ASA 2018

Engaging Architectural Science: Meeting the Challenges of Higher Density

PROCEEDINGS

52nd International Conference of the Architectural Science Association (ANZAScA)
28 Nov - 1 Dec 2018, Melbourne, Australia

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Embracing natural timber features of plantation hardwood: Material-aware digital workflows in product design and development

Nathan Koltarewski
Australian Research Council Centre for Forest Value, University of Tasmania, Launceston, Australia
Nathan.Kotlarewski@utas.edu.au

Lachlan Taylor
Discipline of Architecture and Design, University of Tasmania, Launceston, Australia
Lachlan.Taylor@utas.edu.au

Peter Booth
Discipline of Architecture and Design, University of Tasmania, Launceston, Australia
University of Technology Sydney, Australia
Peter.Booth@utas.edu.au, Peter.Booth@student.uts.edu.au

Abstract: The adoption of digital workflows within the architecture and construction industries is wide spread. Advanced digital methods including parametric and associative tools, integrated and iterative optimisation and file-to-factory automated fabrication workflows are now common in architectural and design offices internationally. These tools offer unique, fast and flexible opportunities for designers to conceptualise, rationalise, communicate and fabricate a wide range of complex designs that were previously deemed too complex to produce. While there are many contemporary examples of digital workflows used in the development of architectural solutions, there are limited examples where these tools have been used to deliver architectural products with low-value materials for the built environment. There is a current market-pull for the use of timber products in Australia and a resource-push to utilise emerging low-value Australian plantation hardwood timber. This emerging resource is deemed low-value by the excessive amount of natural feature that prevent its use in structural and appearance grade products. This research demonstrates the development of unique timber architectural lining products utilising digital workflows to rapidly generate unique product design outcomes with low-value materials that can be manufactured according to user defined parameters.

Keywords: digital workflows; plantation hardwood; natural timber features.

1. INTRODUCTION

The adoption of digital workflows within the architecture and construction industries is wide spread. In their simplest form, digital workflows present as series of steps that can be used to control and manipulate outcomes by user defined parameters. Their main use in contemporary architecture and construction are to rapidly generate solutions for Computer Aided Design (CAD). This CAD focused outcome is useful in conceptualising different designs or constructions rapidly, in which further development and refinement can follow. In this research, digital workflows were used to rapidly develop unique architectural timber lining products from a low-value timber resource that traditionally has been rejected for use in Australian structural and appearance markets due to the presence of excessive natural features. These features include voids, gum vein pockets and lose or dead knots. A key reason for its rejection in appearance and structural timber applications is due to the associated handling and machining costs to manipulate the resource into something usable for secondary manufacturing of appearance products (Davis et al. 2017). It is therefore difficult to implement timber of low-value and quality into a product design and development process to develop products for the built environment that are economically viable to producers. This research demonstrates how a heterogeneous timber resource can be easily manipulated using digital workflows and thus improve Computer Aided Manufacturing (CAM) solutions that are economical for the Australian timber industry.

The constant development of innovative materials and emerging resources presents challenges in the built environment. The current market-pull for timber products in Australia, driven by state-based Wood Encouragement Policies (Department of State Growth 2017) demands design innovation with Tasmanian wood. This market-pull steams from an existing Australian plantation hardwood estate of almost one million hectors that is underutilised for products in the built environment (Australian Bureau of Agricultural and Resource Economics and Sciences 2017). Approximately 80% of this estate is managed for pulp-log production, which produces timber—of a heterogeneous character—high in natural features that has historically been down-graded due to the excessive irregularity of the timber stock. This timber resource presents a challenge to meet the current market-pull with a resource-push if there is no efficient or innovative way of developing products from the varying resource with material-aware digital workflows (Derikvand et al. 2016). The intention of this research was to demonstrate how digital workflows can develop rapid and unique design outcomes for a low-value timber resource that can be manufactured to meet user defined parameters for the built environment. Moreover, digital workflows were used to demonstrate how design innovation in the Australian Timber Industry can aid new product development (Kotlarewski et al. 2016).

