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TRANSFER OF DESIGN TECHNIQUES FOR THE DEVELOPMENT OF COMPLEX NATURAL FORMS IN STEEL – A CASE STUDY

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1. Introduction

The introduction of an industrial design graduate into a steel fabrication and engineering company in Gloucestershire, UK, not only brought fresh ideas for new products but also new design methodologies to improve product development. In particular the introduction of design visualisation CAD packages by the graduate has allowed the company to develop new products in a way that standard 2D and 3D drafting software could not. This paper discusses how the use of surface-modelling CAD software, usually intended for film and graphical applications, was harnessed to provide an innovative and cost-effective way to visualise and develop steel tree-masts. The paper will also highlight how the successful integration of methodologies from a variety of design disciplines can raise awareness of the benefits of this approach.

The exercise documented in this paper is the result of an industry-academic collaboration afforded through the Knowledge Transfer Programme (KTP) which is sponsored by the Department of Trade and Industry in the UK [DTI, 2005]. The scheme allows the creation of a graduate position in a company to develop new capabilities and processes under the supervision and guidance of a specialist department within a University. In this case The National Centre for Product Design & Development Research (PDR) at the University of Wales Institute, Cardiff (UWIC) developed a two year work plan with FLI to develop new design capabilities and diversify into new markets with new products.

2. Background

The UK telecommunications market is considered to be the most competitive and open in the world [Rothschild 1999]. The Universal Mobile Telecommunications System UMTS (or third generation 3G) mobile communication licenses granted by the British government through auction in 2000 generated £22.48 Billion [Byers 2000]. This vast investment was not only a commitment of capital, but also an obligation on each operator to provide network coverage to 80% of the UK population by 2007 [Hewitt 1999]. To meet these obligations and capture new customers ahead of their competition there was a great driving force for operators to expand their networks quickly into more remote areas such as national parks, conservation areas and Areas of Outstanding Natural Beauty.

These locations had been avoided in the past due to public opposition to the towers resulting from their visually intrusive appearance (Figure 1a) and perceived public health issues [Stewart 2000]. To target these ‘sensitive areas’, in 2000, Francis & Lewis International (FLI) began development of a monopole tower disguised as a Cypress tree (Figure 1b).

The environmentally sympathetic appearance of this product gave the phone operators greater ability to negotiate with local council planning authorities over these sensitive sites, enabling them to expand their network competitively and fulfil their license obligations. But the FLI Cypress Tree is not suitable for all locations. Cypress trees rarely grow to heights of more than 20 metres and often the operators demand greater heights to extend coverage to larger areas. Also, Cypress trees are not native to the UK [Aas & Riedmiller, 1994], and so they can look out of place when surrounded by native woodland. There was a need for an alternative tree tower to be developed, a tower simulating an indigenous species of tree and fulfilling tougher technical specifications from mobile phone operators.

Figure 1a & 1b. Standard mobile phone tower and the FLI Cypress tree tower

3. Development of FLI pine tree tower

3.1 The challenge

Once the need for an alternative tree tower was recognised, the design team at FLI set about identifying a suitable indigenous tree which could support mobile phone antennae up to 35metres high. An evergreen, and ideally coniferous tree was essential as a durable man-made tree cannot change with the seasons. FLI decided to produce a pine tree: specifically a variety which would appear similar to a Scot's Pine or a Maritime Pine, both of which are native to the British Isles. These species were chosen for their naturally sparse foliage because a heavily foliated tree would not be an economic solution to the operators. However this sparseness creates design difficulties for a pine tree, relative to a cypress. As the foliage density is reduced, the realism becomes harder to achieve. Standardised branch configurations, a perfectly cylindrical trunk, and up to six 2.5metre tall mounted antennae can look very artificial, even from a distance, because the tree's silhouette clearly displays an unnatural degree of symmetry and uniformity. With dense foliage, the silhouette can be easily disguised, but where there is sparse foliage careful attention must be paid to the branch positions and sizes so that an effective illusion is created. The foliage density therefore became critical. A balance was needed between minimising foliage for economic and engineering reasons against optimising the realism of the tree structure.

