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STANDARD DEVIATION

STANDARDIZATION AND QUALITY CONTROL IN THE MASH-UP ERA

Dr. Robert Phillips, Dr. Matt Dexter, Prof. Sharon Baurley, Prof. Paul Atkinson

ABSTRACT

Standards touch many aspects of our lives, from purchasing to consuming, to maintaining product consistencies (e.g. ISO 9001). Standardization aids replicating: compliance, quality and durability to diffuse geographic areas, driving innovation by providing constraints (BSI). Historically, standardization was a cornerstone for commerce enabling traders to interact, trusting accurate measures, used in judging a product's worth. Open Design utilizes Internet-accessible digital making platforms, for creating and disseminating ideas. The rise of Fabrication Laboratories and distributed digital manufacturing (e.g. domestic 3D printing) has increased accessibility of high-quality manufacture. Design agents as well as designers can create products; either for personal use from the bottom-up, or re-appropriate another maker's solution. Reciprocity is key to the process. As such, in this paper we refer to design agents, *rather than applying labels of "professional" or "user". However, as design agents become enabled to produce complex artefacts, "objective validation" for shared blueprints quality, becomes imminent. For example, 3D printing is reviving DIY toy making, with materials that can degrade overtime, potentially presenting choking hazards. Due to this status quo, the authors are not presenting lawsuit opportunities, but preventative procedures whilst encouraging proliferation of design agent led Open Design. Regulatory requirements for sectors touched by "open phenomenon" are unprepared. How can maker communities, design agents and others lead the way in promoting ways of working that enable robust quality control in open environments? To answer this question, interviews with British Standards Institute (BSI) representatives were triangulated with design workshops. This participatory approach to knowledge creation was chosen due to its inherent compatibility with the theoretical underpinnings of Open Design. This paper presents models exploring "standards integration" for Open Design purposes, enabling design agents to create "compliant" outputs, to benefit all. We conclude that there are possible avenues for standardization, but that this must be tested in the field.*

#open design, #digital manufacture, #industry standards
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INTRODUCTION

Weblogs and Wikis have been readily adopted in civil society; transforming the way many of us access information, spreading information for either re-appropriation or use (Hasan & Pfaff 2006). The access to information and the capabilities to turn a digital file into a product give users the ability to design products they consume, becoming "pro-sumers" (Franke & Piller 2003), as well as enhancing the avenues of creation available to professional designers. Fabrication Laboratories (Fab Labs) housing digital fabrication equipment and manufacturing knowledge have existed in the United States since 2003 (Gershenfeld 2012) and are becoming more commonplace, with their number doubling every twelve months (Charny 2011). Fab Labs run public engagement events providing lay design agents access to equipment usually beyond their means. Open Design is the accessibility of design information providing the ability to produce items and artefacts through digital manufacture (Katz 2011).

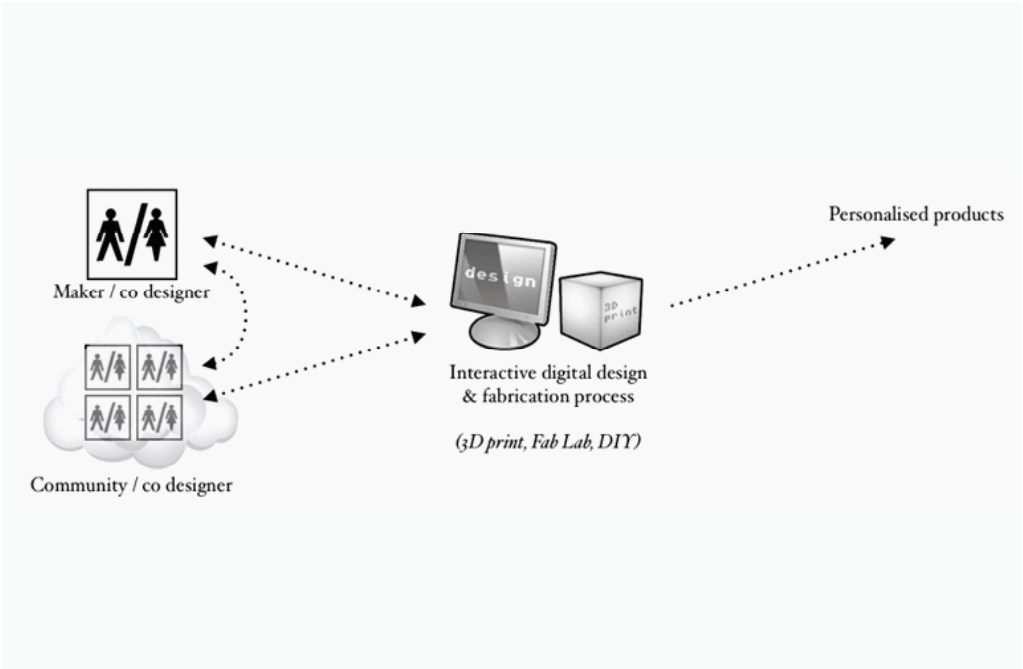

Fig.1. Open Design diagram, adapted from (Atkinson 2011).

[1] *See more at http://opendefinition.org*

Open Design is "the internet enabled collaborative creation of artefacts by a dispersed group of otherwise unrelated individuals" (Atkinson 2011) differing significantly from the traditional product creation. Open Design is born out of two enabling technologies, the Internet, and Distributed Digital Fabrication (DDF). In particular, the shift to "Web 2.0" (technologies for sharing and dialogue) has allowed the rapid community-driven development of technologies that underpin DDF—with one of the most prominent of these being open-source 3D printing.

Open Design has inputs and outputs that can be used by professionals and amateurs (Tooze et al. 2014); therefore Open Design is not necessarily equal to "amateur design", it is also a means for professionals to accessibly distribute content for manufacture at source or provide editable outputs. The authors focus this paper on 3D Printing, as it is the most accessible and ubiquitous form of digital manufacture, emulating its professionally produced injection molded counterparts. However, the concepts can be cascaded to other forms of digital manufacture, and the spaces where collaborative open design happens.