2. RESEARCH METHOD

2.1 Product development process

The nature of this study was to demonstrate the use of low-value timber in functional architectural applications through which digital workflows were employed to rapidly calculate a range of desirable product outcomes. The background and methods are explained sequentially, however the nature of developing a desirable product is iterative to tailor the final product's performance, aesthetics and ease of manufacture.

2.2 Background: timber acoustic products

The literature states timber has acoustic performances when used in products and construction (Bootle 2010). However, timber panel products such as medium density fibreboard (MDF) and particle boards typically reflect sound and absorb minimal sound frequencies (Wassilieff 1996). Environmental acoustics are context specific and can be solved by introducing a variety of materials, surface shapes and or cavities in a dwelling (Everest & Pohmann 2009). In the built environment, timber is used for its strength, versatility, warmth and appearance. In recent times, timber panels such as plywood, MDF, particleboard, and other timber composite engineered wood products have been used as modular acoustic absorption panels. These timber products need to be acoustically designed for the specific environment in which they will be placed which usually consists of removing material from the stock product to create cavities for acoustic absorption. Panel characteristics such as the percentage of open area (cavities), panel thickness, the addition of insulation batts, air gap behind the panel, the surface finish, and the angle at which the cavities are machined at, need to be carefully considered. In this study, a base set of product design parameters (total time of manufacture, performance by percentage of open area and the design aesthetics) were used to quickly generate optimal CAM processes for Computer Numerically Controlled (CNC) machining with high feature timber in a digital workflow environment.

2.3 Material stock lamination

High in natural feature timber boards were randomly laminated together to investigate the potential for material-aware digital workflows to develop value-added architectural lining products. The material used was plantation hardwood *Eucalyptus nitens*. A nonbiased production of timber panels which contained large variations in timber boards with features was undertaken using a water-soluble crosslinked PVA to edge glue the boards together. The panels were machined to 16mm thickness. Figure 1 is an example of the stock laminated timber. Seven panels were created, providing a representation of the normal timber quality and feature distribution.

Figure 1: Randomly laminated timber boards with nature features.

The timber stocks where laminated to dimensions of 1300x2500x16mm and 700x2500x16mm. The larger stocks replicated standard 1:1 sheet dimensions of 1200x2400x16mm and the smaller 1:2, after final machining with a CNC flatbed router.

2.4 Board feature capture

Each individual panel was photographed and converted to a static JPEG format. The images were imported into Rhinocerous3D/Grasshopper parametric modelling environment and analysed using image based feature recognition. This process compared RGB and grayscale brightness to identify dark spots in the timber stock that represent natural features—usually knots—to precisely locate them in relation to the overall board. Key reference points in addition to the timber features where included in the photography of the timber panels to substantiate the accuracy and location of the tool paths generated in the digital model. The location and size of the timber feature was used as an input within the parametric workflow, enabling material responsive design proposals to be generated and tested. Depending on the parameters set in the digital workflow, the outcome of each projected CAD solution was superimposed over the JPEG in Rhinoceros to present the tool paths for manufacturing, as shown in figure 2. Note figure 2 timber stock is different to figure 1.

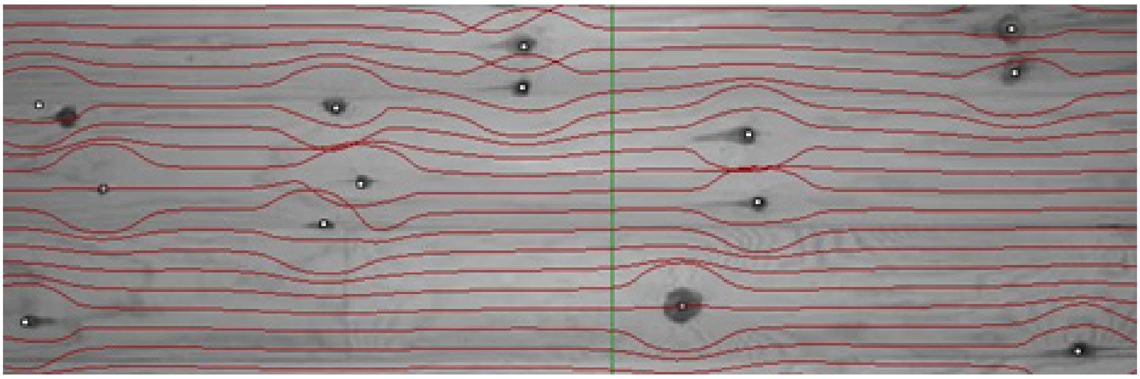

Figure 2: Feature recognition and associated CNC tool paths.

