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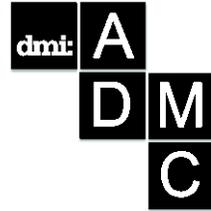
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## Specification of an Additive Manufacturing Consumer Design Toolkit for Consumer Electronics Products

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*Online toolkits, also known as product configurators, are a well established means of enabling consumer engagement in the mass customisation of products. Such toolkits typically require the consumer to select from pre-determined menus of modules in order to create products personalised to match their requirements, however in recent years a new class of toolkit, enabled by additive manufacturing, has begun to appear. Providing consumers the opportunity to change a product's appearance presents designers and brand managers with difficult decisions, yet to date little research has been conducted to understand how a brand might restrict consumer choice in order to protect its corporate design language. This paper reports on ongoing research which aims to understand the ways in which brands with mass-customisation offerings manage their identities across product portfolios, and the impact which AM might have on these management strategies. It begins by introducing the current state of AM technologies and how these are being used in MC systems. Drawing on a survey with senior design and brand managers, a specification of an AM-enabled toolkit aimed at consumer electronics products is presented, and future steps for the implementation of such a toolkit are discussed.*

**Keywords:** Additive Manufacturing; Online Toolkits; Design Language

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## Introduction

Online toolkits (von Hippel and Katz, 2002; Franke et. al; 2010), also known as product configurators (Berger and Piller, 2003; Piller, 2005), are a well established means of enabling consumer engagement in the mass customisation (MC) of products. Such toolkits typically require the consumer to select from pre-determined menus of modules in order to create products personalised to match their requirements (Pine, 1993; Tseng and Jiao, 1998). Modules may comprise physical components in a toolkit such as that offered by Dell, or properties such as colour and materials in a toolkit such as NikeiD. In this way, MC configurators are able to tailor the specification and design of products to a degree in which it is realistically probable that every configuration will be unique. In recent years however, a new class of toolkit has begun to appear; these configurators do not rely on the choice or arrangement of modules, but instead allow the precise manipulation of a product's form. This 'fine grain' control relies on two factors:

- a parametric design interface (Hermans and Stolterman, 2012) as part of the toolkit
- the use of direct digital manufacturing (DDM) technologies, in particular additive manufacturing (AM), to produce the user-customised part

Providing consumers the opportunity to change a product's appearance, as MC does, presents designers and brand managers with difficult decisions. Much MC literature has concentrated on the need to limit the solution space (Franke and Piller, 2004) and extent (Dellaert and Stremersch, 2005) of customisation for production and logistics reasons. Wide ranging evidence also suggests that consumer satisfaction is increased when the number of options is constrained (Iyengar and Lepper, 2000; Moreau et al, 2005; Dahl and Moreau, 2007; Deng and Hutchison, 2007). However to date little research has been conducted to understand how a brand might restrict consumer choice in order to protect its corporate design language. Cross et al (2009), for example, require that derivatives of a MC system should be "aesthetically pleasing", but make no mention of the resemblance of such derivatives to other products in the brand's portfolio. Yet increased consumer control over the exterior appearance of a product inevitably diminishes a brand's ability to manage product styling, both across its portfolio and over time. This difficulty is further multiplied by the use of toolkits geared to production via AM: in their review of the literature, Fogliatto et al (2012) note that the implications of AM for MC have only

recently begun to be appreciated. An understanding of the unique aspects of AM for MC, and the shift from user configuration towards genuine consumer-design which it portends, is therefore overdue.

## **Additive Manufacturing**

Additive manufacturing (AM) is defined as “the direct production of end-use component parts made using additive layer manufacturing technologies” (Hague, 2012). Gibson, Rosen and Stucker (2010; pp. 3-6) describe 8 steps within an AM process, though these can be reduced to 6 for brevity:

1. Create a three-dimensional CAD model of the part to be manufactured and save the model in STL format.
2. Transfer the STL file to the AM machine, and position and orient the part as required (this is usually done via a PC-based user interface to the machine).
3. Ensure the machine is correctly set up with regard to material supply, layer thickness, cycle time etc.
4. Build the part (generally an automated process requiring no supervision).
5. Remove the part from the machine and post process as required. Depending on the AM technology utilised, this may involve removing support structures, removing unused powder, allowing the part to cool, etc.
6. Use the part as required.

These steps reveal what Mansour and Hague (2003) describe as “by far the most important feature [of AM:] the tool-less manufacturing of parts.” Within traditional mass manufacturing technologies such as injection moulding, tooling is both complex and expensive, typically equating to  $1-10 \times 10^5$  of the material cost of an individual part (Wang, Ruan and Zhou, 2003). The need to amortize these tooling costs inevitably leads to uniformity within a brand’s product offering, since the costs of repetition are extremely low, whereas even small design changes require significant reinvestment in tooling. Without the need for tooling, AM offers the theoretical possibility that every product sold can exhibit a unique form. The implications of such a possibility for a brand’s control of its design language form the basis of this paper.

Hopkinson and Dickens (2006) note eighteen distinct rapid manufacturing technologies, many of which have been commercialised in

different ways by different manufacturers. Table 1 summarises the most commonly used processes currently implemented by MC toolkits.

