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# Raising new opportunities for the Next Economy by exploring variable user needs for Computational Co-Design

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**Abstract:** Digital Fabrication promises to revolutionize manufacturing, bringing both economic, social and environmental benefits. Combined with Computational Co-Design it can raise the creative potential of both designers and users. However, today the productive use of Digital Fabrication and Computational Design requires significant effort and specialised know-how, so valorising these practices calls for the identification of the application fields that benefit the most from them. This paper presents a tool for helping the discovery of design opportunities across comprehensive, ramified lists of product categories, where designers can identify possible points of intervention. The web-based tool allows the rapid evaluation of numerous product categories according to an extendable set of factors and inspiring questions related to the necessity of personalization, aiming to stimulate designers to consider unexpected frontiers of innovation. Beyond the scope of the research project, this tool has the potential to assist designers in finding applications also for other emerging technologies in a structured and scalable way.

**Keywords:** technology transfer, ideation, methodology, matrix, software tool

## 1. Digital Fabrication: a (yet unfulfilled) promise for the Next Economy

More than half century have passed since the first Computer Numerical Control (CNC) milling machines have emerged, offering to perform accurately repetitive production tasks which are either difficult or impossible for humans. CAD, CNC control and robotics have transformed mass manufacturing, and the gradual proliferation of Information and Communication Technologies has recently led to a spectacular democratisation of the access to a series of Digital Fabrication technologies, both by connecting efficiently users to machine owners (e.g. web platforms) and by lowering the cost of “sufficiently performant” machines, most notably 3D printers. This latter has captured the public attention, through the sci-fi-like promise of materialising objects where and when they are needed, with no alienating, repetitive factory labour involved. While current DF technologies are far from achieving this level of performance and versatility, they are already helping

the emergence of a smart, distributed and on-demand model of production, a trend often denoted by the Industry 4.0 term (coined in 2011 by a German hi-tech industry research programme).

Design has a long tradition of working with DF as a prototyping tool that bridges the gap between the digital project and physical model, between virtual and real, allowing the verification of functional and morphological ideas. Beyond DF for prototyping for later mass production, the (greater) morphological freedom of DF have also stimulated designers to create shapes that were impossible with conventional manufacturing, such as the now iconic Lotus.MGX lamp (by Janne Kytanen, 2003), an early example of this opportunity. But beyond DF for the morphological freedom of costly design pieces, the recent development and democratisation of DF machines is allowing to turn them into increasingly affordable production tools of everyday products, available not only in well-capitalised factories, but also to SME-s (fundamental in EU and particularly Italian economy), and even to artisanal micro-enterprises, design studios or individual designers. Recognising this phenomenon, authors like Anderson (2011) and Lipson (2013) have envisioned the emancipation of the maker figure, the digital artisan who brings back manufacturing from the far East, creates prosperity and fulfills everyday needs of the people, maybe even better than mass manufactured goods.

While there are positive examples, as of 2017 the occurrence of products made locally with DF is still extremely low in common households: typically none. This poses a threat on the economical sustainability of DF-related activities, as pointed out by Holman (2015), from individual practitioners through collaborative Makerspaces and Fablabs (which are often publicly financed) to 3D printer brands (e.g. the recent Makerbot backlash). The low occurrence of digitally fabricated products can be attributed to the immaturity of DF technologies, but if widespread adoption has not been realised, the desirability of the offering seems a more probable reason. For comparison, the first smartphones appeared in 1994 and widespread adoption started in 2007 (with iPhone) – today smartphones are ubiquitous, 3D printers or their outcomes are still rare.

Hence, we can suspect that a shortage on the part of the Design profession, which has the role of connecting industrial capabilities with human needs. However, as far as DF concerned, it seems that Design has not found a wide enough range of applications that could grant a major role to DF in the production of the everyday artefacts. While B2B DF is well-established in many performance-sensitive niches, DF for consumer products is used principally to achieve decorative effects on products of marginal functionality. We must admit that competition from traditional industry is extremely strong due to the efficiency and low cost of the economy of scale, as well as the wide and immediate availability of numerous options both in physical and online retail. Nonetheless, in order to valorise adequately DF, designers should accept the challenge to come up with viable and desirable solutions for a wide range of everyday needs, with a deep consideration of the (still serious) limitations of DF as well as the novel opportunities it offers.