The precursor for the rapid growth of new companies manufacturing the most popular variants (for example, MakerBot) was the RepRap project (Bowyer 2004) which initiated the open-source development of 3D printers.

The conventional manufacturing process presents a path to a finished product, enabling conventional standards and quality control procedures to be applied at relevant project stages. This is different to Open Design as design agents engage in stages of design that can be uncontrolled or unregulated. Open design can be defined as the four freedoms that a person has with regard to an artefact: "[the] freedom to use the design, and the freedom to use it to make a derivative and use this for any purpose; the freedom to study the design and change it, and then change it to make it do as you wish" (Katz 2011). These freedoms are summarized in the Open Knowledge Foundation's definition of 'openness' (v1.1):[1]

"A piece of data or content is open if anyone is free to use, reuse, and redistribute it—subject only, at most, to the requirement to attribute and/or share-alike."

Open Design is a process intended for all to engage with, not only the technically able. There is a "difference in the ability to use a tool and the intrinsic knowledge of craftsmanship and skill in using it" (Frayling 2011). This study focuses on lay design agents reproducing and developing digitally manufactured goods in compliance with standards and not the design agents' knowledge and capability to design artefacts.

Open Design has engaged many communities where distributed manufacture is advantageous. Example projects include: farm equipment (*www.opensourceecology.org*), remote underwater exploring equipment (*www.openrov.com*) and platforms that enable the free

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sharing of interchangeable parts (*www.openstructures.net*). Open Design has the positive attributes of: economics; product distribution; locals solving local problems and engagement with the products design agents consume (Carson 2009). Open Design is explored by "kit makers" selling components for design agents to assemble into products, (removing technical elements possibly beyond lay design agents). Kits are a variant of Open Design – elements can be tailored to meet specific needs whilst achieving successful, quality outcomes. Businesses using "open" and kit approaches include: DIY Drones, (*www.diydrones.com*), Littlebits, (*www.littlebits.com*) and Sugru's Leon Paul fencing handle (*www.sugru.com*).

These examples (and the uptake of 3D printing) highlight Open Design as an emerging and successful market that warrants quality, compliance and regulation considerations—aiming to protect design agents from construction mistakes and improve the accurate replicability of products.

Atkinson and Cruickshank (Atkinson & Cruickshank 2013) critically look at the types of scenarios where Open Design is best suited; when designing complicated artefacts where a malfunction could endanger or have a serious negative economic impact, careful attention must be paid to the use of a design methodology such as Open Design. Regulatory impacts and safety concerns with distributed manufacturing mean that there are real questions surrounding the ability of current technologies to deliver artefacts of identical (or even verifiable) quality when manufactured by different people in different geographic locations.

Open Design has seen many projects attempt to tackle difficult or complex projects, comprised of multiple systems, sometimes interfacing with proprietary parts and systems (Raasch, Herstatt & Balka 2009). These complex projects follow the same principles of bazaar-like open source software development (Raymond 1999) with modular component parts and collaborative decision-making. The projects mentioned by Raasch et al. (Raasch, Herstatt & Balka 2009) intersect with standards in their inception OpenMoko (*www.openmoko.org*) is a good example; in creating a fully open-source mobile phone this would necessarily mean compliance with different telecoms standards (such as GSM), and emission standards for wireless radiation (as prescribed by the FCC and other bodies). This would appear to be a failing of Open Design, that a diffuse community of people could not begin to tackle these regulatory hurdles. However, as Henkel (Henkel 2006) points out, such an open source approach can create interoperable standards more efficiently since there are no conflicting business interests; the best technical implementation is used, rather than being the survivor of a "format war".

A misconception that designers occasionally have is in underestimating the creative potential of amateur makers (Phillips, Baurley & Silve 2013), in a similar vein to professional scientists underestimat-

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ing or looking skeptically upon data collected by amateur scientists (Cohn 2008). This reticence to value the amateur in a field within the "Web 2.0" era is highlighted by Keen (Keen 2007), who uses prominent examples of communities focused around user-centered content to highlight the perceived negative effects on traditional businesses. Keen's skepticism of 'user' content producers/curators can also be felt amongst designers about the amateur makers of equipment that could be considered "dangerous"—as professional designers specifying artefacts for manufacturers, it is necessary to adhere to and understand the relevant standards and regulations. If an "amateur maker" produces a wooden toy for a family member, they are potentially ignorant of the BS EN 71 standards governing the production of toys—however they may possess a wealth of tacit knowledge about the safe and effective use of oils, paints, and adhesives that are suitable for toy construction and finishing. Similarly, it is important for design agents working for profit that they can demonstrate a rigorous Open Design based product development process to their paying client, who might have to defend said process in a court of law.

Conventional products require trust; provided by standards: i.e. fire alarms (*BS EN 54-1:2011*), life jackets (*BS EN 396:1994*), medical products (*93/42/EEC*), toys (*BS EN 71*). This provides the design agent with safe products, and quality assurance from the manufacturer. Existing standards apply to finished end products, and the processes involved in their creation. However Open Design changes the context of standardization for design agent-creators. Does one standardize the tool that creates the product? Or, the finished product the design agent has created? This paper examines the requirements of moving this activity beyond products destined for the domestic environment via the Fab Lab, or DIY processes, into the realm of Open Design by; SMEs for distributed manufacture; larger corporate entities disseminating products as "pay-per-download" (or other such); or perhaps by individual artisans wishing to release their blueprints for distributed manufacture.

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METHOD

The authors presented contextual Open Design examples (Open Structures, Thingiverse, Hallmarking, Arduino and DIY Drones) to BSI representatives in an interview to discuss;

"*In a world capable of open product creation, what does BSI perceive as opportunities for standardization in the process, delivery or product created; and what do they perceive as difficulties?*"

In addition to discussing this with BSI representatives the Authors ran a LEGO™ Serious Play® workshop with designers to test the Models for standardization created as a response to the discussions with the BSI.