3.2 The engineer's approach

Before the arrival of the industrial design graduate, the engineers at FLI were limited to structural drafting software which lacked the facility to accurately model the foliage and therefore could not produce a realistic model of a tree, see Figure 2a & 2b. Standard structural detailing software is focussed on the joints and alignments between structural elements. In addition, this software is based on templates and macros which the standardisation of most structural materials and fabrication methods require. Most structural models can be built without creating any parts which involve complex geometry. Unusual products like imitation trees which involve complex geometries and a combination of materials are very time-consuming to model and nearly impossible to realistically view in this type of software.

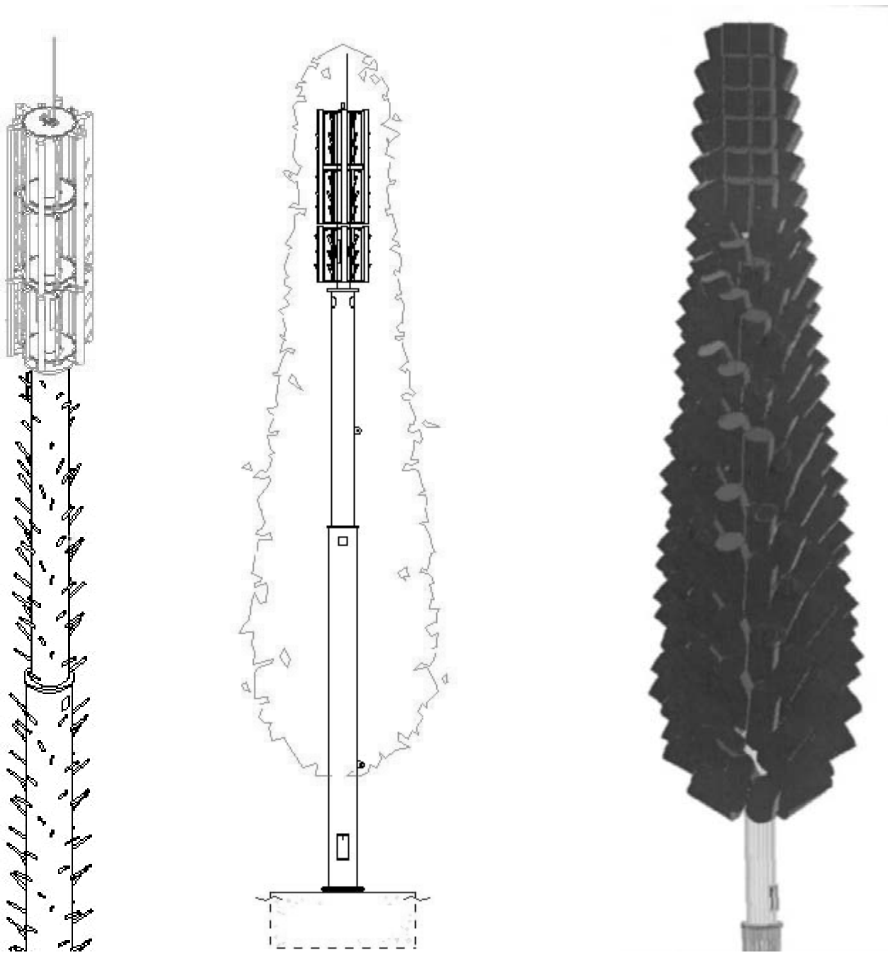

Figure 2a, 2b & 2c. Structural CAD simulations of Cypress tree tower

Foliage design development therefore relied on prototyping which was an expensive, slow, and risky way to evaluate new ideas. Early issues with insufficient randomness in Cypress Tree branches could only be appreciated after the production of several expensive prototypes. FLI attempted to visualise the Cypress Tree within their drafting software (Figure 2c) but lacked the necessary skills and software to achieve a successful result. A method of realistically visualising these designs before fabrication would inevitably avoid future issues and excess expense with the development of the Pine tree tower.

3.3 The industrial design approach

FLI required a programme which could produce a visual representation of a complex form, whilst still being driven by familiar steelwork fabrication constraints and standardised elements. The industrial design graduate had experience of photo-realistic modelling software and was confident of transferring this technology to this large structure application. In creative CAD programs, such as those used for film animations, connection details can be neglected because the software is geared towards the overall visual image rather than finalised fabrication drawings. This extra flexibility enables complex structural forms to be modelled very quickly and edited with creative ease. Of the various surface-modelling creative CAD packages available, Cinema4D [Maxon, 2005] was chosen for its combination of simple and flexible hierarchical control (essential for large assemblies) and fast, high-quality rendering.

