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CAD/CAM and Jewellery Design Education

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Abstract

The paper analyses pedagogical methods for incorporating computer aided design and manufacture into higher education jewellery design based on surveying five European universities: Birmingham City University (UK) Loughborough University (UK), Polytechnic of Milan (I), Kolding Design School (DK), Eindhoven University of Technology (NL). It seeks to identify strengths and weaknesses in contemporary teaching practices; highlighting innovative methods that nurture design problem solving, technical competence, exploration of new materials and dynamic form generation. Investigations concern possible teaching strategies for instructing students in the use of Computer Aided Design (CAD), through software such as Rhino3D, JewelCAD, Illustrator and Maya. Alongside modes of teaching Computer Aided Manufacture (CAM) including subtractive and additive technologies such as 3D Printing and CNC milling, alongside planar production through laser cutting and digital photo-etching.

Introduction

This paper aims to investigate pedagogical methods for incorporating computer aided design and manufacture (CAD/CAM) into higher education jewellery design. In so doing, it seeks to identify strengths and weaknesses in contemporary teaching practices; highlighting innovative methods that nurture design problem-solving skills, engender technical competence, and encourage the exploration of new materials and dynamic form generation. The research is based on surveys of staff teaching jewellery at five European institutions: Birmingham City University (UK) Loughborough University (UK), Polytechnic of Milan (I), Kolding Design School (DK), Eindhoven University of Technology of (NL).

Academic studies into pedagogical methods for the discipline of Computer Aided Design (CAD) cover UK A levels (16-18 years old) through to university education and tend to focus on Design and Technology and Product Design. Studies within the European educational system have dealt with issues concerning the 'transfer of generic CAD skills between school and undergraduate level at university' (Hodgson and Allsop 2003:45) in the Industrial Design and Technology programme at Loughborough University to a comparative study by the Teaching Innovation Group at ETSI Universidad Polytechnic of Madrid, (Lantada 2010).

In contrast, research that investigates CAD in higher education jewellery teaching is relatively limited, or remains oriented towards Design and Technology. Given the increasing adoption of digital technologies for jewellery design and production, this may be considered somewhat anomalous; and reveals an oversight this paper seeks to address.

The Development of CAD / CAM

CAD/CAM technologies first emerged at the Massachusetts Institute of Technology (MIT) in 1969 USA; including Sketchpad created by Ivan Sutherland. This prompted the definition of Computer Aided Design (CAD) as "the use of computer systems to assist in the creation, modification, analysis or optimization of a design" in order to increase the productivity of designer, improve the quality of design, shorten the designing process, improve the communication of the design idea and to create information for manufacturing (Groover and Zimmers 1984) us attempts to commercialise 3D modelling programs followed, such as SDRC, Computer Vision and M&S Company (Bordegoni and Rizzi 2011). However, their software was considered highly specialised and not broadly disseminated or adopted.

The 1980s witnessed the introduction of NURBS to define virtual 3D forms by effectively skinning a linear skeleton, which could itself be manipulated via control points. In 1982 Autodesk released CAD programs for IBM personal computers, with early adopters centred on design and engineering. 3D modelling software gained increased traction in the 1990s with the development of programmes such as ACIS, Parasolids, SolidWorks and Solid Edge.

CAD / CAM in Jewellery

In 1991 some of the first attempts to exploit CAD technologies for jewellery production resulted in the manufacture of rings (Kai and Gay 1991). Whilst CAD software such as Maya, Solidworks, AutoCad and Rhino3D have now become defuse, jewellery specific programmes were created including RhinoJewel, JewelCAD, ArtCAM JewelSmith and Matrix3D.