British Standards Institute Discussion

Fig.2. Open Structures water heater, (Lommee 2012)

Fig.3. Open Structures grid structure, (Lommee 2012)

1. Taking the example of Open Structures (www.openstructures.net) [Fig.2 and Fig.3], and the open platform this represents, what are BSI's thoughts on the pitfalls and opportunities for the standards industry?

BSI feedback: The Open Structures example sparked a discussion around standards for design, with the *BS 8888* series of design standards mentioned. BSI noted that platforms like Open Structures are "definitely an area of interest". BSI is very interested in grassroots manufacturing, with a desire to be more proactive about changes to the manufacturing landscape, rather than reactive. Supporting innovators is a key strategy for BSI, but there is recognition of "Standards surrounding a standard"—the water heater [Fig.2] built from the Open Structures platform was picked out as an example. If such a domestic appliance were produced, there are a number of standards that might not be immediately obvious or applicable, but could be considered, if this device were to be sold in the EU.

This level of complexity presents challenges, as the different standards that intersect with the original document might not be apparent. Standards by their nature are "often dry documents"; necessarily so, as they are to be unambiguous. Translating this technical text into an easy-to-read document is a significant challenge. There was a feeling that BSI "has always been open" in its method of creating standards, as it invites public comment, and allows anyone to initiate the process of standard creation. However, there was a feeling in the discussion that the definition of "openness" was key—perhaps BSI could best be described as having an open innovation strategy. Taking one of Dahlander and Gann's (Dahlander & Gann 2010) four definitions, this might be sourcing—BSI invite innovation from the public in a non-pecuniary manner, and internalize this in the creation of a standard.

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2. BSI has a history in creating standards for processes, systems and quality control. What systems/protocols would be created for a self-made assembled product, designed by a design agent, distributed via a kit or downloaded and assembled by another design agent (particularly in relation to the use of Fab Labs as a distribution model)?

BSI feedback: The introduction of the Fab Lab concept sparked considerable interest from BSI, as it was seen as a model to help engage Small to Medium Enterprises (SME) in the use of standards for their products; an area that BSI has previously found difficult to reach. The use of Fab Labs by SMEs (perhaps on days at the Fab Lab that are privately rented as a revenue source for the Lab) was a new concept to BSI. The discussion about self-certification (using hallmarks, for example) led BSI to be wary about this method, since it may compromise the effectiveness of the standard. BSI recognized that their traditional model for funding was more appropriate for large corporations with the means to send personnel for training, and to buy copies of the relevant standards for themselves. BSI is actively seeking new ways to engage (and therefore fund) standards for other entities—with SMEs being a particular focus.

During this discussion, the idea of "pay per download" (PPD), or a royalty scheme was suggested. These ideas have possible legal issues that would require resolution, with the current status quo having a concise definition of BSI's legal standing in relation to the creation of a standard that a corporation might apply. The use of a royalty or PPD system may change the legal footing of the standard; potentially exposing BSI to charges of complicity in a faulty product.

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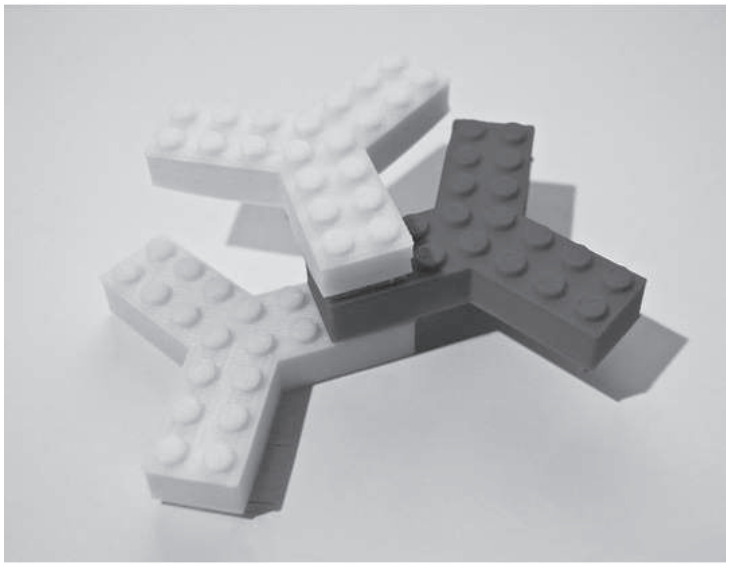
Fig.4. 3D printed building blocks



BSI feedback: Currently, there are standards that govern the process by which a product is designed along with many other granular aspects of the development process. There was the suggestion that an application of a standard to Open Design would be about the process by which the product is designed. What was considered when certain aspects of the product were conceived? Designing toys was a popular example in the discussions [Fig.4].

One idea was that standards might be applied "further up the supply chain", and begin with the manufacturers of 3D printers (as an example). The printer would identify the appropriate standards from the file (e.g. via metadata), or the maker could be prompted "prior to print" through a checklist procedure ensuring that the maker had considered alternate factors surrounding their design. This would then print, or grant access to the full standard if the procedure was deemed appropriate. The BSI suggested a nominal fee, with standards delivered via the 3D printer manufacturer's website as a distributor. There was a feeling this method would be more suitable for SME engagement in Fab Labs, but perhaps not for individual domestic makers.

Fig.5. Silver Hallmarking

3. What would BSI's standpoint be on digitally approving products, imprinting or certifying a digital hallmark into individual products? What would it communicate and what would bespoke digital manufacture bring to standards?

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BSI feedback: The difficulty in allowing a person to self-certify centers around the scope of the standard; especially for such disparate objects as those created by makers in Fab Labs, and in their own homes. As such, the use of a self-certified hallmark (as opposed to a third party certified quality mark, like BSI's Kitemark) was not enthusiastically received by BSI.

However, the layout of a "maker's hallmark" could be standardized including, for instance, the maker, identification of the Fab Lab, and the country of origin. The concept of a digital hallmark raises wider questions of counterfeiting and liability in cases of misuse. This notion of hallmarking was recognized as not being a new idea since Artists sign their work as an approval of its authenticity.

