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Edited by Kelly Greenop and Chris Landorf

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The Conference Convenors received a total of 44 abstracts. Abstracts underwent a double-blind peer review by two members of the Conference Organising Committee. Authors of accepted abstracts (32) were invited to submit a full paper. All submitted full papers (18) were again double-blind peer reviewed by two reviewers. Papers were matched as closely as possible to referees in a related field and with similar interests to the authors. Sixteen full papers were accepted for presentation at the conference and a further 6 papers were invited to present based on submitted abstracts and work-in-progress. Revised papers underwent a final post-conference review before notification of acceptance for publication in these conference proceedings.

Please note that papers displayed as abstracts only in the proceedings are currently being developed for submission to a digital cultural heritage special edition of an academic journal.

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Digital fabrication of parametrically generated Māori carvings

Abstract

Wood carving is one of the important carriers of indigenous culture. In New Zealand, Māori carving forms a distinctive part of its culture. Traditional carvings require skilful handicraft techniques and complex knowledge of carving patterns. The emerging technologies of digital fabrication can provide highly efficient fabrication solutions. This motivates us to intersect traditional indigenous wood carving in conjunction with computational instruments and methodologies. Our research focuses on underlying parametric systems to develop a rule-based algorithm that allows for the automatic generation of 'koru'-patterns for CNC and robotic supported fabrication. First, we study the topology and culture context of the carving. Next, we model parametrically the koru patterns according to the underlying logic of the patterns. In the forward-reverse translation process of form and algorithm, cultural heritage and digital realm, we intend to make the overall process more accessible and interpretable. After the digital modelling, digital fabrication is carried out using a CNC machine or single arm industrial robots. Our research proves the feasibility of a digital generation and fabrication process in the heritage realm of Māori wood-carvings. We end the paper with a discussion of how our methodology can be used to investigate the potential for indigenous development, cultural empowerment and innovation. A contemporary translation of cultural heritage into the current realm of digital technologies and possibilities has research potential that needs to be debated further.

Keywords: Māori carving; digital fabrication; indigenous parametric patterns; robotics; CNC

Introduction

Koru is a spiral shape based on the shape of a new unfurling silver fern symbolizing new life, growth, strength and peace (Royal 2009). The plant silver fern, also known as the *cyathea dealbata*, silver tree-fern, ponga or punga, is a species of medium-sized tree fern, endemic to New Zealand. It has been treated by Māori people as a god comes from the sea. It is a symbol commonly associated with the country both overseas and by New Zealanders themselves (Wilson 2017) (Figure 1, left).

The Māori wood carving forms a distinctive part of its indigenous culture. Skilful handicraft techniques, complex knowledge are some requirements for the traditional carvings. The high-efficient fabrication solutions provided by emerging technologies of digital fabrication motivates us to further develop the intersection of traditional indigenous design techniques, in this case wood carving, in conjunction with computational instruments and methodologies (Kawiti *et al.* 2016). Our research focuses in this study on the digital fabrication of koru patterns. First the topology and culture context of the carving is explored. Then we parametrically model the koru patterns according to the underlying logic of the patterns. After the digital modelling, digital fabrication is carried out using a CNC machine. We intend to prove the feasibility of a digital generation and fabrication process in the heritage realm of Māori wood-carvings. We believe the methodology can be used to investigate the potential for indigenous development, cultural empowerment and innovation (Kawiti and Gordine 2017). We acknowledge that it is not simple to translate a culturally rich artefact into a computational code that may lose its spiritual and cultural context. At this point however, we are interested in exploring the underlying geometrical descriptions of the patterns to be able to explore novel avenues, so then these descriptions can be applied in the right contextual settings.

Manual modelling and fabrication test

The test is meant to explore manual modelling and verify the capability of fabrication hardware. We generate the models manually according to a carving sample. The model is exhaustive enough to reflect all levels of details (Figure 1, middle). Then the model is transferred into a file that can be used by a CNC machine. According to our test result, the precision of the CNC machine has been proved capable enough to produce a high-quality artefact. We test that it is suitable to fabricate more sophisticated wood carvings. Then, if the manually-made model can be fabricated well, it should be the same as the situation of parametric modelled samples (Figure 1, right).

