous characteristics such as timber or stone is scanned, and information about its properties are recorded and analysed. Scanning devices used include a Kinect camera, Xray-CT scanners. Features recorded with devices include such visual properties as grain-stratification, knots, aggregates and defects such as fungal stains and cracks, as well as internal structures not able to be detected by the human eye. A design decision is then made as to which feature to utilise as a design input in the next step. The input is then fed into an algorithm developed within the coding environment Processing, which translates this input into machine code to create a unique cutting path for each material piece. The piece is then fabricated using its custom tooling path, using digital fabrication machines such as a 3 axis CNC milling machine, or a 6-axis KUKA robotic arm.

STP CONSIDERED AGAINST CURRENT PRODUCTION PROCESSES

From the stones of the Egyptian pyramids to the modern brick, from the handworked logs of a log cabin to industrially manufactured dressed timber, we have continuously developed new ways of flattening and standardising irregular materials from natural environments into regular, uniform, repeatable and measurable units. Our living environment today consists mostly of mass-produced artefacts, which is typically considered to be the consequence of industrialisation and subsequent mass-production (Sigfried, 1948). Our tools of production mark out the stages of civilisation – the Stone Age, the Bronze Age, the Iron Age, the Industrial Age. Tools are the result of successive improvement, and the effort of all generations is embodied in them, and is the direct and immediate expression of progress – it gives essential assistance and essential freedom.

(Le Corbusier, 1923). Likewise the perceived merit of standardisation throughout history has changed – from the Arts and Crafts rhetoric of the dehumanising effects of industrialisation, to the Modernists sleek promise of the machine. Fast forward then to the age of digital fabrication and distributed design process, the Third Industrial Revolution. The STP process is no different to historical tools in that it is a mark of its age. However this is the age of web-based collaboration, and small batch technology that has the potential to transform manufacturing. The STP process then, differs from traditional manufacturing processes in that it uses readily available technology: Kinect scanners, an open source coding environment (Processing), and fabrication machines that could be readily hired (KUKA robotic arm) or built at home (3 axis CNC, RepRap). The use of this now readily available technology is what allows the STP process to deal with material irregularity and natural complexity creatively as direct design input.

EXAMPLE PROJECTS

The following design projects are worked examples of how the STP process was successfully employed as a design and fabrication process.

Example 1: Digitized Grain (2010)

Digitized Grain is a study of gradient material transitions for interior, furniture and product design applications. The properties of the material – in this example the wood grain – inform the transition of one material to the other, in contrast to conventional joining seams usually employed when transitioning from different product surfaces. The two materials used are a plywood panel and polyester resin. The algorithm used in this project transforms the scanned 2D data to a 3D model by converting the color values to depths of each pixel and connecting them with vector lines, which is used for CNC tooling. In this example the cutting path was utilised to reproduce the grain pattern as similarly as possible, to explore how the material could directly inform the tooling process – thus the material behaves as if it defines the tooling processes. As a prototype in-

Figure 1
Digitized Grain prototype.
T-B, L-R 1: original panel; 2:
thresholding; 3: generated
toolpath; 4: milled panel; 5:
finished resin-plywood panel.



terior wall panel, a 1200 mm x 2400 mm x 12 mm board was fabricated (Figure 1). The outcome was

a hybridization of materials enabled by a vivid, superimposed material texture on both materials. The



Figure 2
Detail of Abstracted grain
pattern.

resulting contrasting material combination between wood and polyester resin highlights their physical properties (opaque/transparent, elastic/ rigid) and emotional materiality (natural/synthetic) (Yoshida, 2012).

Example 2: Digitized Grain at Milano Design Week (2012)

The STP installation recently completed at Milano Design Week allowed for the STP artefacts to be tested at an architectural scale. Moving up from a plywood panel to x16 3 metre long timber planks, the earlier product design application now becomes a fragmented wall. In contrast to the earlier *Digitized Grain* prototype, the cutting paths used in the fabrication of these planks was further refined and abstracted so that the grain pattern was less 'literal', while still hinting at the materials grain structure (Figure 2). The scale of the installation highlighted the physical properties of the hybrid material to an another level of experience from product to spatial element (Figures 3 and 4).