4. In a world of pay per download would BSI consider similar certification processes to ensure SME's could PPD rather than an initial investment, securing a longer-term revenue stream?

BSI feedback: The radical shift from the traditional funding model of selling individual standards, or licenses to access the entire catalogue to a PPD or royalty funding model highlighted significant challenges for BSI. In particular, the "cost to setup and manage a system" such as this one, with multiple funding streams coming in does not exist at BSI presently. Similarly, there are legal issues, as touched on above. The concerns centered around legal liability, and the economics of charging smaller royalties regularly, rather than large amounts initially. This became complicated when weighed against the choice the company has to comply with a standard, or to not (but declare as such). In a royalty-fee system, the BSI could face a situation where a "company pays for a standard and then it is their decision to comply or not comply". The BSI is actively seeking new business models for revenue — and something similar to PPD or royalties might spur a 'new product lifecycle' for standardization.

These factors raise the question; "How can the application of standards to the Open Design process be delivered, to benefit the designer in the act of designing, and the maker in the quality assurance of the designs received?"

OPEN DESIGN STANDARD INTEGRATION MODELS

The discussions with BSI representatives, resulted in the creation of design models enabling design agents to pursue "Open Design activities in compliance with standards". The context of the models is critically based on the target audience for an "Open Design system" and could be applied fordesign agents, SME's or enterprise. 3D printing is used as an example in some models due to its popularity, however the models themselves could represent a wide (and expanding range of DDM techniques.

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1) Standards pre-approved manufacturer parts library (Model 1)

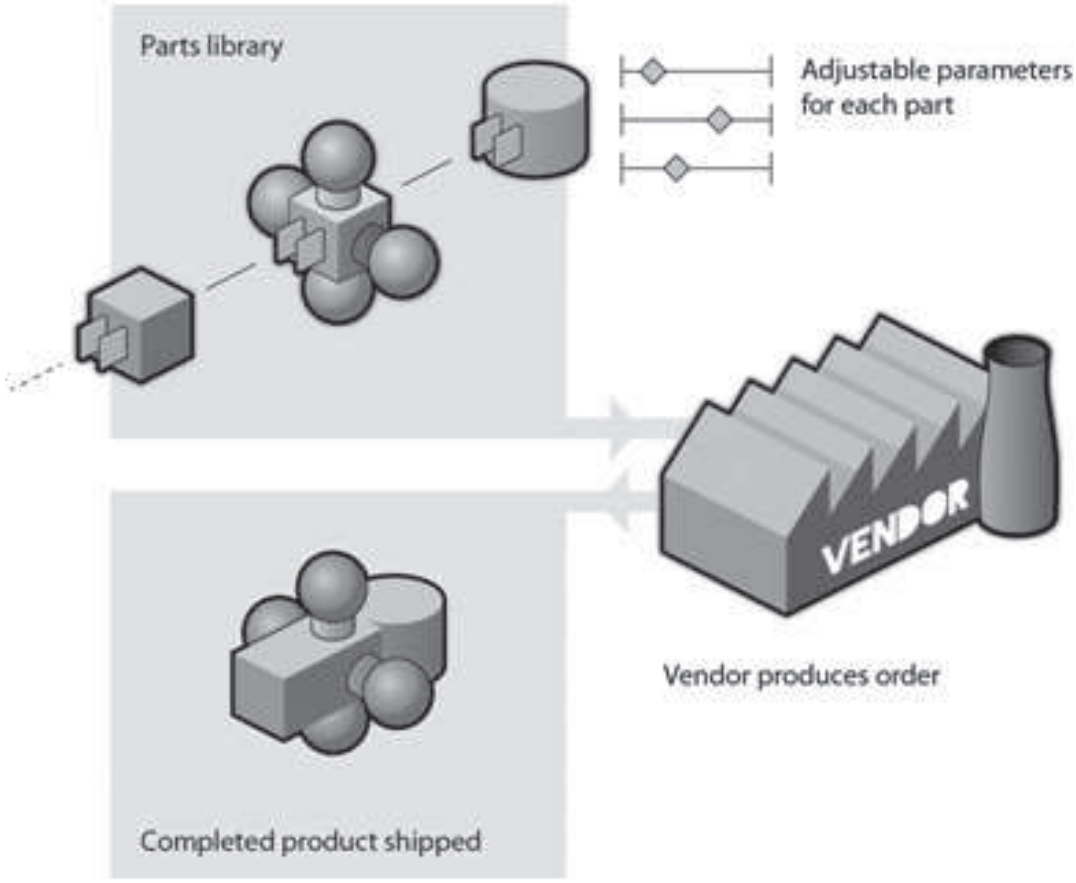

Fig.6. (Model 1) Specification of individual parts, in a mass-customization mode

This model illustrates the mass customization of an object—since collaborative elements might not be required, and the only aspect that might be open is if the maker (who specifies some parts, or an assembly from those parts) could share that data. Even though Mass-customization is not Open Design (it does not provide design information for alternate use), it is a step to design agent controlled standards approved products. Some parts suppliers (*www.mossexpress.co.uk*) already provide 3D models of products for "scale & fit" not for standard compliance, suggesting viability of such a system.

2) Upload approval process (Upload & Download/Model 2)

The design agent uploads their file for analysis, and the system suggests design alterations or networking to complement a design agent's components based on the file attributes. Design agents could then contribute to component/product libraries for alternate parties to buy or use.