The engagement of parametric design software (Grasshopper3D) within this process allowed for the interplay between natural material characteristics and desired product performance. The balanced relationship between visual and acoustic properties was necessary in assessing the outcome of the project. Critically, the machine time for material aware adaptive patterning was of considerable concern given that an increase in machining time directly impacts the products economic viability. Considering this, two strategies were identified as core considerations for the development of panel designs and fabrication. These strategies were feature avoidance and feature engagement. In both cases, locations of natural timber features—identified by the RGB processing—were utilised as core drivers for the panel patterning. They were used in conjunction with properties relating to the specified percentage of open area or surface modification as required by the desired acoustic absorption performance. This allowed for the fine-tuning of panel performance against the time required to CNC machine the unique design.

2.5 Feature avoidance

The feature avoidance strategy adopted an approach that the timber knots already provided either perforation or surface modification. By employing this approach, the resulting panels would contain a higher level of natural character. The example outlined in figure 2 demonstrates the pattern being generated around the knots, creating a curve-based design that resulted in a reduced machine time. This strategy proved more advantageous if the natural features had greater distance between them (not in clumped groups) allowing tool path generation to spread apart more evenly.

2.6 Feature engagement

The feature engagement strategy aimed to create a panel that was visually more consistent, by removing the natural feature within its machining approach. Figure 3 demonstrates the design and tool path generated for the removal of features. The generated design first identified and located the features, and secondly calculated the area by percentage to be removed. The intensity of additional holes could be specified in the digital workflow to increase the total percentage of open area to increase acoustic absorption performance.

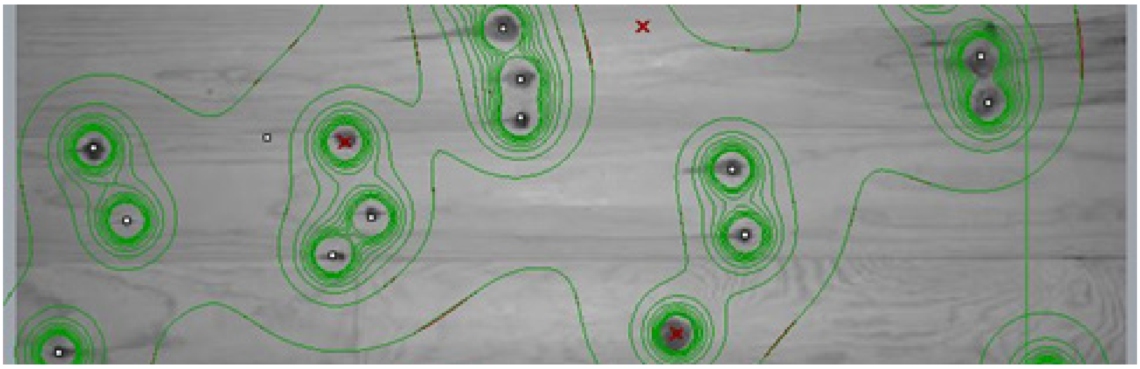

Figure 3. Feature recognition and associated CNC tool paths to remove natural features.

2.7 CNC setup

Panels were machined on a flatbed CNC router. The parametrically generated design drawings were converted to line based geometry and exported to V-carve to generate tool paths. Two machining strategies were employed, online cutting and pocketing. The tooling used was an 8mm compression spiral 2 flute endmill.

2.8 Digital workflow analysis

Individually, the parametric solutions were quantitatively and qualitatively analysed to justify manufacturing constraints such as efficiency, function and aesthetics for each architectural lining product. This analysis is depicted in Figure 4 and includes:

- The time it takes to machine the proposed solution with CNC machinery.
- The associated performance of the panel, i.e acoustic absorption.
- The overall composition and aesthetics of the generated design.