Table 1. The most commonly used AM processes (Upcraft and Fletcher, 2003; Mansour and Hague, op.cit; Hopkinson and Dickens, op. cit; Z-Corp, 2005; Altair Consulting, 2012)

PROCESS NAME	MATERIALS	PART QUALITY	PROCESS DESCRIPTION
Stereolithography (SLA)	Polymer: Epoxy	Appearance: Good Strength: Good	Liquid resin material is cured by moving laser
Laser Sintering	Polymer: Nylon, Filled Nylon, Polystyrene Metal: Stainless Steel, Aluminium, Titanium	Appearance: Good, though slightly porous Strength: Very Good	Powder material is fused by moving laser
Electron Beam Melting	Metal: Titanium, Cobalt Chrome	Appearance: Good, though generally requires finishing Strength: Very Good	Powder material is fused by moving electron beam
Fused Deposition Modelling (FDM)	Polymer: Polycarbonate (PC), ABS, PC-ABS, PC-ISO, Polyetherimide (PEI)	Appearance: Poor Strength: Good	Filament material is extruded through moving heated nozzle, then welded to previously extruded material
Multi-Jet Modelling	Polymer: Acrylic (PMMA)	Appearance: Good Strength: Good	Liquid photo-sensitive material is jet-sprayed, then cured by UV light

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Perfactory Process	Polymer: Photocurable Acrylate	Appearance: Very Good Strength: Poor	Liquid photopolymer is cured using DLP projector. Parts are often used as investment casting patterns for jewellery
Z-Corp Process (3DP Process)	Polymer: Composite Polymer	Appearance: Good Strength: Poor	Powder material is fused by printed liquid binder

## **Product Design Language and Brand Equity**

At its simplest,

*a brand is a name, term, sign, symbol, design or combination of these, which is used to identify the goods and services of one seller or group of sellers and to differentiate them from those of competitors (Kotler et al, 1996, p. 556).*

The purpose of identification is to encourage in the customer perceptions of "relevant, unique, sustainable added values which match their needs most closely," (de Chernatony, 2003: p. 9). This in turn leads to customer satisfaction and 'brand loyalty', ensuring customers return to the brand to purchase again, rather than buy a competitor's product (Kapferer, 2003: pp. 164-166). Consequently, for a large manufacturer, managing a brand or brand portfolio is a complex and multi-faceted task.

One way of measuring the success of brand management is through brand equity, a way of describing a brand's intangible assets such as "awareness, image, trust and reputation, all painstakingly built up over the years," (Kotler et al. op. cit: p.16). Initially brand equity was understood, in somewhat basic terms, as "outcomes [that] result from the marketing of a product or service because of its brand name that would not occur if the same product or service did not have that name," (Keller, 1993). This later became recognised as just one definition of brand equity, what Wood (2000) classes brand strength, the others being brand value (the total value

of a brand as a separable asset) and brand description (the associations and beliefs the consumer has about the brand).

Olins (2007: pp. 201-202) describes Peter Behrens work for AEG as the blueprint for a brand's corporate identity: products, buildings, logos, advertising and communications were all managed and required to adhere to an over-riding philosophy. By unifying elements in this way, Behrens increased AEG's recognition and reputation amongst consumers and so increased the value of its brand. As the industrial design profession matured it came to recognise ways in which a brand's image could be enhanced and maintained through the development of a "repeatable language, which can be used to generate products consistent with the brand," (McCormack and Cagan, 2003), and thus a consistent treatment of common design features across a brand's product portfolio (Karjalainen and Snelders, 2009) is now recognised as a contributing factor to brand equity. Perhaps the best known example is the Coca-Cola bottle (McCormack and Cagan, op. cit.), which has evolved over more than a century but remains recognisable when applied to both plastic and glass bottles of different sizes. In addition, Apple's filing of a lawsuit against Samsung for infringement of "trade dress" (Fried, 2011), claiming the latter's products copied the industrial design of the iPad and iPhone, is particularly relevant.

## **AM-Enabled MC Toolkits**

Piller, Salvador and Walcher (2012) describe the purpose of MC toolkits as affording consumers the opportunity to specify the "Fit, Form and Function" of a product, to more accurately meet their needs. Thus the Dell configurator mentioned above offers choices of components to customise a computer's function, whereas the NikeiD configurator offers choices of shoe size (i.e. fit) and colour and material choice (form). However, whilst configuration choices may indirectly affect a product's shape (a bigger battery in a laptop might require a larger casing, for example), toolkits such as these offer the consumer no opportunity to directly interact with either the product's shape or its styling. The ability of the user to act as designer, as often claimed in MC literature (Ciccantelli and Magidson, 1993; Franke and Piller, op. cit; Randall, Terwiesch and Ulrich, 2003), is therefore a considerably limited one.

AM-enabled MC toolkits overcome some of the limitations of conventional MC systems by no longer relying on mass manufactured, multiply-reproduced modules. Instead, product enclosures produced via 3D

printing can be individually styled such that not only might the component specification of a consumer's purchase be unique, its visual appearance may be also. Such an opportunity risks placing considerable burdens on the consumer however – namely how to design an attractive, functional product, and how to ensure the designed product can be manufactured. AM-enabled MC toolkits must therefore provide both design freedoms and design safeguards. This is achieved by constraining the solution space within which the user can operate (Franke and Piller, op. cit.), but with additional limitations such that the brand's design language is not compromised. Two examples of AM-enabled toolkits which work in such a way are presented below.