The compromise between realism and cost created many design challenges including the decision whether or not to produce a new injection moulding tool to replicate typical pine foliage. A decision was taken to use the original Cypress tree foliage (Figure 3) for the Pine Tree to save time and money on tooling due to the fact that the distance from which these trees will be seen, differences between the foliage of various tree species cannot be distinguished easily. The foliage moulding which was developed specifically for the Cypress Tree is essentially flat, but with relief along the stems and needles.

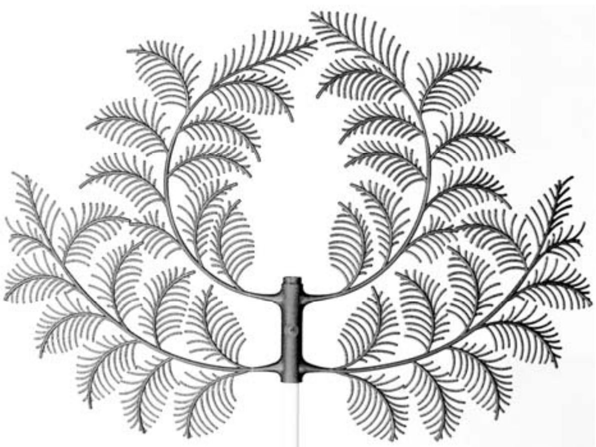

Figure 3. Cypress tree tower injection moulded foliage

3.4 Replicating natural form

The fractal form of tree growth results in tremendously detailed and complex geometry. Simplification of this geometry is relatively easy in two dimensions, but very hard to achieve in 3D. Accurate reproduction of the geometry for one instance of this moulding would be difficult for a typical desktop computer to calculate. For the several thousand such mouldings which compose a complete tree, a vast amount of random access memory would be required to calculate the 3D geometry for the foliage. To be feasible, a neat method of simplification was required that would allow flexible editing without sacrificing the necessary realism of the model.

The solution was to use alpha mapping to create the illusion of a three dimensional form without producing real geometry. All modern creative CAD programs allow transparent textures to be mapped onto geometry to control the light which is reflected off this geometry. A photograph of the Cypress tree moulding was applied as an alpha channel to simple planes in the 3D model, each representing the position, size and orientation of a moulding. The alpha channel determines the transparency of the texture based on the colour of the template image. This effectively masks the light which will reflect off each of the planes. By setting the alpha channel to white, light only reflects off the areas of each plane which are mapped by the dark areas (the silhouette) of the photograph. This has the effect of transforming the simple planes into mouldings complete with their needles and stems, creating the illusion of much greater geometry (Figure 4a & 4b). Without this technique, it would not have been possible to produce a realistic model of the FLI Pine Tree using this type of foliage.