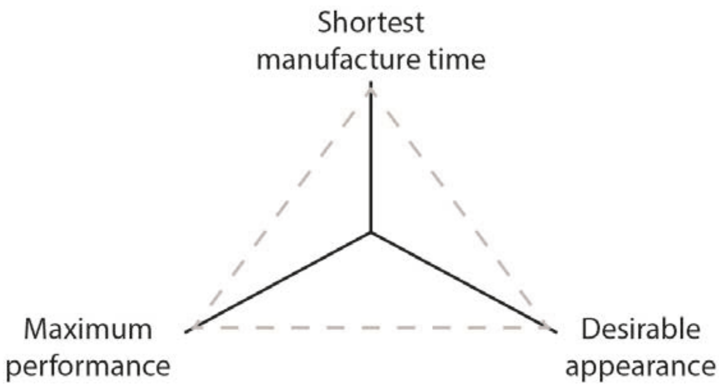

Figure 4. The visual analysis and depiction of the digital workflow.

This method of analysis helped reconcile the manufacturability, functionality and aesthetics of each product solution generated from the associated digital workflow. The time to manufacture was measured in hours, the maximum performance related to the open area of perforations by percentage machined into the timber panel and the desirable appearance was ranked by a score out of 3 (1 being poor, 2 acceptable and 3 exceptional). The time it took to manufacture a panel with the CNC router and the resulting open area were quantitatively measured whereas, the aesthetics of the panel were measured qualitatively. It is acknowledged that the score provided for the aesthetics is subjective to the user's preference in design style and intensity of natural timber features however for this study the scores were denoted by majority ranking from each of the authors.

3. RESULTS AND DISCUSSION

3.1 Nature of the product: acoustic panels

A series of digital workflow solutions were developed in this study for the low-value timber resource. The use of real timber stock images to develop CAD concepts allowed for rapid and unique material-aware decisions to be made in order to manufacture architectural timber lining products. The visual demonstration of a material-aware solutions displayed in CAD allowed the user to dictate and control whether or not timber features were removed or highlighted in the overall design. In addition, the user was able to control the overall design and appearance of the panel from the inclusion or exclusion of organic shapes and lines, the final CNC manufacturing process such as the appropriate tooling, depth of cut and the percentage of porosity for acoustic applications. The final product performance was not measured for acoustic absorption or validated in this study however they can be predicted through acoustic modelling, product characteristics and environmental data (this is beyond the scope of this study). Figure 5 demonstrates the designer's ability to manipulate the porosity of an acoustic absorption panel by open area. The features identified for removal in the original image (figure 3) are outlined with green circles as four per cent total area. In figure 5, each line represents a different tool path and its depth of cut to create an undulating surface. The user can further manipulate the CAD to CAM solution by increasing the desired open area. In this scenario, the original pattern does not change, rather additional tool paths are overlaid to increase the total area for removal.