### *Makielab*

MakieLab is a London-based toy manufacturer, which incorporates an online customisation toolkit to allow consumers to design poseable dolls. As well as choosing clothes and hairstyles, facial features and expressions can be modified, and the doll is 3D printed in laser sintered nylon. MakieLab therefore represents a hybrid MC system, using both a modular and a parametric design approach. The hair and face section of the MakieLab configurator (Figure 1) demonstrates the ability of AM to create visually unique products. Divided into features such as eyes, nose, mouth, etc. the user controls sliders to determine the feature's shape and size. In designing the doll's nose for example, the user can control the length, width, arch and size of nostrils. These sliders offer a very 'fine grain' interaction, and the on-screen image of the doll is updated in 'real time', providing accurate feedback to the user in terms of how his/her inputs affect the doll's design.

The solution space within which the user can affect the doll's design is carefully considered. The MakieLab dolls have a recognisable aesthetic which is maintained throughout the customisation process, and which is determined by a number of factors which the consumer is unable to influence: for example the available choice of hairstyles and clothing suggests the doll represents a young 'hipster' adult, rather than a child. The proportions of the head and body are reminiscent of Japanese anime characters (some of the choices of hairstyle are described as 'Manga'), as are the over-large eyes. These features combine to create a 'collectable' product, one which appeals to those who shop in comic stores rather than toy shops, and results in a product design language able to encompass all possible variants of the MakieLab doll.



Figure 1. The MakieLab configurator.

### *Nervous System*

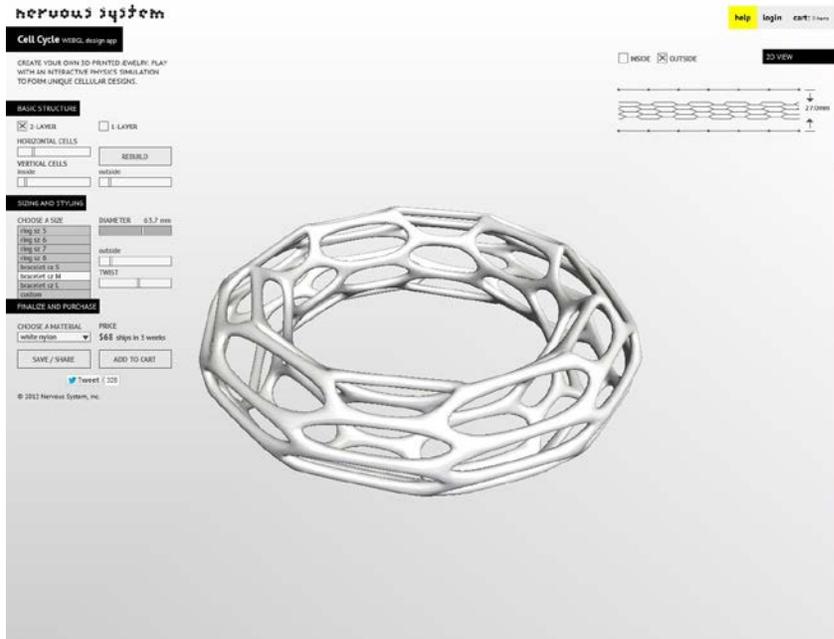
Nervous System is a design studio creating jewellery and housewares, based in Somerville Massachusetts. It specialises in the use of generative design – software algorithms that create forms based on both user input and the interaction of the form with itself (Rahim, 2009). Generative design typically produces naturalistic forms, a fact reflected in names given to some Nervous System products: Algae, Ammonite, Dendrite and Xylem, for example.

The Nervous System website features three generative design configurators, the most sophisticated of these is the Cell Cycle configurator, which allows users to create jewellery items such as rings and bracelets. An on-screen model of the product can be rotated and viewed from different angles, and the design is automatically updated to reflect user changes. Although the products exhibit the naturalistic aesthetic described above, an underlying mathematical logic is also apparent, and this is reflected in the

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visual design of the configurator, which has a grid-like layout and monochrome colour palette.

Unlike the MakieLab configurator, Cell Cycle uses only additive manufacturing technologies, with users able to order products in either laser sintered nylon, or precious metals, made by the Perfactory process. The majority of interactions are via slider bars which increase or decrease a given parameter, such as number of cells or degree of twist.



*Figure 2. The Nervous System Cell Cycle configurator.*

The Cell Cycle configurator again exhibits a very carefully considered solution space. Crucially, the limits set within the configurator ensure that the consumer designed product is manufacturable – for example the minimum material thickness for a piece manufactured in silver is 0.9mm; this specification automatically updates to 1.2mm if nylon is selected instead. In contrast to the the MakieLab configurator (which currently manufactures only one product), designs resulting from the Cell Cycle system must fit within a much broader product portfolio. This is achieved largely by the nature of the configurator’s generative design algorithms, which are similar to those used in other, non-customisable products. The

uniqueness of such an approach means there are few findings applicable to more conventional consumer goods manufacturers. Thus, whilst MakieLab and Nervous System both indicate the potential of AM to increase the extent of customisation, they are less able to demonstrate how a brand with an established product design language might integrate AM-enabled MC products into its portfolio.