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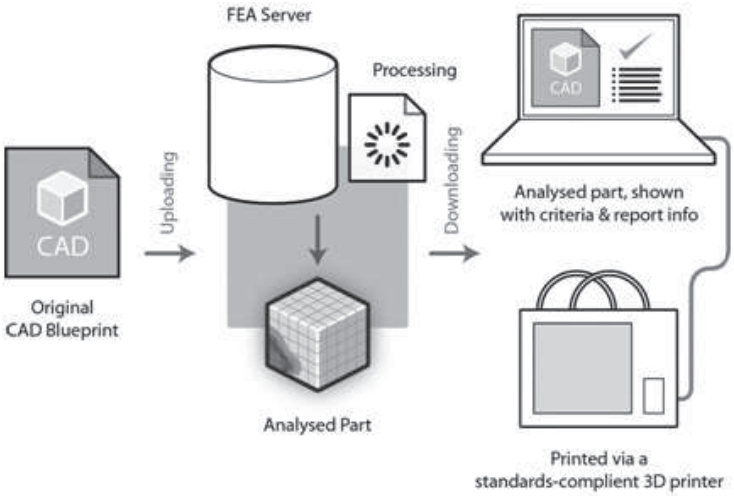

Fig.7. (Model 2) FEA analysis of a part, and electronic verification for appropriate standards to suggest/apply.

This model combines the BSI notion of a standards-aware domestic 3D printer (or equivalent manufacturing technique), and a cloud-based service providing detailed analytical information of the digital blueprint. In much the same way that Shapeways analyzes the CAD files uploaded to its service for their viability in different manufacturing processes, this service would go further and analyze the structural integrity of the finished part based on Finite Element Analysis (FEA). This service would therefore provide design guidance to the uploader of the designs, suggesting improvements based on the selected end material, and the stresses/use case prescribed. In order to make the use of such a service compelling (and therefore, economically viable) a suitable design agent experience would need to be developed to lower the cognitive barrier associated with FEA.

This information about standards compliance, combined with the structural report as to the integrity/durability of the part for its stated purpose would be made known to the person downloading the file—and perhaps even embedded within the data itself. Based on the analysis of the part, the report could also highlight applications inappropriate for a part; if an object is submitted that has sharp edges, or small parts, then an accompanying note could advise against its use for a child's toy.

If the producer decided to use the part for an application outside of the original scope for the product, then the original designer, and the service would not be liable since the information (contained in the report) would outline what the part was rated to achieve. In the same way that a person may use an artefact in any number of ways that the original creator did not envisage (and is not therefore liable). The aim of these systems is to instill confidence on the part of the producer that the proper due-diligence has been undertaken by the designer—the mechanism outlined aims to lower the barrier to entry for the amateur designer to access the useful and rigorous guidelines contained within a standard, whilst concurrently exploiting that technology to

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add value to the process for the designer uploading their designs (via the use of FEA).

3) Design agent defined pre-approved library
(Upload & Download/Model 3)

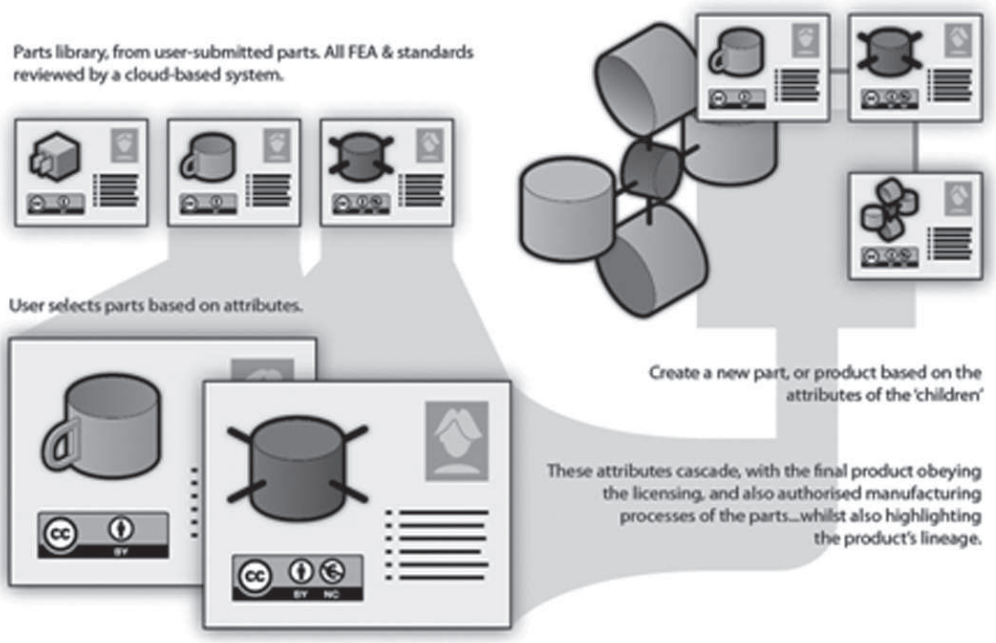

Fig.8. (Model 3). The combination of design agent-designed parts, cloud-based FEA, and lineage of the included parts.

In this system, the designer can search for and include parts that have already been verified by the system in their own designs. These parts can be combined into products, or assemblies for products; at every stage with the lineage of the parts available. This lineage is important, as it allows the licenses applied to the parts to cascade down, with the most restrictive license dictating the overall license of the finished product. Similarly, the lineage will dictate the final DDM process; if one analyzed part can only be reliably produced at a Fab Lab, then this would set the conditions for manufacture for the overall product. This then would best ensure compliance with licensing, and also the electronic guidance based on the standards.

The lineage of components would show the bill of materials for the artefact, and help to credit the people who have therefore contributed to the creation of the new artefact. Of course, these systems are not intended to restrict the creative interpretation of the producer (except where licensing dictates), since the intended use of the final artefact might be outside the scope of the original component. This free agency of the producer places the liability on them. The issue of control is touched upon here—as the process by which the models are analyzed

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might rely upon a proprietary technology to provide the FEA, or measure against the standards available. In taking the democratic principles that underpin the Open Design movement, this would mean that such a system should not seek to be the only method by which files are disseminated; rather, it should be a system that adds value to the eventual customer of the artefact (this may or may not be the producer) by demonstrating the trustworthiness of its design, and construction.

LEGO™ SERIOUS PLAY® (LSP) WORKSHOP

Creative strategy tools have gained much traction in the business sphere, with many coming to prominence through the use of the term "Design Thinking".