Figure 1. The silver fern plant (left), the manual modelling (centre) and the test outcome of the CNC machine (right). (Source: © Alkalyne/Getty Images)

The generation mechanics behind the spiral patterns

The koru patterns are formed by spiral curves. So, the methodology of generating the spiral curves is one of the key foci of this research. In this section, the generation mechanics behind the spiral curves are explained in detail. For the curve-creating, the basic idea is to locate the control points first and then link them to form the curves. After studying and testing, we have developed three 'rotate- and move algorithms', as well as 'evaluate- and point-cylindrical algorithms' to create point coordinates spirally in a parametric computational environment using

Grasshopper3D and *Rhinoceros3D* Software (Payne and Issa 2009).

The rotate and move algorithm is to use the basic 'Rotate' component and 'Move' component for spiral curve generation. By using the series component, arithmetic sequences can be created to set the translation vectors for defining the movements of an original point. After generating a column of points, then we can use the Rotate component to rotate them accordingly for spiral points. The key point of the 'evaluate algorithm' is the mathematical application of the modified sine and cosine formulae. In the context of point construction, we develop two different formulae for the 'Evaluate' component to define the values of X and Y coordinates.

Spiral curve generated by point cylindrical algorithm

After testing and evaluating the three algorithms, the point cylindrical algorithm is chosen for further research development. The reason is that using the 'Point Cylindrical' component makes the algorithm become the most concise one of the three (Figure 2). Theoretically, fewer components lead to quicker calculation speed to gain a result, which means the program runs faster. Another reason for choosing the algorithm is that the input and output parameters are easier to be dealt with, which means that we can control the pattern generation more easily. The main idea of the algorithm is to use the principles of point cylindrical and series. We use arithmetic sequences to define the regularly-increasing angle and radius of the points for their spiral coordinates generation. The synergistic effect of their combination can produce a group of cylindrical points.

When creating these points by the cylindrical component (point cylindrical), the four input parameters include plane defining cylindrical coordinate space, angles in radians for P(x, y) rotation, radius of cylinder and elevation of point. The only output is the cylindrical point coordinate. To set up the point cylindrical component, we have to use the series component to create the series of parameters. These parameters can be spaced according to the

{Step} value. The input parameters of it include the first number in the series, step size for each successive number and number of values in the series. To define the angle in radians for the points' rotation, we use one series component with the step input being the product of π and a controllable constant. For the radius of cylinder, we use another series component and share the same number of values with integers input. As the angle and radius increase regularly according to the two arithmetic sequences created by series components, the related spiral points' coordinates are generated.

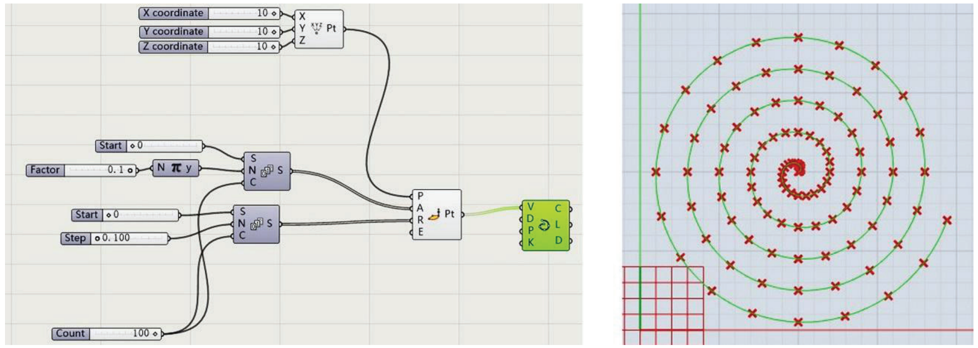

Figure 2. Screenshot of the script in Grasshopper3D (left) and the outcome of the point cylindrical algorithm (right). (Source: authors)

The unit modification

By studying the samples of the traditional hand-made carvings, we notice that the unit is formed by not only one curve but often two opposite spiral curves. The method of generating the unit is to use 'Move' and 'Rotate' components to do the proper movement of the original curve. So, we use the 'Rotate' component to rotate the original curve by 180 degrees. However, a gap can be found between the original curve and the rotated one, as their ends are not connected. And the further expression of the curves shows that it doesn't fit exactly with the samples. In order to improve it, we develop another algorithm module.