## **Product Design Language Within AM-Enabled MC Toolkits**

A carefully conceived and orchestrated product design language is not something a brand would wish to sacrifice were it to allow consumers to engage with the design of its products to create unique manifestations of those products (Abdallah and Chan, 2011). Such caution can be recognised in the NikeiD, configurator, where palettes of colours and materials available to the consumer for each model of shoe are deliberately limited, allowing Nike's designers to retain a degree of control over the brand's design language. A system which incorporates AM-enabled MC must similarly exercise control over the possible product forms which a consumer might wish to manufacture. However, by providing the user the opportunity to manipulate a product's shape and exterior surface definition, a new degree of complexity is introduced to the management of a brand's design language.

### *Survey Design and Participants*

To better understand the commercial realities of brands' design languages, and how these might be protected in an AM-enabled MC toolkit, an internet-based survey was undertaken. Since a product design language is applied across a brand's portfolio and may exist (and evolve) over time, it was reasoned that survey participants should be experienced in design and/or brand management, as evidenced by the participant's job title. All respondents were therefore required to be practising at a minimum level of 'senior designer' or equivalent. Invitations were sent to 91 potential participants and 39 completed surveys (43%) were received (4 unfinished surveys were discarded from the results). Invitations were sent to personal email addresses and contained a link to the survey web page together with a personal log-in name and password.

Details of respondent demographics are shown in Figures 3-5 below. It should be noted that although the country of work is shown, no

assumptions should be made regarding the nationality of respondents (many are living outside their home country) or the target markets for which they are designing.

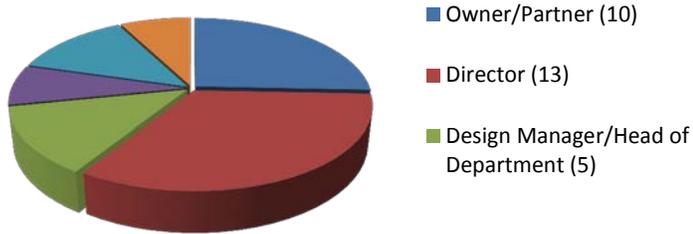


Figure 3. Survey Respondents Job Description.

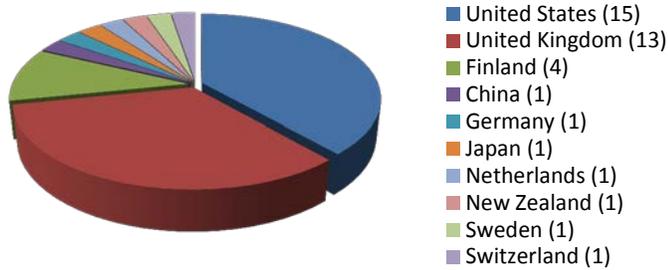


Figure 4. Survey Respondents Country of Work.

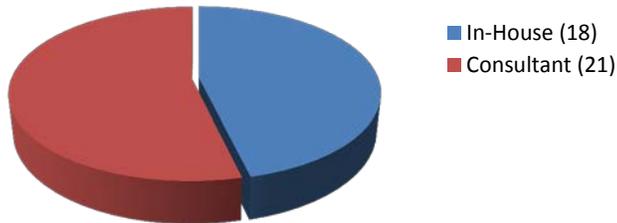


Figure 5. Survey Respondents Designer Type

### **Sampling Bias**

Sampling bias, defined as "the difference between the expected value of the sample estimator and the true value of the characteristic which results from the sampling procedure" (Federal Committee on Statistical Methodology, 1978: p.9), occurs when a surveyed sample does not

represent a random sample of the population being studied. The most obvious bias within the survey presented below comes from the geographical location of respondents: 38.5% are based in the United States and 54% in Europe. The extent to which this bias distorts the survey's findings is unclear however - it is possible to argue that Japanese, Korean and, increasingly, Chinese consumer product manufacturers (for example) operate as global brands, in which case designers working inside those corporations would record similar responses. However the authentication of such a statement is outside the scope of this research, and so the survey results should be understood as applying primarily to Western brands.

### *Survey Results*

Chen and Owen (1997) propose that a form language is comprised of six attributes: form elements, joining relationships, detail treatments, materials, colour treatments and textures. These attributes were used as the basis of questions aimed at revealing the relative importance of constituent elements of a design language. However in the survey materials and textures were treated as one element; in addition a new consideration – logos or other brand identifiers – was introduced.

With particular regard to the survey's relevance to the specification and design of a consumer design toolkit, four specific findings are noted:

**1. A successfully implemented product design language is an important factor in a brand's image and profitability.**

More than 90% of respondents considered a coherent design language to be a critical factor in a well designed product, and more than 75% considered it to be critical to a product's commercial success. Respondents unanimously believed that a successful design language leads to differentiation from competitors and increased sales to returning customers, and a substantial majority believed it results in increased consumer awareness of the brand (98%); increased consumer loyalty (95%) and a willingness on the part of the consumer to pay more for a product (82%). One caveat should be noted however - approximately half of all respondents believed the companies they work for (either as employees or consultants) placed too little importance on developing a coherent design language. Thus it may be argued that these organisations would be willing to sacrifice design integrity if it led to increased sales.