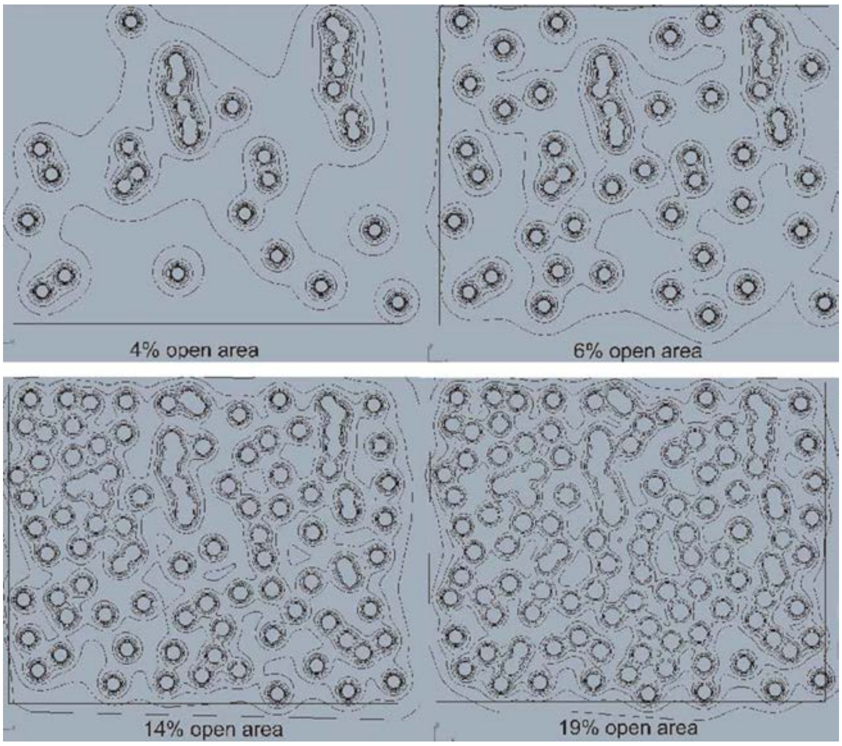

Figure 5. Acoustic panel with a variation in open area to remove natural timber features.

3.2 Product analysis

The designs shown in figure 5 were analysed and the data presented visually in figure 6. An increase in product performance directly impacted the total time to manufacture a single product. The overall appearance of the product was subjective to user perception, however maximum performance and therefore open area perforated into the panel did affect the desirable appearance of the panel. An open area below 10% had minimal design appeal but could be manufacture in the shortest time. By contrast, panels with up to 20% open area became clustered and over whelming. Figure 6 demonstrates the balance between time of manufacture, product performance and design appeal.

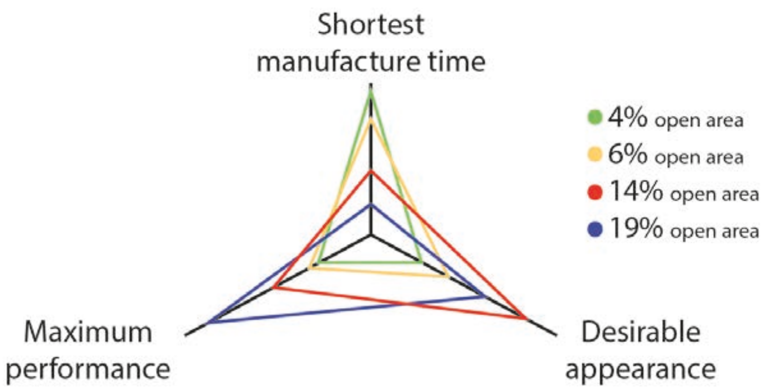

Figure 6. Analysis of digital workflow output.

The results in figure 7 showcase the development of feature avoidance and engagement of natural timber features, thus demonstrating innovative and rapid ways in which a low-value timber resource can be utilised to support the current market-pull and resource-push in Australian built environments. Figure 7 presents the final design outcomes and data analysis of each panel.