The main idea behind this is to extend the original spiral curve to fit our sample. This can also make the gap between the two curves become smaller by one unit. Though the gap between the original spiral curve and the new one becomes smaller, it can still be detected. To improve it further, a specific component is used to extract the end points of a curve. After inputting the curve to evaluate, its outputs can conclude the start and end points. Then we can use the 'start point' and its 'closest point' to create a vector between them. The vector is for moving the new generated curve to the proper position connected with the original one. Through this modification algorithm, the gap between the two curves can be eliminated significantly.

The interactions within pattern groups

For complex patterns, there are different relationships within the basic units. After categorization, the underlying logic can be summarized as linked, intersected and tangent relations. The main difficulties of developing such algorithms include the continuously changing radii of spiral curves and their unclear boundaries. In this section, we are explaining how we develop these algorithms and how the units react to their neighbours.

The linked relationship of spiral-patterns units

For the linked relationship, the main strategy is to generate a major unit first, then the left units are attached to it. To do this, a group of spiral-curve patterns has been created by duplicating the unit script modular we explained in the previous section (Figure 3). The distribution of them can be adjusted by altering the parameters of the start points' coordinates. Their orientations can also be modified by altering the parameters of the 'Series' components which related to the angles in radians in the 'Point Cylindrical' component. After adjusting, the units should be surrounded by the main one, and their ends are rotated to be orientated to it.

Then the 'curve closest point' components mentioned above are used to create another script modular to find the closest point on the major curves from the ends of the minor units. The 'end points' components are applied to locate the ends of each minor unit. After that, we can create the vectors from the ends to their closest points on the major unit. By using these vectors, the minor units can be moved to the target points on the major one. In the end, the linked relationship has been built up. To improve the patterns' overall expressions, the positions and orientations of the attached units can be adjusted minutely by re-defining the parameters of each modular.

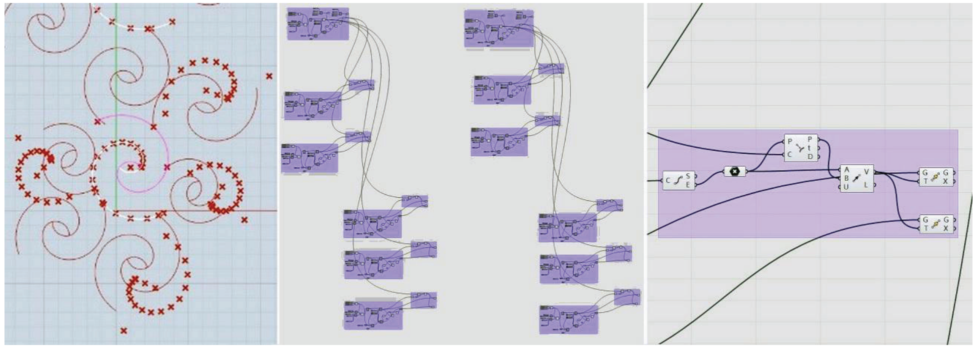

Figure 3. The linked relationship of spiral-pattern units showing an example of the outcome (left), groups of the script modular with different functions (centre) and the key script modular to make the minor units connect to the major curves (right). (Source: authors)

The intersected relationship of spiral-pattern units

In the creation of the intersected relationship of spiral-pattern units, the first step is similar to the operation in the linked relationship situation (Figure 4). A group of spiral-curve patterns has been created by duplicating the unit script modular. Their orientations can be modified by altering the start angles in radians in the 'Point Cylindrical' component. After the adjustment of the distributions and orientations accordingly, an intersection within units can be generated.