**2. Consumers have insights and expertise which allow them to custom design products which meet their own needs better**

**than non-customised products, however this may be in conflict with a brand's image.**

72% of respondents believed that consumers have valuable insights into the design of current products and ways of customising or configuring them. Almost all believed that current mass customisation toolkits are useful to consumers and enhance the consumer's experience of both the product and the brand. Significant majorities of respondents believed that existing mass customisation toolkits enhance the consumer's perception of a brand (84% for the Herman Miller Sayl, 97% for NikeID). However there is much less enthusiasm for AM-enabled consumer design toolkits, with a majority (57%) believing a brand's reputation for design quality would decrease.

**3. The quality of a brand's product design language may be diluted by consumer customisation, therefore any consumer design toolkit should be constrained in its capabilities in order to be acceptable.**

A significant minority (43%) of respondents felt that allowing consumers to customise products would dilute a brand's design language. Most respondents preferred to reduce the number of options for customisation that a design toolkit offers, suggesting they would seek to retain control over a brand's design language by restricting the consumer's ability to customise a product. This is confirmed by 77% of respondents who suggested a consumer design toolkit should set boundaries of acceptable designs.

**4. In order of degree of influence, a consumer design toolkit should allow:**

- Changes to the position of logos and brand identifiers
- The use of non-standard colours, patterns and graphics
- The use of non-standard materials or material finishes
- Changes to the position of common elements
- Changes to the product silhouette
- Changes to the way in which common elements are detailed

This final finding is of particular importance for the specification of an AM-enabled MC toolkit. Figures 6 and 7 show the degree of importance placed on attributes of a brand's product design language. The necessity of

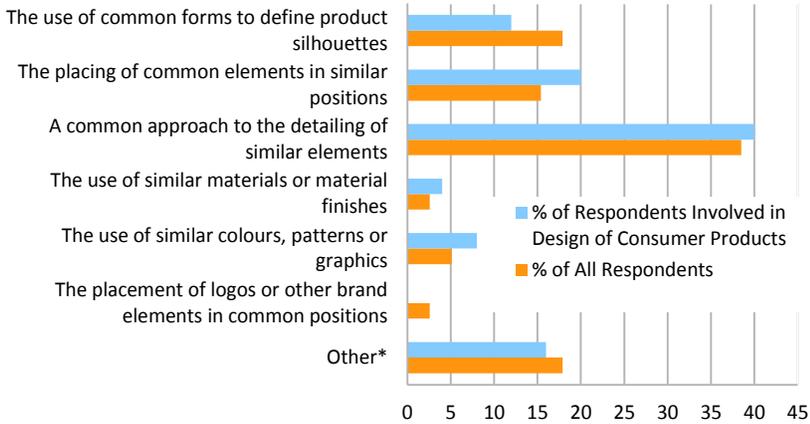


Figure 6. Survey Participants' responses to the question: "Which of the following attributes is the most important to a successful and coherent design language?"

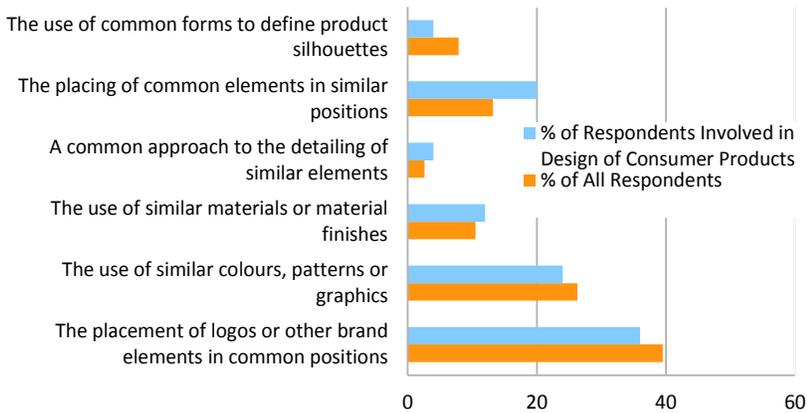


Figure 7. Survey Participants' responses to the question: "Which of the following attributes is the least important to a successful and coherent design language?"

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incorporating a common approach to the detailing of common elements is clearly revealed, particularly in comparison to the importance of using common forms to define product silhouettes. This is largely in accordance with previous studies (e.g. Karjalainen and Snelders, op. cit.). Colour and graphic treatments, and the position of logos or other brand identifiers, are revealed as the least important attributes of a brand's design language.

*Table 2. Respondents answers to questions regarding AM-enabled consumer design*

	Strongly Agree	Agree	Disagree	Strongly Disagree
The system should allow the maximum design freedom possible	10.5%	39.5%	36.8%	13.2%
The system should set boundaries of acceptable designs	35.9%	41.0%	17.9%	5.1%
It would be possible to maintain a coherent design language	23.7%	52.6%	18.4%	5.3%
The system would be an addition to the brand's standard products	26.3%	57.9%	15.8%	0.0%
The brand's reputation for design quality would increase	2.7%	40.5%	54.1%	2.7%

Table 2 above shows respondents' answers to a scenario in which AM-enabled toolkits allow consumers to design unique products. A 50:50 split occurs in opinions regarding whether the system should allow the maximum design freedom possible, however approximately three-quarters of respondents believed the system should set boundaries of acceptable designs. Such answers show that there is little common agreement amongst participants regarding the involvement of consumers in the design of

personalised products. Participants were also divided on whether a brand’s reputation for design quality would be enhanced or harmed by such a system, though a significant majority believed a coherent design language could be maintained.