## **2. Computational Co-Design: an approach to valorise Digital Fabrication**

To compensate Digital Fabrication's shortcomings of cost/quality, designers should offer significant benefits by exploiting its most characteristic strength: the independent elaboration of workpieces, resulting potentially unique products, which can be an essential part of the product concept in order to accommodate user diversity in physiological needs and aesthetic preferences. Such adaptability is what Mass Customisation has been aiming since its introduction in the early 90's at well-capitalised industries such as automobile and footwear (Pine, 1993). Subsequent practice and academic

research have produced a rich literature around the topic (e.g. proceedings of the Mass Customization & Personalization Conference series).

Recent technological development has lowered the necessary investment to start this practice, allowing also smaller organisations to offer customised products with the Industry 4.0 approach, at a reasonable effort and price point. With DF even micro-enterprises can offer to rapidly tailor a variety of products which are typically mass produced today. While a great part of the repetitive or precision labour of the artisan can be shifted from the hand to machines, that machine still needs a virtual model of the personalised product to be fabricated. Emerging parametric modelers (e.g. Grasshopper) can be used to generate a diversifiable CAD model which can be personalised by modifying a set of parameters, effectively incorporating designer's understanding of the object in a flexible way through an algorithm. Computational Design (also called parametric, generative or algorithmic design) can help to act similarly to an artisan with deep knowledge of 'tailoring', with the difference that creating an effective parametric model is a one-time effort, after which the effort needed to produce personalised instances of the product is minimal.

While the use of DF for personalisable products with Computational Design (CD) needs less investment in equipment and logistics, more effort is needed to develop the parametric model which offers an adequately wide 'solution space', to use a term borrowed from the mass customisation literature (Piller 2009). Another essential element of successful mass customisation is 'choice navigation', that is helping the user to find the right solution among the possibilities without an excessive burden of choice; this is equally important for the discussed topic of small-scale on-demand production, and it requires a creative use of technological possibilities. In other words, the designer should adopt an Open Design approach, meaning to "become a metadesigner who designs a multidimensional design space that provides a user-friendly interface, enabling the user to become a co-designer, even when this user has no designer experience or no time to gain such experience through trial and error" (De Mul, 2011).

Therefore, creating an unforeseeable multitude of products needs a different design approach compared to designing a single solution: user diversity should not be circumvented, but considered as a resource to create authentically personal artefacts. This opportunity is well acknowledged in the literature on Open Design; however, as Cruickshank (2014) notes, providing adequate guidance is fundamental: "with too much structure the outcomes are controlled by the hidden hand of the designer and people are simply selecting from a range of options laid down by them. Too little support and many potential creative contributions are lost because starting from a blank page is difficult, even for experienced designers." Hence, aiming a widespread adoption of open design practices calls for a systematic work to find out: what and why should we diversify? While the overall investment need has decreased, it is still important to develop products which the users will desire to personalise, strongly enough to offset the necessarily higher cost and effort of obtaining the product. For practicing economically sustainable DF it can be extremely useful to identify which products make personalisation particularly desirable and how hard that personalisation process is with the current technological possibilities (of DF and CD).

Finding ways to expand application fields towards currently ignored product categories could facilitate the diffusion of DF for what it can do best today, and therefore speed up the process of adopting a local, on-demand model of production, potentially leading to positive consequences regarding employment, economy and sustainability.

### 3. Application fields for Digital Fabrication and Computational Design

As we have seen before, a need has emerged to apply radical process innovations (DF and CD) across as many product categories as possible, which poses a challenge from the methodological point of view. Today, most design methods focus on target users or functionality, while valorising new manufacturing technologies and a new CAD paradigm might require the comprehensive exploration of all product categories for opportunities, rather than heuristic idea generation. The barely structured initial phase of the new product development (NPD) process which includes opportunity identification, analysis and idea creation, is also called “fuzzy front end” of innovation (Koen, 2007), indicating the unpredictability of the results. This might be unavoidable in case of product innovation based on novel functionalities, but DF and CD are process innovations aimed at the transformation of the entire design-production-consumption chain, suggesting that there should and could be methods to identify reliably new product opportunities that benefit from such promising technologies.

This paper aims to contribute to the development of DF and CD by offering an approach and tool for the comprehensive opportunity exploration. As a first step towards developing a useful methodology, we must recognise that in marketing terms it will need to support a strategy of Technology Push, rather than Market Pull, which is more dominant among design methodologies, being focused primarily on user needs. There is a debate whether Push or Pull is the better for leading to successful innovation; according to Osterwalder (2014), “Contrary to popular belief, great new value propositions don’t always have to start with the customer. They do, however, always have to end with addressing jobs, pains, or gains that customers care about.”