Considering the intersected relationship, our first reaction is to use the split commands to cut the curves. However, there is no suitable component to deal with the curves in this way. What is more difficult is how to make the overlapping spiral curves go on extending after being cut. So, we develop an algorithm for this. Our strategy is using the curves to create the meshes for splitting first; secondly, these meshes are used to cut the curves; at last, the segments we wanted are selected and preserved.

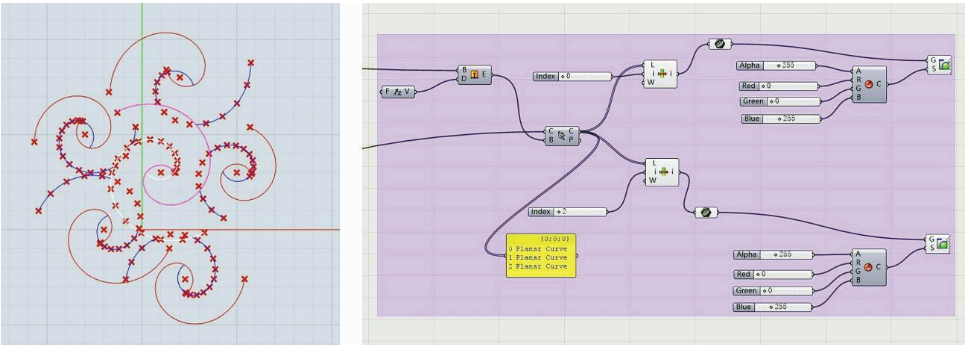

Figure 4. The linked relationship of spiral-pattern units showing an example of the outcome (left) and the key script modular to split the minor units and select the certain segments (right). (Source: authors).

The 'Extrude' component is applied to extrude curves along the setting vector in 'Z' direction. The component includes input parameters of the geometry and the vector. The geometry can be profile curve or surface. Here, it is linked to the major spiral curve patterns. Then the minor curves can be split by the previous extrusion result through the 'Split with Brep' component.

Though the curves have been split, the results are all mixed. So, we use the 'List Item' component to select certain segments and preserve them. The function of this component is to retrieve a specific item from a list. The split result is input to the component as the base list of generic data. After linking the integer slider to the input of item index, we can choose the wanted segments of the curves by changing the parameters of integers. That means certain items have been selected from the base list. All the unchosen curves can be eliminated (hidden) by cancelling the preview option of the components. We set the components group as a functional modular and use them for the object

curves. In the end, the intersected relationship of the spiral-pattern units can be built up.

The tangent relationship of spiral-pattern units

The strategy of the generation of the tangent relationship is to create a group of the units along the major spiral curves (Figure 5). Their distributions just need to be in the range of the certain area. Our script offers a variation to calculate the vectors of moving the minor spiral curves to the tangent positions automatically. In the creation of the tangent relationship of spiral-pattern units, the first step is nearly the same as operation in the linked relationship situation. After a group of spiral-curve patterns has been created by duplicating the unit script modular, their positions and orientations can be modified by altering the start angles in radians in the 'Point Cylindrical' component.

The complex algorithm of the vectors calculation works based on the application of auxiliary lines in geometry. As there are overlaps within the minor and the major curves, their intersection points can be used for creating the line. These points can be solved through the 'Curve Intersection' component. After creating a line between the two points using the 'Line' component, we can find the middle point on it. The 'Curve Closest Point' component is applied to locate the closest points on both curves from the middle point. By using the 'Move' component to create the movement on the vector generated through the two points, the spiral-pattern unit can be moved to the tangent position on the major curve.