Example 3: Timber X-Ray Scanning (ongoing)

With support from EMPA (Swiss Federal Laboratories for Materials Science and Technology), aged lumber materials are scanned with an industrial CT scanner (Figures 5 and 6) to extract data about inner material structures. The project is currently investigating the development of a scanning system that uses a mobile x-ray source and a line detector attached to two robotic arms, to develop a system that can overcome the static size limitation of conventional CT scanners. This potentially allows for more flexibility of the material scanning process, with further application to the onsite scanning of buildings. The non-destructive analysis procedure could be particularly beneficial to analysis of existing buildings.

RESEARCH THROUGH DESIGN PRODUCTION

The practice of research through design production allows for a method of enquiry to be applied and tested against a specific design outcome, the results of which can then be fed back into further research.

Figure 3
Digitized Grain installation
@ Ventura at Work, Milano
Design Week.



Through the design and production of the above projects, the STP process has been, and continues to be, refined and developed. In particular the following techniques evolved in the following ways during the course of the above projects:

Scanning

In early development of the scanning process for the first *Digitized Grain* project, the system required users to bring in a static image for tool path generation. Thus the image quality was not optimised for processing into fabrication toolpaths. For the Milano Design Week installation, the scanning system was developed to use a slit scanning method by attaching a Kinect Camera to an industrial robotic arm fitted with a light source to obtain consistent brightness across the scan. The RGB camera scans the input material with consistent velocity and height, before being automatically resized and

cropped to correspond with the dimensions of the scanned material.

Image Processing

At the initial development of the image processing stage, the algorithm generated toolpaths from a binary image by means of brightness thresholding. The binary image was used for deciding where to cut the material. As used in the early *Digitized Grain* project, the resulting toolpaths created patterns which simply aimed to reproduce the grain pattern. In order to create visually recognisable but more abstracted patterns (as demonstrated in the Milano installation), the image processing algorithm was refined to incorporate brightness equalisation, high-pass filtering and sampling of neighbouring pixels for better conversion from 2D image to 3D path structure.



Figure 4
Digitized Grain installation
@ Ventura at Work, Milano
Design Week. Spatial qualities
of the material are highlighted
through its application at
architectural scale.

Tooling Path Generation

Generating a 3D milling path from 2D scanned data is the main feature of the algorithm developed for STP. The resolution of the image corresponds to the dimension of the material stock – for example, a board of 3 metres by 300mm (as used in the Milano installation) equates to a scan resolution of 3000x300 pixels. The algorithm converts brightness values of pixels to cutting depth and connects these points parallel in length with the milling bit stepovers. Early versions of this algorithm generated machine code for a 3 axis CNC, which was later developed to output tooling paths to SRC and DAT files written in KRL (KUKA Robot Language).

Fabrication

The early *Digitized Grain* project was fabricated using a 3 axis CNC milling machine, while the Milano installation was fabricated using a KUKA KR 250 Ro-