Recent developments include parametric modelling that permit form generation based on algorithms; thereby increasing means of producing design solutions in jewellery. For instance, Grasshopper is a graphical algorithm editor that operates within Rhino3D and consents the generation of complex geometries through mathematical algorithms. Variations of chosen characteristics can be manipulated intuitively through graphic sliders. This permits multiple iterations to be produced from a single Grasshopper definition. The creation of the definition is synonymous with permitting users to create their own modelling tools, rather than employing standard digital toolsets. Therefore, it constitutes a new and compelling direction for CAD driven jewellery design. The potential modelling power is confirmed by jeweller, lecturer and proponent of generative jewellery design Andres Gonzalez. Since the emergence of Grasshopper he can now ask his students, "do you learn how to use commands, or, do you learn how to make them?" (Gonzalez 2012: 27.15'). The possibility of creating tools extends the design language and offers users greater flexibility in form generation than previous possibilities within CAD software.

The use of CAD can now play an important role in jewellery design and goldsmithing. While it may increase the quality of design idea representation, it can also provide feedback on the feasibility of production through geometric analyses that reveal surface errors. CAD software can also expand possibilities for form generation and therefore make acquisition of its skills an imperative for many students.

Once form is developed virtually, manufacture can be swift through one of the two kinds of CAM systems: Subtractive Prototyping in which Computer Numerically Controlled (CNC) machining carves away unwanted material from a block to reveal the desired form and Additive Prototyping based on 3D printing. In the latter, layers of material are sequentially fused or sintered to solidify the required geometry from a liquid or powdered material. Both systems are commonly used in jewellery production for prototyping, mould making, casting, and the direct manufacture of the final product.

Digital manufacturing technologies can effectively permit jewellery design students to build prototypes within hours of completing models in the virtual realm. Whilst this can reduce the time and cost of realising design ideas, it may accordingly minimise students' opportunities to improve their hand skills whilst making physical models. Perhaps more tellingly, it may diminish the sensibility students have for physicality. Indeed, Matt Coleman observes how "good designers have a good intuition for the physical thing, and CAD can't replace that intuition" (Brown 2009:61). This ethos ascribes value to the craft of hand production in designing jewellery. Atkinson et al. (2008) question whether the new design and production techniques have sufficient 'craft' characteristics to reflect 'personal meanings'.

Nascent digital solutions endeavour to bridge the haptic divide. For example, haptic devices by companies such as Phantom enable the designer to touch and manipulate virtual models with sensory feedback similar to that experienced when shaping a physical model. This technology may therefore offer a balanced means of harnessing CAD without discarding possibilities for learning that depend on making by hand.

While the use of CAD technology reduces the time span and number of phases in the design process by creating digital models, CAM turns these models into physical objects that can be produced by machines in mass production. Each technology brings considerable benefits to the jeweller and naturally this is appreciated by jewellery educators and students.

CAD/CAM in Teaching Curricula

With the emergence and increased use of digital technologies in both artistic and industrial jewellery the desire to incorporate CAD/CAM into teaching curricula has inevitably accelerated. In England, for example, CAD /CAM was introduced in the National Curriculum for Secondary schools for Design Technology in 2000 (Fullwood 2002).

The subject of Jewellery Design is now taught at A level, Bachelor (BA) and Masters of Art (MA) in the majority of European universities. Although the terminology that defines the programme can vary from Silversmithing & Jewellery to Jewellery Design & Related Products, most Undergraduate or Masters Programmes consider the integration of CAD/CAM necessary to prepare students for professional practice.

Survey Participants

In defining what best practice might be for teaching CAD/CAM, the paper first explores the historical uptake of CAD/CAM in each of the five sampled institutions. Namely: the Polytechnic of Milan, Fashion Department; Birmingham City University, School of Jewellery; Eindhoven University of Technology, Industrial Design Department; Kolding Design School and Loughborough University, School of Arts English and Drama. Thereafter, it analyses the results of a survey with staff teaching CAD in the aforementioned higher education centres.

Loughborough University has had a Silversmithing & Jewellery BA programme since the 1970s. This was merged in 2006 with Studio Ceramics and Furniture into the hybrid programme 3D Design New Practice. 3DDNP students are introduced to Illustrator as a starting point in Year 1 of the BA. Subsequently, they attend introductory workshops on CAD/CAM to explore equipment including a 3D Printer, 5 Axis milling machine and laser cutter. Year 2 workshops introduce Maya and are delivered by technical teachers who are not necessarily experts in jewellery. This reveals a split analogue/teaching strategy with division between software experts and practical teachers knowledgeable in the design and making of jewellery.