In order to allow for a participatory exchange of ideas around the Models proposed above, an LSP workshop was organized with designers. An approach that allowed for genuine participation (Luck 2007) was essential to allow for a full critique of the models. LSP is fundamentally concerned with communicating ideas via metaphors rendered in 3D using LEGO bricks. This has the advantage of being readily and immediately accessible, whilst also a powerful means of thinking through making. This experiential learning (Piaget's constructivism) through doing helps bring the mental models of the participants into a physical artefact able to be critiqued and reflected upon (Papert's constructionism).

LSP was developed by The LEGO Group as such a strategy tool in 1996 in collaboration with Johan Roos (Roos, Victor & Statler 2004), for use at a boardroom level, tackling open-ended questions that have a high impact on the core activities of a business. LSP has moved beyond the boardroom and into other spheres, such as pedagogy (James 2013) and healthcare (Swann 2011), due to the potential for the methodology to tackle exceptionally complex or open-ended questions. These often involve personal, political, emotional, social and cultural dimensions which are easily missed in a systems approach, or a tokenistic method.

The workshop followed a simple structure of introducing the LSP kit to the participants. The introduction was followed by a presentation on Open Design giving contextual examples. Finally, the participants were introduced to the open design standards models.

WORKSHOP OUTPUT

Response to Model 1

The designers engaged with Model 1 by building the process as a linear metaphor. An example is given in [Fig.9]—the designer created a one-way flow of data from the digital world to the physical. The output is a car, a device that is heavily regulated and expensive—suggesting that the benefits of rapid manufacture are well matched to complex, dif-

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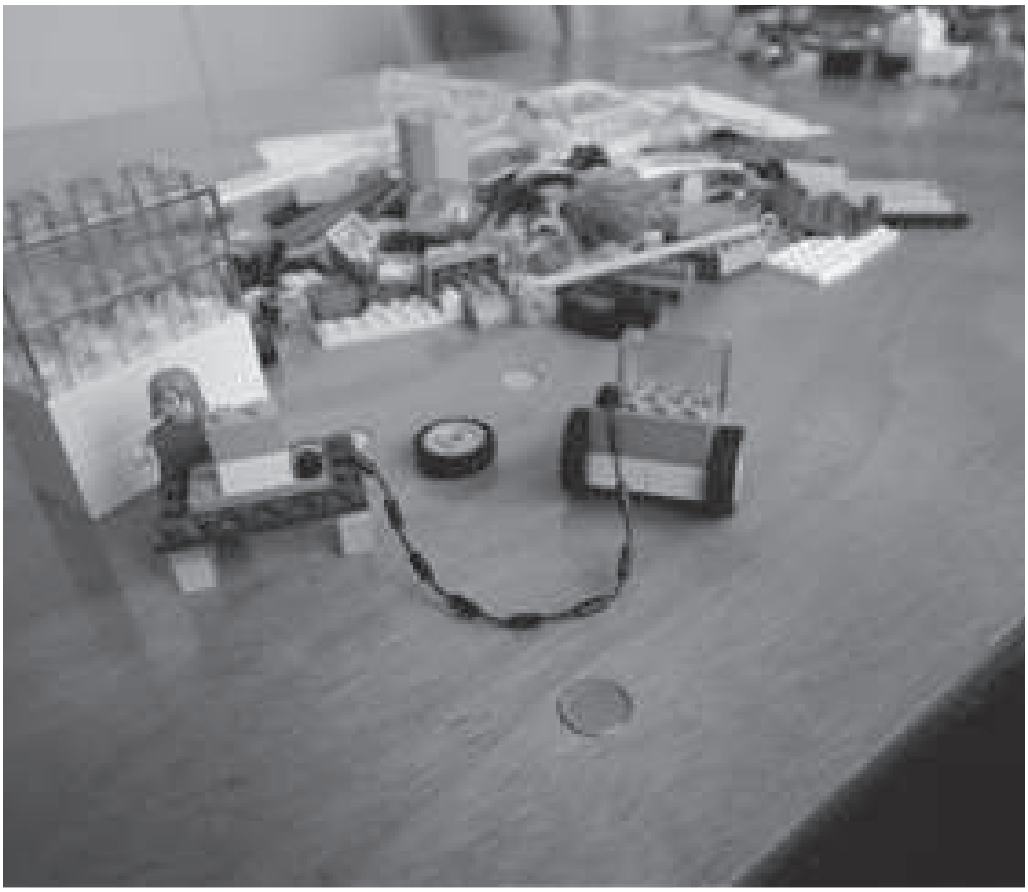
ficult to regulate products perhaps beyond the scope of an individual artisan. The designers felt that Model 1 should have gateways to check the product at stages of importance, designed into the design agent experience of the enabling software platform.

Branding was an important feature of this process, as it was felt that Model 1 could extend to a branded product; or that this might be a good way for a brand to foster engagement with a product offering that is difficult to release as a fully Open Source artefact (due to the regulatory burden, for instance).

The biggest criticisms of Model 1 came from the supporting system cost, and how this might be borne by SMEs with restricted capital that larger brands have. Similarly, how this cost might be borne by individuals—either individual makers (who use the platform for making their own work available), or "pro-ams" who use the system to create bespoke products. It was felt this could potentially be the biggest barrier to entry for the implementation of Model 1. There was also the recognition that this process is not actually Open Design. Hence the recognition that this might be useful for Brands, and some SMEs, but missing the point of Open Design somewhat.

Fig.9. Artefact A, created in the LSP workshop



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Response to Model 2

Model 2 provoked reactions that were less linear, as highlighted by Artefact B [Fig.10]. Here, we see a central column denoting an authority (with the crown), that judiciously applies the FEA and therefore analysis to individually uploaded blueprints. This is the central pivot around which the collaborating makers orbit—they combine in an environment that is strengthened by the extra data provided by the service. The complex nature of this design process was highlighted in Artefact C [Fig.11], with the red paths representing the touchpoints with Model 2 for critical components, and the grey paths representing the non-critical aspects of the design.