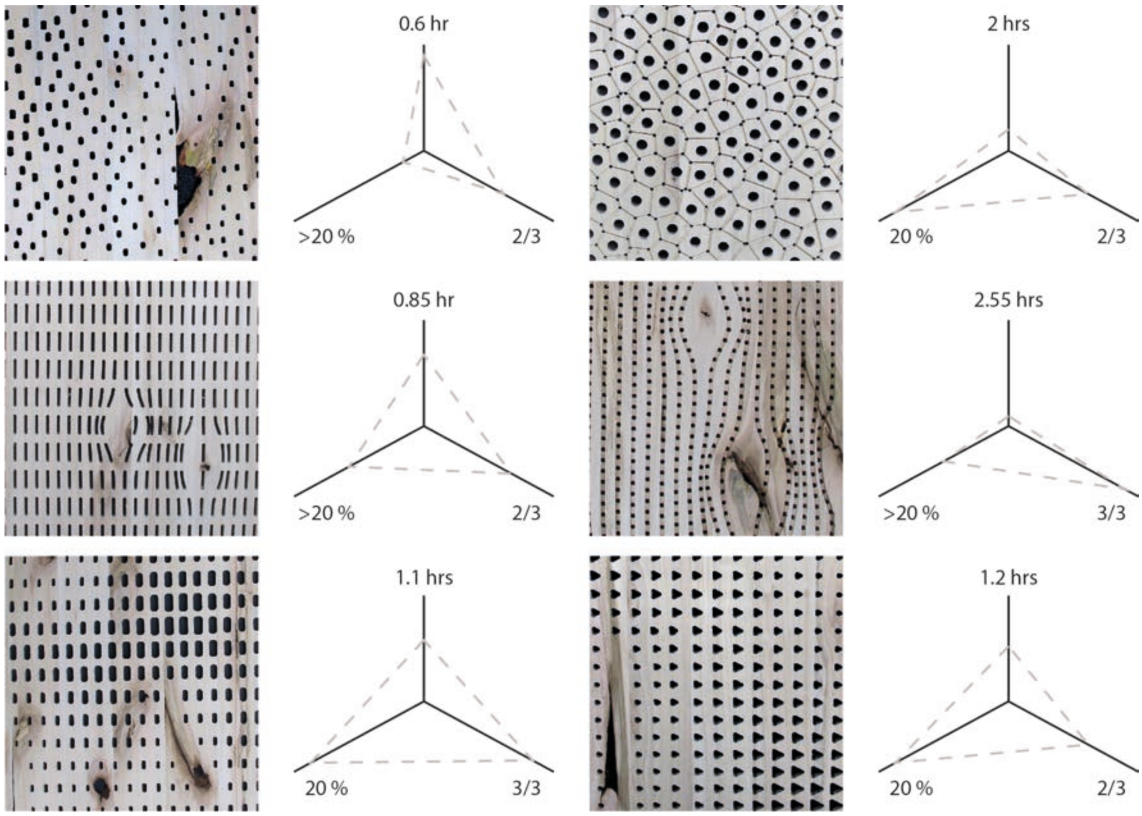

Figure 7. Final manufactured product and analysis of digital workflow output.

The scope of this study was to demonstrate the ability of Rhinoceros and Grasshopper to design acoustic panels from a set of parameters whilst adapting to a timber resource that is high in natural features. The limitation of set parameters to simply avoid or engage with natural timber features in a panel to produce value-added products with low-value materials was successful. The use of entry level photography, basic Rhinoceros and Grasshopper skills and a flatbed CNC router demonstrated an efficient way to handle a low-value material for product development in the built environment. The accuracy and ability to manufacture unique and application specific timber lining products from a high feature timber resource—that is unsuitable for most product markets—is an example of how digital workflows can showcase design innovation in the Australian timber industry.

3.3 Further research

Further research is needed to determine additional opportunities associated with an increase in defined parameters to develop acoustic panels that are machined at multiple layers, incorporate radii, champers, undercuts and compound joins. In addition, the unique nature of individual boards manufactured out of high feature timber would make it difficult to join panels along a large interior wall without having the panels look unrelated and visually compete against one another. There is an opportunity to develop feature and individual panel awareness for large scale fit outs to modulate the outcome. There is also an opportunity to develop efficient tooling parameters in the digital workflow to reduce the machining time of products.

4. CONCLUSION

This study demonstrated the use of parametric modelling to value add to timber high in natural feature to produce architectural acoustic panels. Digital workflows successfully generated rapid design and CAD solutions to avoid and engage with natural timber features in architectural panels. Three base parameters were used in this study to explore and demonstrate the flexibility of design solutions that could be generated through digital workflows. The parameters were the total time to manufacture a panel, the acoustic absorption performance of the panel (determined by an open area) and the overall aesthetics of the generated solution. Seven different designs were produced in this study and measured quantitatively and qualitatively to determine the best product outcome that could be generated with the parameters set in the digital workflow. A key result of this research was the use of a low-value material that is deemed unacceptable for use in contemporary markets due to its excessive features and the associated cost in design, handling and processing to develop a useful product. This streamlined process has demonstrated the rapid development of architectural products controlled by user defined parameters to value-add to a material constrained by naturally occurring features, thus rendering it useful for product development in the built environment.

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