## Specification of an AM-Enabled Consumer Design Toolkit for Consumer Electronics Products

As mentioned above, the ability of existing AM-enabled MC toolkits to demonstrate how a brand with an established product design language might integrate AM-enabled MC products into its portfolio is relatively poor. In addition, the complexity of product in comparison to a typical consumer electronics product is low. The following guidelines therefore represent a first attempt to formulate a specification for a toolkit suitable for the Consumer Design of consumer electronics products.

### Framework Definition

The framework definition (Table 3) of the toolkit refers to decisions required before the detail design could commence. A framework definition involves the specification of "the supporting structures and underlying concepts upon which every detail depends," (Goodwin, 2009: p. 377), and in a commercial context would typically involve inputs from product and brand managers as well as designers (ibid).

Table 3. Framework Definition of an AM-Enabled MC Toolkit Suitable for Consumer Electronics Products

FRAMEWORK DEFINITION FEATURE	EXPLANATION AND APPLICATION IN PROTOTYPE TOOLKIT
<p><b>Design Method Type</b> AM-enabled Constrained Consumer Design</p>	<p>A development of mass customisation, allowing user-modification of a product’s form via a software toolkit. Constraints ensure the resultant product is safe, functional and acceptable within the brand’s product design language guidelines.</p>
<p><b>Value of Customisation and Design</b> Function and Form (Piller, Salvador and Walcher, op. cit.)</p>	<p>Allows users initially to choose from products whose specification targets usage scenarios (e.g. sports, business, etc.).</p>

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	Subsequently allows users to choose whether design decisions are made for functional or aesthetic (form) reasons.
<b>Type of Modularity</b> Component Sharing and Component Swapping (Ulrich and Tung, 1991)	Basic module of electronic hardware and non-visible chassis provides basis of all designs (component sharing). Consumer-designed parts fix to chassis using standard features (e.g. screw bosses) (component swapping).
<b>Extent of Customisation</b> (Dellaert and Stremersch, op. cit.).	Extent of specification customisation (screen size, memory, etc.) is small, as determined by hardware modularity. Extent of design customisation is unlimited within boundaries set by designer and brand. Functional detailing (wall thicknesses, draft, etc.) and cosmetic detailing (fillets, chamfers, etc.) is automated (Sinclair and Campbell, 2009).
<b>Customisation Type</b> Primarily Parameter-based	Needs-based systems are more complex to implement (Walcher and Piller, op. cit.); parameter-based systems are better suited to users who understand technical details (Randall, Terwiesch and Ulrich, op. cit.) Consumers choose base product by usage scenario, then define specification by technical details.
<b>Design Interaction Type</b> Direct interaction with on-screen CAD model	Model shapes and surface definitions are modified directly using tools to push and pull surfaces by click-and-drag type interactions. Model shapes and surfaces are constrained within limits determined by designer and brand.
<b>Manufacturing Scenario</b> Production by manufacturer or authorised vendor	AM parts would be produced by manufacturer or authorised vendor (no 'at home' production). Product assembly carried out by manufacturer.

	Consumer assembly of changeable cosmetic parts would be possible, if intended (and designed) by brand.
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### *Detail Definition*

The detail definition of the toolkit (Table 4) refers to decisions governing the implementation of features with which the consumer would interact directly.

*Table 4. Detail Definition of an AM-Enabled MC Toolkit Suitable for Consumer Electronics Products*

DETAIL DEFINITION FEATURE	EXPLANATION AND APPLICATION IN PROTOTYPE TOOLKIT
<b>Platform and Installation</b> Platform-independent, in-browser application	An in-browser application would require no download or installation ensuring maximum availability to users. Current web infrastructure would preclude the use of detailed, fully rendered models; this issue is anticipated to reduce in future.
<b>Visualisation</b> Products visualised with maximum realism	Realistic visualisation increases customer confidence in the product being customised (Walcher and Piller, op. cit.). Colours and materials are represented accurately. Model is shown in 3D perspective with ability to rotate as required.
<b>Price</b> Continuously updated	Final price of product is updated continuously as changes are made (Dellaert and Stremersch, op. cit.). Default product is lowest priced such that consumer choices add cost rather than reduce it (ibid.).
<b>Default Option</b> Five basic choices, with option to browse library of previously submitted designs	Needs based system determines choice based on manufacturer’s recommendation. Also possible to choose from a library of designs previously submitted by