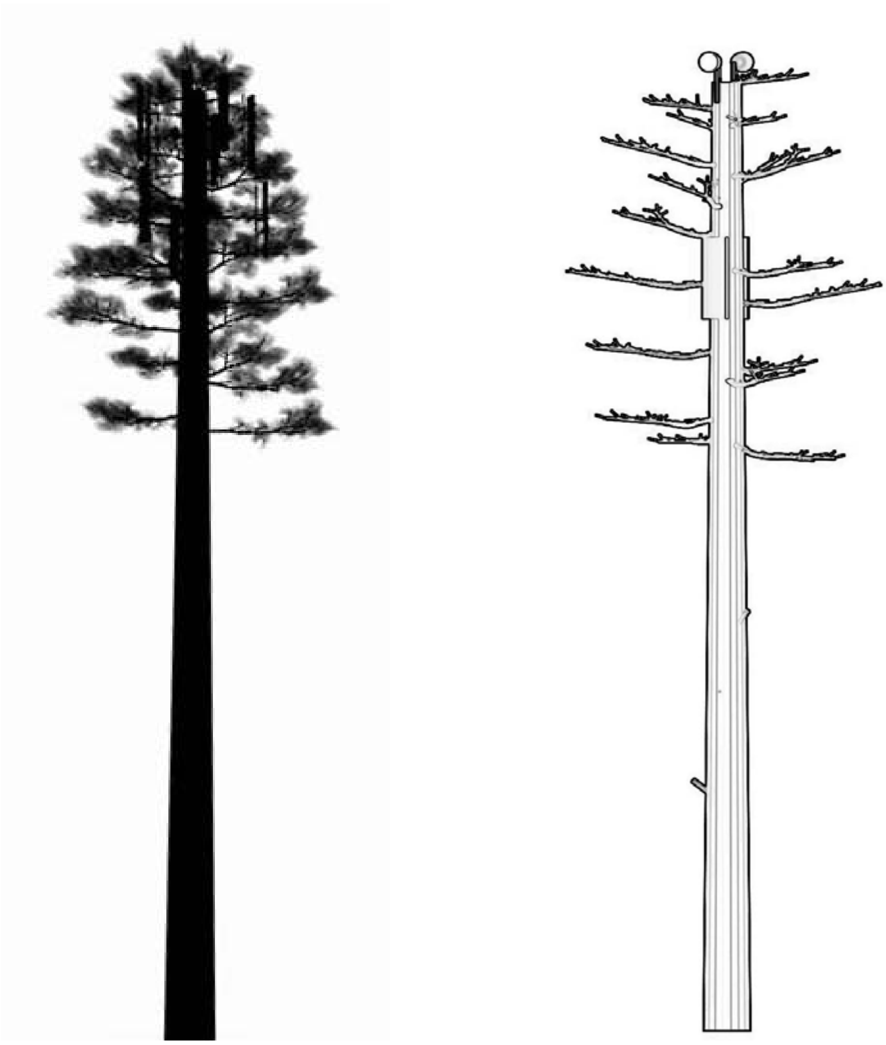

Figure 4a & 4b. Cinema 4D images of pine tree tower with and without foliage

The design method afforded by the industrial design graduate also allowed the possibility of photo realistic renderings to be produced for customers to submit to planning authorities (Figure 5). This added value design service communicates a level of professional ability not usually offered by the steel fabricators.

4. Implementation

Initially the company were sceptical. A program which allows elements to clash, which requires no precise alignment or measurement and is advertised as a tool for animating cartoon charaters appeared to be little more than a novelty to a market leader in steel tower construction.

Figure 5. Photo-realistic rendering of Pine tree tower (tallest tree)

Figure 6. Comparison of C4D model and photo of the first 15m Pine Tree

The graduate confronted the issue as an industrial designer, seeking to visualise the whole product at an early stage of development. Most tower structures are not visually-critical: they can be designed based on calculations and then detailed using standard elements. An overall view is not necessary until the final assembly on site. As a result, the company were unsure of the benefits of this industrial design approach. However their experience with the Cypress Tress allowed them to see the potential in the tool if it could create a sufficiently realistic model.

The first 15m Pine Tree, erected in May 2005, illustrated the effectiveness of this approach. FLI were very surprised at how closely the finished product matched the CAD rendering (figure 6). Some changes were made in fabrication to the angles at which branches were mounted but the density of foliage in the renderings proved to be surprisingly accurate. Following this job, FLI discovered that a complete General Assembly (GA) drawing was not necessary for the fabrication of Pine Trees. Further, it was found that the CAD visualisation software could actually be used to generate a matrix of branch parameters, the blueprint of each tree, whilst retaining the flexibility and realism of the model. This discovery has sinced been used to save weeks in the development of further Pine Tree variants.

5. Conclusion

The creation of a flexible and realistic CAD model was a transformation in the way products could be developed at FLI. The new process allowed the company to resolve aesthetic issues at an early and inexpensive stage of the process. It justified the need to try different design methods and has encouraged the company to test other cross-disciplinary ideas. Recognising the benefits of CAD visualisation, the company has since integrated this new facility into the standard development sequence for new structures and has already located ways to exploit its potential in other new markets.

For FLI the greatest benefit has been in enhancing the certainty of results. Engineers are accustomed to designing structures to have predictable behaviours and capacities. It is therefore no surprise that the engineers were keen to adopt a means of visualising the final product which provides equal certain in the visual aspects. The confidence that this method of development creates also serves to help the company management who can benefit from a greater understanding of the project and appreciation of the options available.

The decision to recruit an industrial design graduate to be integrated into the existing engineering team was a risk for the company because of the potential for conflicts in design practice and methodology. But the management recognised the need to bring new skills to add value and to open new markets and opportunities.

This exercise highlights the need for businesses who wish to enter new markets and create new opportunities should seek a wider perspective on design. Introducing a new design culture in a medium sized manufacturing business can be difficult for all involved but once the benefits of the new skills are realised can professional barriers come down and business prosper.

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