However, the restrictive nature of the analysis was a concern (Artefact B is built on a small base, not diffused very far), as was the ambiguous nature of the authority. What is the motivation of the authority providing the FEA service? The participants were skeptical of a "pay per download" model, pondering about individuals and small SMEs use. Instead thinking that an "in-house" service might be more appropriate; for instance, a Fab Lab providing or licensing the service from member's dues, rather than this being under the control of a dispassionate corporate entity. This response came in conjunction with concerns over the perceived *value* to the maker of such an FEA system; or indeed, the barrier to entry that such a complex system might have (with a steep learning curve).

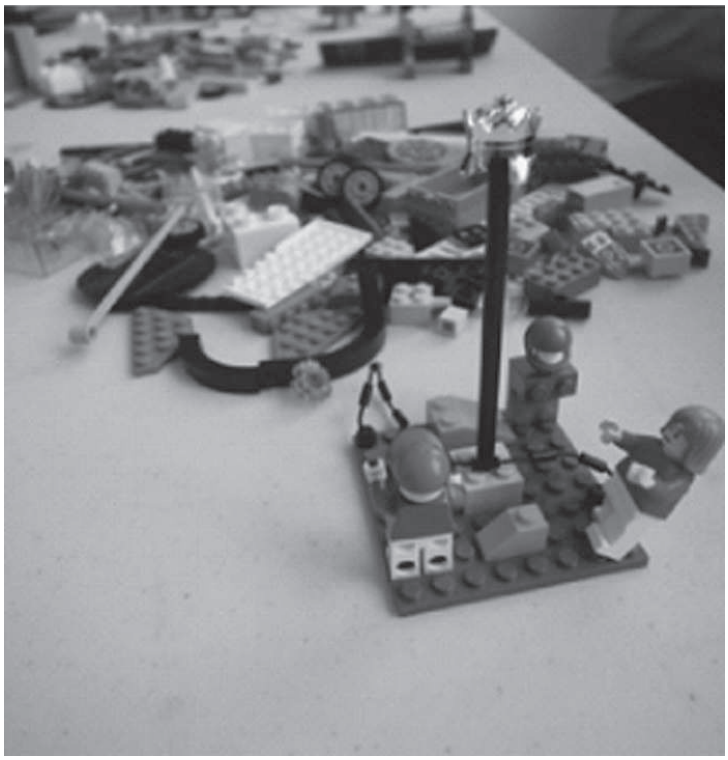

Fig.10. Artefact B, created in the LSP workshop

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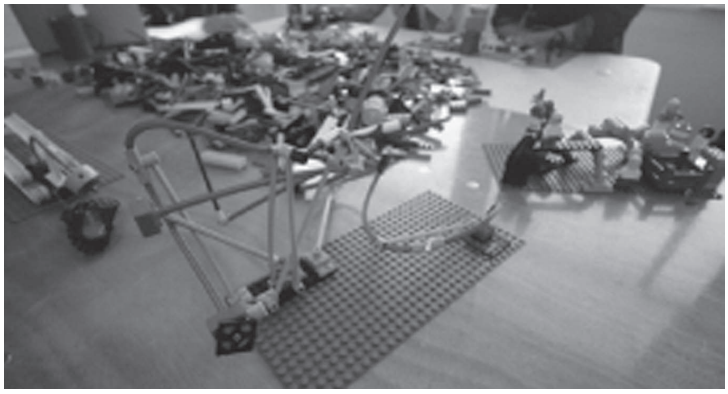

Fig.11. Artefact C, created in the LSP workshop

Response to Model 3

The artefacts created in response to this model featured feedback loops required for meaningful combinations of individual artefacts, suggested in Fig.12 by the flexible sections connecting the modules from different creators. This feedback should therefore actively notify makers of derivations made. The creator of Artefact D initially thought about singular objects, but through the process of modelling and critically thinking through the scenario posed by the model began to represent and comprehend elements that work in unison.

Concerns were raised about the ability for the system to comprehend all real-world aspects of the objects in use, and that this predicated the use of standardized (or "approved") digital manufacturing techniques. The concerns about the "authority" behind this work were also carried forward from the analysis of the previous Model 2. The applications of standards are often linked to the *process* that the designer/maker has followed, rather than just the finished product. Meaning that the use of a hallmark, or "maker marque" might be necessary in conjunction to this system denoting that the product has an appropriate provenance, and that a standardized process has been followed.

Fig.12. Artefact D, created in the LSP workshop

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DISCUSSION

This paper begins a discussion around the application of standards and meaningful provenance in DDM products, to allow for Open Design to have a role in sectors where a tight adherence to standards and regulations is absolutely required. The authors recognize that various standards function in unison, with production processes and dynamic factors that are difficult to simulate in software, but that this is an area for further investigation. The creation of standards can be expensive so the viability and justification of "why the access needs to be open" requires scrutiny.

Open Design also can present pitfalls in file or product misuse (Phillips, Baurley & Silve 2013) going against the creators intention, the most topical example of this is the Defense Distributed (*www.defdist.org*) open source weapons project. The ideas of cascading "rights" through the product provenance could be used to communicate a maker's wishes, but ultimately the freedom to "derive a product" from another is a cornerstone of Open Design. In discussions around Artefact D [Fig.12], the feedback loops could be used to keep design agents informed of work based on theirs. Whilst using "Open Design Standards" is an opportunity for NGOs, charities and those who cannot afford the traditional standards method, it has to clarify products or scenarios that it is not prepared to cover/standardize. Design agents already take responsibility for the construction of products and procedures. For example: car repair manuals (*www.haynes.co.uk*), household DIY (*www.harpercollins.co.uk*) and home beer brewing (*www.brewuk.co.uk*). The bigger question is, who is liable for using or adapting a "design agent created Open Design"? The models [Figs.6-8] propose ways that design agent-created products can be "standards compliant". Companies giving design agents control through digital manufacture of products opens opportunities for: "point of sale" design agent-adaptable manufacture; expanding on others parts; expanding business opportunities for geographically dispersed communities, and realizing compliant "downloadable" products. This might lead to companies allowing alternate parties to use their parts or components, whilst still crediting the original creator.