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	consumers, then use as the basis of a new design.
<b>Order and Degree of Design Interaction</b>	<p>Order of interaction is suggested by the system, but not enforced.</p> <p>Specification of the technical details should take place first.</p> <p>Design phase has an implied order, according to importance of features (see page 13). However consumer can carry out tasks in any order.</p>
<p><b>Design Tools</b> Direct interaction with on-screen CAD model</p>	<p>Toolkit provides consumer with the following tools:</p> <p><b>Scale:</b> model scales as required; features such as the display window remain fixed in size and position during this operation.</p> <p><b>Shape (Silhouette):</b> silhouette of the phone can be modified as required; as the shape is changed features such as fillets or buttons update automatically.</p> <p><b>Shape (Move Surfaces):</b> model allows individual surfaces to be moved; connected surfaces and features update to reflect these changes.</p> <p><b>Shape (Modify Surfaces):</b> model allows individual surfaces or connected surfaces to be modified and re-shaped.</p> <p><b>Colours, Materials and Finishes (CMF):</b> CMF is applied at the part level. System allows designers to link the CMF of parts such that when consumer changes one part, others also update.</p> <p><b>Detailing:</b> detailing of the product (however defined by the designer and brand) should be 'protected' and non-changeable by the consumer; a menu of alternative choices might be provided.</p> <p><b>Logo:</b> consumer has the opportunity to upload a logo or type a message which would appear on the phone's cover.</p>
<b>Model Integrity</b> Production by manufacturer or	Any consumer design resulting from the toolkit should be manufacturable by a

authorised vendor	suitable AM system. Integrity of any design should be guaranteed in terms of safety, functionality, consumer law, etc. Toolkit should prevent compromised performance, e.g. by specifying metal parts close to antenna.
<b>Community</b>	Toolkit provides opportunity to share and discuss designs, also to discuss the system, suggest improvements etc.

## Conclusions

Currently AM-enabled toolkits have been implemented only by brands specialising in the application of these technologies; these toolkits are therefore of limited value in terms of demonstrating how AM technologies might be integrated into the portfolio of a brand which also includes more conventional offerings. This is particularly significant in light of the survey research presented in this paper, which shows that senior design professionals have reservations regarding the quality of design which might result from AM-enabled toolkits. In order to protect the brand equity which a successful design language contributes, AM-enabled toolkits must therefore take account of, and be limited by, the components identified as contributory to design languages.

The literature commonly identifies six influences over the design of the form of products, and the design languages which result when these are applied in a common way across a product portfolio. However, the degree of importance associated with each of these influences has not previously been demonstrated. This paper therefore presents valuable insights to a brand which wishes to introduce customisation toolkits which allow the user to interact with a product's form. This in turn has led to a specification of the design tools required to enable interaction with an AM-enabled toolkit, whilst at the same time constraining the user's ability to create product forms which lie outside of a brand's design language.

Whilst this paper presents a first specification of an AM-enabled toolkit intended to safeguard a brand's design language, clearly further work is required to demonstrate its effectiveness. Preliminary instantiations in the form of wireframe prototypes would allow feedback to be gathered from both users and product designers, who would be required to submit designs

*Specification of an Additive Manufacturing Toolkit for Consumer Electronics Products* which could subsequently be modified by users. This feedback would then inform the design of a chauffered prototype (Usability First, 2014) with which to demonstrate interaction methods and the types of tools needed to modify product forms as users wish.

## References

- Abdallah, H. and Chan, T-H. (2011), An integrated design framework for mass customisation in the consumer electronics industry, *International Journal of Computer Applications in Technology*, 40(1/2), pp. 37-52.
- Altair Consulting (2012), Envisiontec Perfactory [online], available from: <http://www.altairconsulting.com/envisiontec-perfactory.htm> [accessed 23.03.2014].
- Berger, C. and Piller, F. (2003), Customers as Co-Designers, *IEE Manufacturing Engineer*, August/September, pp. 42-45.
- Chen, K. and Owen, C.L. (1997), Form language and style description, *Design Studies*, 18(3), pp. 249-274
- de Chernatony, L. (2003), *From Brand Vision to Brand Evaluation - Strategically Building and Sustaining Brands*, Oxford: Elsevier Butterworth-Heinemann.
- Ciccantelli, S. and Magidson, J. (1993), Consumer Idealized Design: Involving Consumers in the Product Development Process, *Journal of Product Innovation Management*, 10(4), pp. 341-347
- Cross, R; Seidel, R; Seidel, M. and Shahbazzpour, M. (2009), Design Communication for Mass Customisation, *International Journal of Mass Customisation*, 3(2), pp. 146-164.
- Dahl, D.W. and Moreau, C.P. (2007), Thinking inside the box: why consumers enjoy constrained creative experiences, *Journal of Marketing Research*, 44(3), pp. 357-369.
- Dellaert, B.G.C. and Stremersch, S. (2005), Marketing Mass Customized Products: Striking the Balance between Utility and Complexity, *Journal of Marketing Research*, 42(2), pp. 219-227.
- Deng, X. and Hutchinson, J. (2007), 'A Three-Factor Model of Consumer Preference for Self-Designed Products' *Proceedings of the MCPC 2007 World Conference on Mass Customization & Personalization*, 7-9 October, Massachusetts Institute of Technology (MIT).
- Federal Committee on Statistical Methodology (1978), *Statistical Policy Working Paper 4 - Glossary of Nonsampling Error Terms: An Illustration of*