Whilst studio based modules encourage innovation and experimentation with innovative materials and technology though the Intended Learning Outcomes, the incorporation of CAD/CAM is not compulsory. This gives students the freedom to explore through handicraft, but may well leave some underprepared for professional practice. At MA level, Jewellery students undertaking the MA in Art and Design Studio Practice work on a personalised Project Proposal. This optionally includes CAD/CAM through Maya and Rhino, when relevant to the project aims.

Links to industry is a foundation of Kolding Design School's philosophy, with a view to increasing employability. In contrast to Loughborough University the teaching of CAD is embedded in the teaching of jewellery, as in the BA in Accessory commenced in October 2014. In the second semester of their first year, BA students are asked to become familiar with 3D printing and Rhino software through the Wearables module, by designing a piece of jewellery in response to a selected object from the permanent collection at the National Museum of Denmark in Copenhagen. Part of the module required attendance of an intensive week long Rhino workshop to learn basic tool sets and virtual modelling skills. After one week, all are expected to master the necessary basic tools to design a simple object such as a memory stick.

The Polytechnic of Milan (POLIMI) offers a 3 year Bachelor Degree in Fashion Design and a 2 year Master of Science in Design for Fashion System that focuses on 'system' design as a whole. In semester two of the third year BA, students have a Digital Representation course that aims to teach the basics of digital modelling and three-dimensional digital representation. The course is divided into two stages of learning; the first focuses on the construction of the virtual model, whereas the second examines techniques of representation by rendering materials through Maya's Mental Ray.

At MA level there are more specialised courses: including Digital Modelling for Fashion, Reverse Modelling, 3D CAD, Virtual Prototyping and Generative Design. In the second year the Accessory Design Studio course is dedicated to fashion accessories, including jewellery. Students are required by the professional designers who lead the course to design and implement a prototype for each theme. Students often use 3D modelling and Rapid Prototyping to visualise their ideas and to create intricate models swiftly.

POLIMI often involves professional companies and designers within their teaching activities to confront students with the reality of design beyond academia. One pertinent collaboration involved a Precious Plastic Workshop where students were asked to design jewellery for Kartell and Bijouets by 3D printing plastics.

Jewellery is taught at BA level within the department of Industrial Design at Eindhoven University of Technology. The main focus is on jewellery as a cultural carrier. CAD/CAM facilities are provided to permit students to acquire digital design skills. Instruction in CAD (mainly Solidworks and Rhino) is taught through dedicated courses or learnt in extra-curricular workshops. CAM facilities like 3D printers and laser cutters are available in-house, and this provides students with the possibility of having digital geometry manufactured quickly.

The School of Jewellery at Birmingham City University runs multiple courses at undergraduate and postgraduate levels. During the BA in Jewellery Design and Related Products students are introduced to various CAD software through group sessions taught in a computer suite. Subsequently, any keen students are encouraged to incorporate CAD into their design practice, but further study is not obligatory. However, students may perceive the free supply of Laser cutting services and access to jewellery specific 3D Printing technologies and generic 3D printers as an incentive to pursue digital design.

The Jewellery and Silversmithing – Design for Industry BA is one year conversion course for those with a HND in jewellery or equivalent qualification. Whilst the latter focuses on hand skills the former introduces CAD in group workshops with one to one mentoring available thereafter. All students are expected to acquire a basic knowledge and understanding of CAD, with an expectation of enhanced skills where individual projects demand.

Online Survey

The six aforementioned European universities were requested to respond to an online survey, which consented international respondents autonomous and flexible means of participation. A total of seventeen participants responded to twenty-four questions (twenty-two open-ended questions that sought quantitative data and two closed questions).

The first five questions sought to garner details about the respondent's teaching experience, institution and the level and number of students. The remaining questions sought technical responses in relation to methods for teaching CAD programs, availability of CAM in the respective institutions, and the perceived advantages and disadvantages for students in learning and using CAD/CAM. Qualitative questions were employed to trace the evolution of teaching CAD/CAM. The questions also sought to elicit feedback on classroom experiences.