Discussion

Through these algorithms, interactions such as 'linked', 'intersected' and 'tangent' relationships can be achieved. Using a combination of these script modules, a vast majority of situations of koru patterns can be generated. To simplify the modelling process, we have developed an algorithm of tangent pattern units. These algorithms have already shown their potential

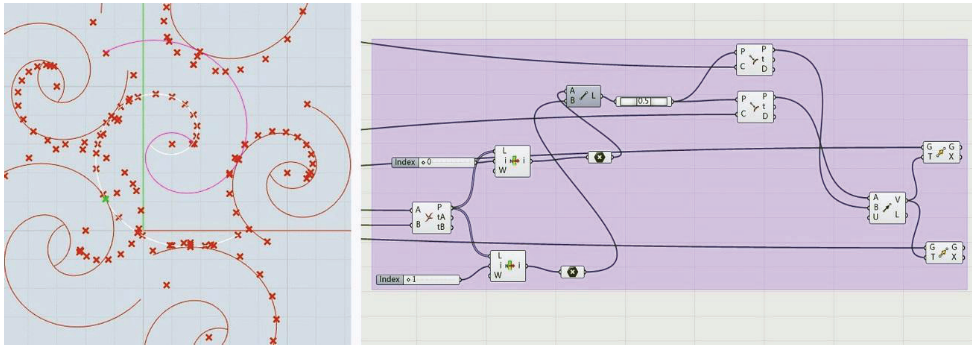

Figure 5. The tangent relationship of spiral-pattern units showing an example of the outcome (left) and the key script modular to calculate and move the minor units to the tangent position (left) (Source: authors).

in developing more complicated patterns. Besides, we also explored some additional algorithms such as the 'Arithmetic Sequence Array', 'Rectangular Array', to increase the pattern diversity.

The 3D-model generation and the fabrication

In this section, we mainly focus on explaining the algorithm that bridges the 2D patterns to 3D models, and how the modelling links to the fabrication process.

The generation of the 3D models

After studying the carving samples, we found that they can be categorized into two parts. One is the main body of the spiral geometry; another one is the affiliated ridges attached to the main body that fills the gaps within them. So, our strategy is to develop two algorithms for these two cases individually (Figure 6).

The main idea is to offset the spiral curve twice in different directions with the same distances. Then these curves are elevated to certain heights before using them as the boundaries to create the surfaces. The main inputs of the 'Offset' component include the curve to offset and the offset distance. Finally, we use the 'Ruled Surface' components to create the surfaces between the curves one by one. The component contains only two input parameters of the first and

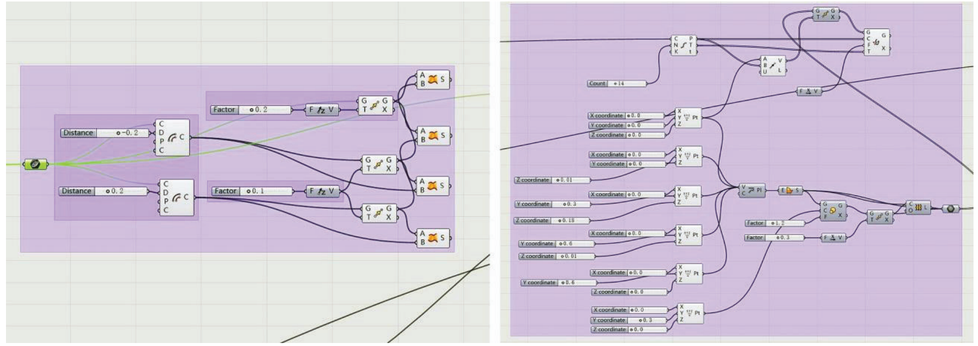

Figure 6. The algorithms behind the generation of 3D models. (Source: authors)

second curves, so we utilize these four for the main body generation.

To the affiliate ridges, the situation is intricate because of the ridges' complicated shape. The strategy is to create the ridge unit first, then use the common 'Move' and 'Rotate' components to make the array of them along the main body of the spiral curves. In the process of the generation of 3D models, the models sometimes need adjustment by modifying the parameters. Most modifications are the ratio of certain shapes. The advantage of parametric modelling makes the adjustment easy. But in some situations, assistant algorithms are developed to improve the final 3D models. Some modifications are necessary, especially considering the characters of the fabrication tools (Figure 7).