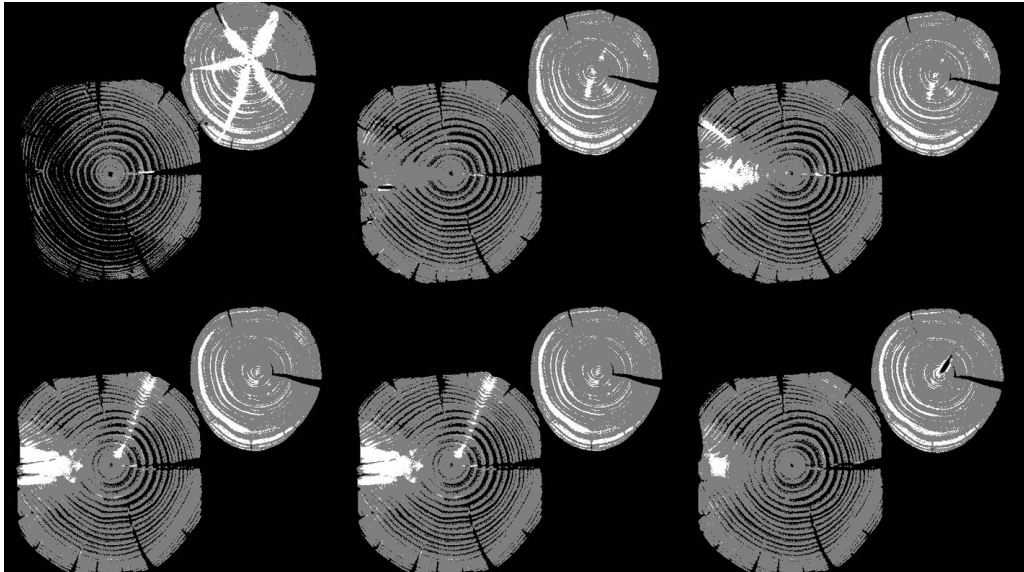
botic arm. Although the Milano project only utilised the arm as a 3 axis CNC, the setup opens up further development possibilities, such as variation of scanning angles for 3D virtual model reconstruction, and variation in fabrication cutting angles. Regarding the presented work, the tool angle is set perpendicular to the stock material.

FUTURE DEVELOPMENTS

Scanning

The current system adopts a slit scanning method to achieve uniform brightness values as well as to avoid lens distortion. Since both aspects can be computationally solved (i.e. through image reconstruction calculating lens distortion, sampling multiple RGB value on a same position and normalizing them), it is more robust to take several scans from different positions and stitch the images together

Figure 5
CT Scans of timber made at
EMPA.



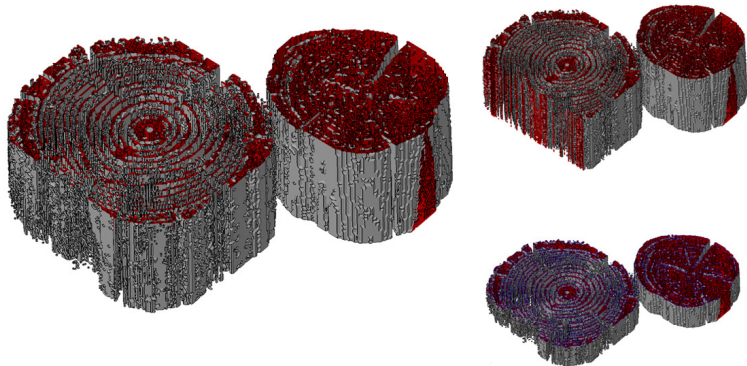
respectively. This method is also relevant to 3D model reconstruction with 2D images from different perspectives.

Image Processing

Image segmentation is a key technical process in the development of STP. The current algorithm requires users to decide the right threshold value to segment grain patterns from backgrounds. This decision mak-

ing process can potentially be automated by developed algorithms such as Otsu-method and ROC (receiver operating characteristics). Other image processing techniques that could be implemented include blob detection (OpenCV), where outlines of grain structures can be detected and labeled according to an index system. This would be useful to generate toolpaths to exactly follow grain patterns instead of generating parallel paths.

Figure 6
Isosurface output meshes
generated from CT scans.



3D model reconstruction from scanning data

Using the depth camera feature of the Kinect camera, the 7 axes of the KUKA robotic arm can be utilised to allow for a greater degree of freedom in generating and recombining point cloud data. In combination with RGB camera inputs, this would be a significant technical development in the scanning process.

CONCLUSION

These design and production projects illustrate how the STP process can provide alternative methods for design, prototyping and fabrication. The setup as currently developed provides an alternative approach to dealing with the complexity of natural materials, and the illustrated projects demonstrate the potential for this process to allow for design engagement to generate artefacts at multiple scales. The outlined projects further suggest how the STP approach has applications beyond material production that could be potentially developed for new architectural and prototyping means.

PROJECT CREDITS

- *Digitized Grain (2010)*
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- *Scan To Production @ Ventura at Work, Milano Design Week (9-14 April, 2013)*

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