Survey Results

The profile of survey respondents identified teaching service ranging from two to thirty four years in length. Most acknowledge that CAD/CAM is now an integral part of the jewellery industry and therefore future jeweller designers and makers will need to know how to exploit these technologies.

Student cohorts ran from 12 to 150 students at BA level; a spread accounted for by differences in target numbers, physical space and fee structures. Each university adopts a similar approach to supporting students learning CAD/CAM, based on a mix of online tutorials and access to skilled technical tutors. Therefore, student numbers appear to have limited effect on the kind of support system available. This might be as expected in relation to online tutorials given the relatively fixed cost input of time and energy to set up resources irrespective of end-user numbers and length of use (allowing for revisions due to software updates). Yet, the extent of demand for direct access to technical skilled tutors is proportionate to student numbers. The greater the student cohort the more tutors are required. If this need is being met then it is evident that institutions believe best practice is to provide adequate contact support; which perhaps confirms the efficacy of having staff who can respond to specific, rather than generic learning requirements.

Notwithstanding the varying foci of the jewellery courses taught, from Design to Industrial Manufacture, the presence of a prior design phase was a consistent element, and accordingly the vast majority of teachers had assisted in the delivery of CAD teaching. To facilitate digital design, commonalities in software usage exist through the shared use of Adobe Illustrator to create vector paths for eventual laser cutting and the predominant use of Rhino3D as the CAD modelling software of choice.

Through the survey it was also possible to establish the percentage of practical teaching relative to theoretical delivery, with no course offering less than 50 percent practice. This consequently underlines the need for Computer Aided Manufacture to be available to students to transition digital geometry into real world objects.

Student access to CAM is facilitated through RP machines, laser cutters, multi axis milling machines. The percentages of students having direct on site access is as follows: 72.7 per cent Laser Cutter, 45.5 per cent Multi-Axis Milling Machine and 9.1 per cent Water Jet Cutting. Despite the existence of online bureaus, the relatively low cost of machines and the ample usage in institutions makes them a viable addition to workshop facilities.

Methods for Teaching CAD/CAM

With regards to the methods employed to teach CAD/CAM commonalities exist through the use of video tutorials, pictorial explanations and direct teaching in IT labs. The subject is often introduced in the first year of the BA programme either in the first or second semester. Some of the surveyed teachers argue this may be too early and in contrast it might be preferable to "first gain inside in more conventional techniques (sketching, manual production)."

The majority of teachers (58 per cent) confirm that their students undertake a module specifically dedicated to the application of CAD/CAM technology. This can be seen as an active integration of CAD/CAM into curricula, especially once this activity becomes assessed by teaching staff. Again, the majority of teachers affirm the desirability of introducing CAD/CAM in modules where the production of multiples is involved; it being naturally adept at replication.

Another factor in the successful transmission of CAD/CAM skills relies on teachers setting suitable project briefs that can complement modes of digital design and production. As one respondent noted "the most interesting projects are those that explore new possibilities that are related to the digital nature of CAD-CAM, e.g. personalisation, sharing, manipulation and mass-customisation."

Perceived disadvantages of teaching CAD/CAM and associated solutions

When answering questions about the potential disadvantages of teaching CAD/CAM, concerns were raised by those questioned because students may assume that the "kit allows minimal investment of time" and that the "computer solves their design problems". Therefore a successful teaching strategy should manage expectations and instil in students an understanding that CAD/CAM is not a substitute for design thinking, intellectual rigour and effort. Attention needs to be given to the transmission of digital technical skills, just as much as in hand production.

The survey also records the pitfalls of focusing too much on CAD/CAM because students may "become practitioners unable to use traditional 2 and 3D skills that may be more appropriate to their practice." As another respondent observes, CAD software can provide "an excellent perception of proportion, but not of the actual size of an object". An assertion further supported by a cautioning statement on using CAD "as a design process up until the final outcome is realised can be problematic. Issues such as scale, build time and appropriate build material/method must also be considered fully, as must the design of support structures, etc." Other respondents lamented the potential reduction in "hand drawing" and noted how "practical skills decrease". This may also be associated with a haptic reduction due to "losing tactile parts of the making stage".