This partnership could offer opportunities to NGO's and organizations not usually able to develop products. For example, "charities forming alliances with communities to create products that inform a wider community cause" (Phillips et al 2013). A central charity or organization could create product plans that design agents download or produce in a local Fab Lab. This concept could also expand to develop medical product prototypes as open source hardware,having potential benefits for multiple stakeholders (Dexter, Atkinson & Dearden 2013) yet the issue of standardization and the ability to trace the product's development process is currently unresolved with current tools for the facilitation of distributed, collaborative design. Open design, enabled by distributed

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digital manufacture enables people who would traditionally be excluded from the collaborative development of medical devices to have a role in their development; beyond simply being consulted on human factors/usability studies of a completed device. There are existing projects investigating the marking and tracking of 3D printed objects mainly for the purposes of intellectual property and authentication of an item's provenance (Seabrooke 2013). These considerations of watermarks do not consider the functional or contextual nature of a product. This initial discussion raises several questions including what repeatable symbols or watermarks do digitally manufactured objects require for standards compliance.

We imagine that the cloud-based system here defined as being the provider of the FEA suite and the standards compliance, would be a Notified Body—e.g. testing services laboratories in the current sense of standards compliance. The cloud-based FEA and standards analysis that this service would provide would be most advantageous to SMEs and corporate clients. If a "pay-per-download" or subscription based model was used, then this would broaden the market for standards provision beyond the high-cost, low-volume market currently delivered. Similarly, the use of a system like this could be advantageous for large brands wishing to foster engagement with their customers—as per the discussion around Artefact A [Fig.9].

Such a new market for standards could coexist with the existing one, as alluded to in the interview with the BSI. As SMEs use a service such as this, the utility and efficacy of working with standards could become more apparent and deepen the appeal of purchasing reference volumes. Standards are encouraged when selling products that an entity has produced; yet standards for open-source products cannot make such a distinction. A maker might design and produce an artefact for their own use, but if adopted and produced by another maker for retail (assuming the originator sanctions this), is it fair to insist that the original maker always seeks the proper standards? From the LSP workshop, can the individual maker bear the cost of the pay per download of the standardized (FEA analyzed) plans? Similarly, questions remain about the level of certification required for a part or assembly, and whether this can be determined by the digital system in a meaningful way [Fig.12].

Outcomes of the discussion could lead to standards integration opportunities within Open Design, both short and long term. Initially standards accessible within Fab Labs could help enable SMEs to integrate standardized products in approved spaces for international fabrication and local product distribution. Longer term, a plugin for CAD or digital fabrication layup software could integrate standards, enabling co-creators to produce downloadable products meeting quality and safety approvals. Standards could be a brand differentiator between domestic and profit based manufacturing. Raising the bigger question, "when should a design agent of an Open Design process, be aware of

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standards affecting their output and who in the process enforces or dismisses that protocol"?

Material simulation is already considered of benefit to designers and engineers who use sophisticated CAD software. Since rapid prototyping can still be a lengthy process for very complex parts, and as such guidance on the structural integrity of a blueprint before prototyping can mean that the design process is further expedited. Domestic additive manufacturing (or, Fab Lab based) does not incur the same expense as industrial processes (especially those using exotic materials, or finishing), but building complex models can still take a long time. As per the discussions around Artefact A [Fig.9], there may be a place for a cloud-based system of FEA for objects of significant complexity as a way to mitigate certain aspects of this and lower the barrier to entry for makers. However, the models would require real world testing to ascertain at which point the complexity of the processes becomes too high a barrier to entry for makers, and whether the system complexity is sufficient and valued by makers.

It may be that design agents of a service that implement standards as a means by testing the compliance of digital blueprints actually performs as a business. This could give design agents access to complex processor-intensive simulations, with the standards procedure forming the rigorous foundation upon which a consumer-facing FEA platform is built.

CONCLUSION

From the discussion with BSI, there appears to be short and long term perspectives with relation to the application of standards within Open Design practice. For instance, the use of Fab Labs to support SMEs in the act of designing (via process standards) or testing (through creation of their own test equipment to BSI standards) could be considered open via an open innovation model; the SMEs might not release their plans to wider communities as open source. However, this approach could be a stepping stone to define the legal ramifications, and economic implications for UK and international standards bodies. Overcoming these new challenges to the traditional funding, and legal positions would then lead to the long-term view of domestic production by individual makers. These may engage with a Fab Lab, but on different terms (if they visit the Lab for free, reciprocity in sharing their ideas source would be expected—therefore open source). This model might require the implementation of standards further up the supply chain; the manufacturers of domestic digital fabrication equipment becoming licensed vendors of standards, providing portals to checklists and considerations for the individual maker—or the ability to scan the file for FEA or reading the metadata from the file (if downloaded from a repository, such as Thingiverse) to check the intended use.

Standards provide valuable guidance for designers, with important considerations and information; but they are also complicated, opaque

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documents. There appears much to be mutually gained by both makers and standards industries in successfully implementing a method facilitating the application of standards within Open Design practice. This would include translation effort for standards, perhaps akin to the work of Creative Commons, providing a "human readable" layer to the standard. This non-binding (in a legal sense) summary could assist the maker in judging whether the standard is right for them, with benefits for the existing BSI funding model also.

FURTHER WORK

These discussions with BSI have not closed the questions originally asked; if anything, these questions have broadened territories within this investigation. For further research, the authors suggest a PhD inquiry into these approaches would be appropriate. Standards might not simply cover the design of the final artefact however, and could instead facilitate the creation of a "maker's hallmark" layout for digitally distributed designs. This mark could not function as the BSI Kitemark does, but would instead indicate an agreed layout of information to identify an artefact. This information could act in addition to the application of Creative Commons licenses (identifying originators, and archiving version numbers or derivatives) and with the use of machine readable elements (such as QR codes) they could allow for augmented hallmarks with digital and human readable information.

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