The fabrication

For the fabrication of the outcomes we used a Roland MDX-40A CNC machine. It is a versatile CNC mill that handles a wide variety of non-proprietary plastic and resin materials, including ABS, nylon, acrylic, chemical wood and tooling board. Everything from smooth art sculptures to high-precision parts and prototypes can be created with the machine, helping transform concepts into functional objects.

Figure 7. The 3D models of the patterns. (Source: authors)

Before using the machine, the models have to be transferred and exported in 'stl' format. Then the files can be uploaded to the operation interface on the computer that is linked to the CNC machine. A five-step workflow takes us through effortless milling, while speed, cursor and cutting tools offer further control. After setting all the parameters of the machine, the machine will calculate the fabricating route automatically by itself. Then we can place the prepared timber board on the base of the machine. After final checking and setting the local origin-coordinates on the centre of the board, we can begin with the fabrication. The whole process usually takes more than ten hours, which depends on the complexity of the models, required quality and accuracy, the hardness of the timber, as well as the size of the drilling head and the overall pattern (Figure 8).

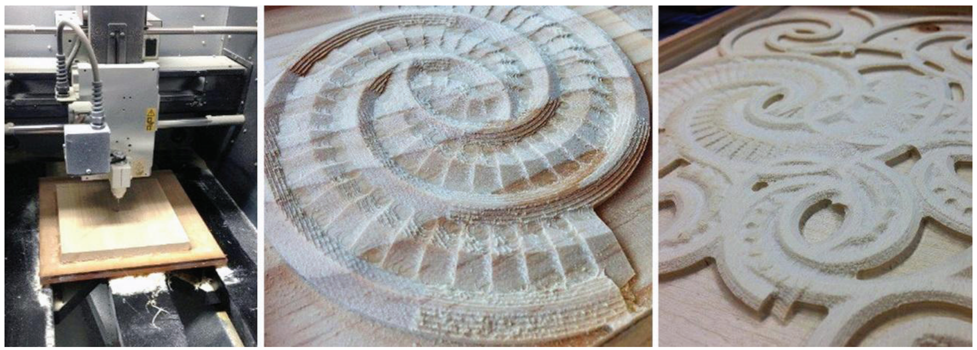

Figure 8. The digital fabrication using the CNC machine. (Source: authors)

Discussion and conclusion

Intersecting traditional indigenous wood carving in conjunction with computational instruments and methodologies, we can use the emerging technologies of digital fabrication to provide high-efficient fabrication solutions. In our research, we have studied a methodology of applying these evolving technologies in the context of heritage by developing a rule based algorithm of a parametric system that produces a koru pattern using CNC aided fabrication techniques. The research continues our explorations of a contemporary translation of cultural heritage into the current realm of digital technologies (Ballantyne *et al.* 2016; Kawiti *et al.* 2016). The conclusion of this study can be summarized as follows.

First, based on study of the topology and culture, we have developed the algorithms of Kuro pattern generation according to the underlying logic. The study of parametric modelling has included the generation of spiral curves, interaction within the pattern units and the transformation of 2D-3D modelling. By using our computerized interpretation of the pattern, we are able to offer current interpretations and variations to expressions of the koru.

Second, our study has made the overall forward-reverse translation process of form and algorithm, cultural heritage and digital realm become more accessible and interpretable. The feasibility of a digital generation and fabrication process in the heritage realm of Māori wood-carvings has been proved.

Third, our study has proved the integrated development of parametrical modelling and digital fabrication can be achieved through the methodology we developed. The methodology can be used to investigate the potential for indigenous development, cultural empowerment and innovation (Sass 2007). Koru patterns in the Māori cultural context come in many varieties and interpretations. The here presented research is only a starting point from which individual variations and interpretations can easily be generated to match the spiritual and cultural heritage context.

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