In response to these concerns one might argue the best jewellery toolset would entail a combination of digital and analogue. Indeed, several respondents highlighted strong professional use of CAD/CAM as exemplars for students; citing the jewellery produced by Carrie Dickens and Willem Horsten's Hirocon as particularly valid for their synthesis of analogue and digital production.

Perceived disadvantages of teaching CAD/CAM and associated solutions

In contrast, acknowledged advantages are that CAD/CAM enables students to make forms and structures that would be extremely difficult to make in other ways. However, even in the digital realm complexity of form is associated with the virtual dexterity of students; again underlining that the imperative to acquire technical skills exists in digital production as much as in traditional hand manufacture. Therefore, students need to be encouraged to advance beyond a basic skill set in CAD software to achieve results of sophistication.

Nonetheless, CAD/CAM "enables students to translate their thinking into 3D very quickly and with an exceptional level of accuracy and precision." As in industry, perhaps one of its strongest benefits for students is how it "can allow for design possibilities to be more fully explored within the time constraints of modules." This can permit, or even encourage teachers to set demanding briefs that will stretch the jewellery languages of students.

Another perceived advantage amongst the surveyed teachers is that it may also allow students to tap into pre-existing digital design knowledge. For example, "2D software, such as Adobe Photoshop enables students to use their photography skills to translate hand-made models into multiples. They are able to change the designs surface texture/colour and place it within a specific context that enables a transformation of scale or wearable function, the results of which can be highly professional and quick to produce."

One interesting CAD/CAM teaching method that emerged was developed by requesting students to use CAD/CAM as a "design tool to explore professional presentations and or portfolios". This is obviously useful to students who want to promote themselves and increase their employability. Consequently, professionalising their CAD/CAM skill set incentivises students to learn.

Conclusion

Within the survey there was little doubt as to the merits of incorporating the teaching of CAD/CAM into any jewellery education. According to 91.7 per cent of the teachers, students who have acquired skills in CAD/CAM have a better chance of succeeding in the jewellery business. Therefore, it is understandable that institutions and their teaching staff will want to transmit the required digital skills to their students. Certain strategies have been identified to encourage student uptake of CAD/CAM, by setting projects where they can exploit pre-existing skills in Photoshop and Illustrator to produce laser cut jewellery. The use of two dimensional vectors in Illustrator can offer a pathway to the acquisition of 3D modelling skills in Rhino using NURBS; thereby expanding planar designs into voluminous pieces.

It is also interesting to note how certain respondents asserted that teaching projects need to be conceived in a way that fully exploits CAD/CAM's inherent precision and capacity to replicate forms. Briefs should therefore ideally integrate production in multiples, personalisation and the mass customisation of forms. Further incentives for students to acquire digital modelling and production skills can derive from establishing 'live' projects using CAD/CAM. As in the Polytechnic of Milan's Precious Plastic Workshop where students created jewellery for Kartell and Bijouets through 3D printing. Other suggestions involve creating projects in which students exploit CAD/CAM to produce portfolios and self-promotional items such as innovative business cards or personalised give away objects. This effectively encourages the acquisition and refinement of digital skills by giving tangible means for improving future career prospects.

In order to neutralise some of the perceived disadvantages for students in their usage of CAD/CAM, namely a reduction in hand skills, the loss of tactile making and the reduced appreciation of physical dimensions, the teaching of CAD/CAM is best synthesised with traditional modes of design and production. In other words, CAD/CAM should ideally become an addition to the process of form generation, design development and production through drawing and hand produced models, rather than a substitute for them. In fact, when discussing examples of best practice a commonly voiced opinion was that a successful combination relies on "traditional skills taught alongside of CAD/CAM skills" in order to "successfully translate tacit knowledge into CAD/CAM outcomes".

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