- a *Semantic Problem in Statistics* [online], available from:  
<http://www.fcs.m.gov/working-papers/sw4.html> [accessed 19.02.2014].
- Fogliatto, F; da Siveira, G. and Borenstein, D. (2012), The mass customization decade: An updated review of the literature, *International Journal of Production Economics*, 138(1), pp. 14-25.
- Franke, N. and Piller, F. (2004), Value Creation by Toolkits for User Innovation and Design: The Case of the Watch Market, *The Journal of Product Innovation Management*, 21, pp. 401-415.
- Franke, N; Schreier, M. and Kaiser, U. (2010), The "I Designed It Myself" Effect in Mass Customization, *Management Science*, 56,(1), pp. 125-140
- Fried, I. (2011), *Apple Files Patent Suit Against Samsung Over Galaxy Line of Phones and Tablets* [online], available from:  
<http://allthingsd.com/20110418/apple-files-patent-suit-against-samsung-over-galaxy-line-of-phones-and-tablets/> [accessed 22.02.2012].
- Gibson, I; Rosen, D.W. and Stucker, B. (2010), *Additive Manufacturing Technologies*, London: Springer.
- Goodwin, K. (2009), *Designing for the Digital Age*, Indianapolis: Wiley.
- Hague, R. (2012), *Abstract, EPSRC Centre for Innovative Manufacturing in Additive Manufacturing*, [online], available from:  
<http://gtr.rcuk.ac.uk/project/70CAB846-F382-44E9-89A0-945EB71C1DFD> [accessed 19.03.2013]
- Hermans, G. and Stolterman, E. (2012), Exploring Parametric Design: Consumer Customization of an Everyday Object, *Leading Innovation through Design: Proceeding of the DMI 2012 International Research Conference*, 1-4 July, Chulalongkorn University, Bangkok, Thailand.
- von Hippel, E. and Katz, R. (2002), Shifting innovation to users via toolkits, *Management Science*, 48(7), pp. 821-833.
- Hopkinson, N. and Dickens, P.M. (2006), Emerging Rapid Manufacturing Processes in *Rapid Manufacturing: An Industrial Revolution for the Digital Age*, Chichester: John Wiley and Sons.
- Iyengar, S. and Lepper, M. (2000), When Choice is Demotivating: Can one desire too much of a good thing? *Journal of Personality and Social Psychology*, 79(6), pp. 995-1006.
- Kapferer, J-N. (2003), *Strategic Brand Management - Creating and Sustaining Brand Equity Long Term*, 2nd Edition, London: Kogan-Page.
- Karjalainen, T-M.; Snelders, D. (2010), Designing Visual Recognition for the Brand, *Journal of Product Innovation Management*, 27(1), pp. 6-22.
- Keller, K.L. (1993), 'Conceptualizing, Measuring and Managing Customer-Based Brand Equity', *Journal of Marketing*, 57(1), pp. 1-22.

- Kotler, P; Armstrong, G; Saunders, J. and Wong, V. (1996), *Principles of Marketing - The European Edition*, Hemel Hempstead, UK: Prentice Hall.
- Mansour, S. and Hague, R. (2003), Impact of Rapid Manufacturing on Design for Manufacture for Injection Moulding Proceedings of the Institute of Mechanical Engineers, Part B, *Journal of Mechanical Engineering Science* 217(4), pp. 453-461.
- McCormack, J.P. and Cagan, J. (2003), Speaking the Buick language: capturing, understanding, and exploring brand identity with shape grammars, *Design Studies*, 25(1), pp. 1-29.
- Moreau, C.P; Dahl, D.W; Iacobucci, D. and Anderson, E. (2005), Designing the Solution: The Impact of Constraints on Consumers' Creativity, *Journal of Consumer Research*, 32(1), pp. 13-22.
- Olins, W. (2007), *On Brand*, London: Thames and Hudson.
- Piller, F. (2005) Mass Customization: Reflections on the State of the Concept, *International Journal of Flexible Manufacturing Systems*, 16(4), pp. 313-334
- Piller, F; Salvador, F. and Walcher, D. (2012), Solution Space Development: Understanding where Customers are Different, *Innovation Management* [online], available from: <http://www.innovationmanagement.se/2012/04/23/part-3-solution-space-development-understanding-where-customers-are-different/> [accessed 24.04.2014].
- Pine, J. (1993), *Mass Customisation: The New Frontier in Business Competition*, Boston: Harvard Business School Press.
- Randall, T; Terwiesch, C. and Ulrich, K. (2003), Principles for User Design of Customized Products, *California Management Review*, 47(4), pp. 68-85
- Sinclair, M. and Campbell, R.I. (2009), From Configuration to Design – Capturing the Intent of User-Designers, *Proceedings of the MCPC 2009 World Conference on Mass Customization and Personalisation*, 4-8th October, Helsinki.
- Tseng, M.; Jiao, J. (1998), Concurrent design for mass customization, *Business Process Management Journal*, 4(1), pp. 10-24.
- Uprcraft, S. and Fletcher, R. (2003), The Rapid Prototyping Technologies, *Assembly Automation*, 23(4), pp. 318-330.
- Usability First (2014), *Glossary: Chauffeured Prototype*, [online], available from: <http://www.usabilityfirst.com/glossary/chauffeured-prototype/> [accessed 27.04.2014].

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Wood, L. (2000), Brands and Brand Equity: definition and management, *Management Decision*, 38(9), pp. 662-669.

Z Corporation (2005), *Z Corporation 3D Printing Technology*, White Paper, available for download from:

[http://www.zcorp.com/documents/108\\_3D%20Printing%20White%20Paper%20FINAL.pdf](http://www.zcorp.com/documents/108_3D%20Printing%20White%20Paper%20FINAL.pdf) [accessed 01.05.2014].