DF and CD have a characteristic set of advantages and limitation, hence leading to a peculiar set of design principles. Therefore, a systemic investigation for new application fields should consider a corresponding set of enabling (or disabling) factors. While a creative mind might be able to consider rapidly and intuitively a wide variety of possibilities, the high number of possible enabling factors and product categories to consider suggests the necessity of an accurate mapping. Such mapping should help to clarify the possible extent and evolution of DF and CD, as well as to the ideation of new, market-ready products, especially for SMEs.

## 4. Mapping opportunities: principles, axes, tool

### 4.1 Principles

The mapping previously identified as useful for the progress of DF and CD will need to offer the opportunity of exploring effectively a series of product types, examining the presence of a series of enabling criteria. Crossing these two series suggests a tool formatted as a matrix. Discussing product concept design, Keinonen and Takala (2006) note how industries (particularly engineering ones) have traditionally trusted various matrix methodologies for evaluating their products. On the other hand, in the community of industrial design there is a mistrust towards formalised approaches, which, however, can be comforting when trying to achieve borderline possible innovations. As a precaution, the authors also note that various causes can render counterproductive the so-called scoring methods during the conceptual development of new products: the difficulty of quantification, the risk of mediocre solutions, the lack of logical structure between aggregated scores, and the large effort needed.

Being conscious about the risks, we uphold the opinion that in our case, a matrix method can enable a useful systemic investigation because the visual recording in a matrix can offer a rapid visual feedback regarding the progress. The valorisation of a technology in previously ignored fields requires a significant mental effort, which will not result particularly promising concepts in the majority of examined product categories. Nonetheless, it is important to register also the encountered difficulties. because it can help to identify not only the right directions, but also the sectors where the designer should expect major difficulties. If used well, Matrix tools can help to recognise interesting patterns of promising points of intervention, while acknowledging also the effort made to consider less promising product categories, incentivising an accurate and therefore reliable exploration.

## 4.2. Mapping axes

Considering the high number of product categories on the highly articulated contemporary market, no mapping of potential application fields can pretend to include all possibilities. Nonetheless, choosing a well confined field and deciding the depth of the investigation according to the available human resources, an organisation can have a homogenous exploration with more or less details within the main sector of its interest. Therefore, it is crucial to choose the adequate elements to examine with the necessarily limited resources. The list of products and the list of criteria can be considered the two axes of a cartesian mapping.

The usefulness of this kind of investigation depends on two main factors:

1. the completeness of the product list to be examined
2. the relevance of the evaluation criteria list

1. The list of examined product is useful if it includes and thus enabling to consider numerous fields which are unexpected for the person who carries out the exploration, so it would be ideal to start from an already existing and objective list, possibly allowing extension. According to the working scenario of the designer we can hypothesise various sources. Considering a client that sells a range of specialised products (e.g. sporting goods) one can start from the hierarchical list of the products sold, to be evaluated and expanded where necessary. Considering a client with manufacturing equipment (FD machines) but without direct retail channels, one can start from existing product taxonomies: various organisations have already published hierarchical lists for tracking commerce. Some examples are the Standard International Trade Classification, the Combined Nomenclature of EU or the Google Product Taxonomy (with over 5000 categories organised in 5 levels of hierarchy).

2. On the other hand, the effective mapping requires a well-reasoned list of evaluation criteria which could stimulate the identification of the enabling factors and hence facilitate the application of the innovations to be promoted. In case of the current research, we are aiming to valorise DF for personalisable products through CD. Therefore, the enabling factors are those that allow the variability of the examined product; the current research have identified 9 main criteria organised in 3 groups:

- Physical variability: functionality and performance, ergonomics and physiologies, material circumstances
- Psychological variability: culture and society, emotions and aesthetics, experience and narrative
- Technological variability: morphological freedom, material resistance, special components

To each factor (here represented with keywords) corresponds a quantitative question which asks to evaluate approximately the variability of various aspects; high evaluations would indicate greater probability of developing viable personalised products according to the evaluated parameter. The described system of criteria is specific to the objectives of the doctoral research of the author, who aims to valorise DF and CD, but the same logic of analysis according to a structured list of criteria could be applied also to other projects aimed at the technological transfer.

### 4.3. Mapping tool

Considering the high number of elements to examine, the mapping requires not only well-chosen criteria of evaluation, but also a tool to minimise the time of compilation while maximising the quality of the observations made. As mentioned before, engineering design use matrix method with enthusiasm evaluating solutions, e.g. weighted decision matrix, solution-selection matrix, grid analysis, Pugh matrix analysis (Pugh 1991). Regarding the phase of preliminary analysis the widespread Design Structure Matrix (Eppinger, 2012) allows the discovery of logical groupings within complex systems of numerous components. These matrix methods can be practiced through popular software such as Excel and a few specialised software tools.

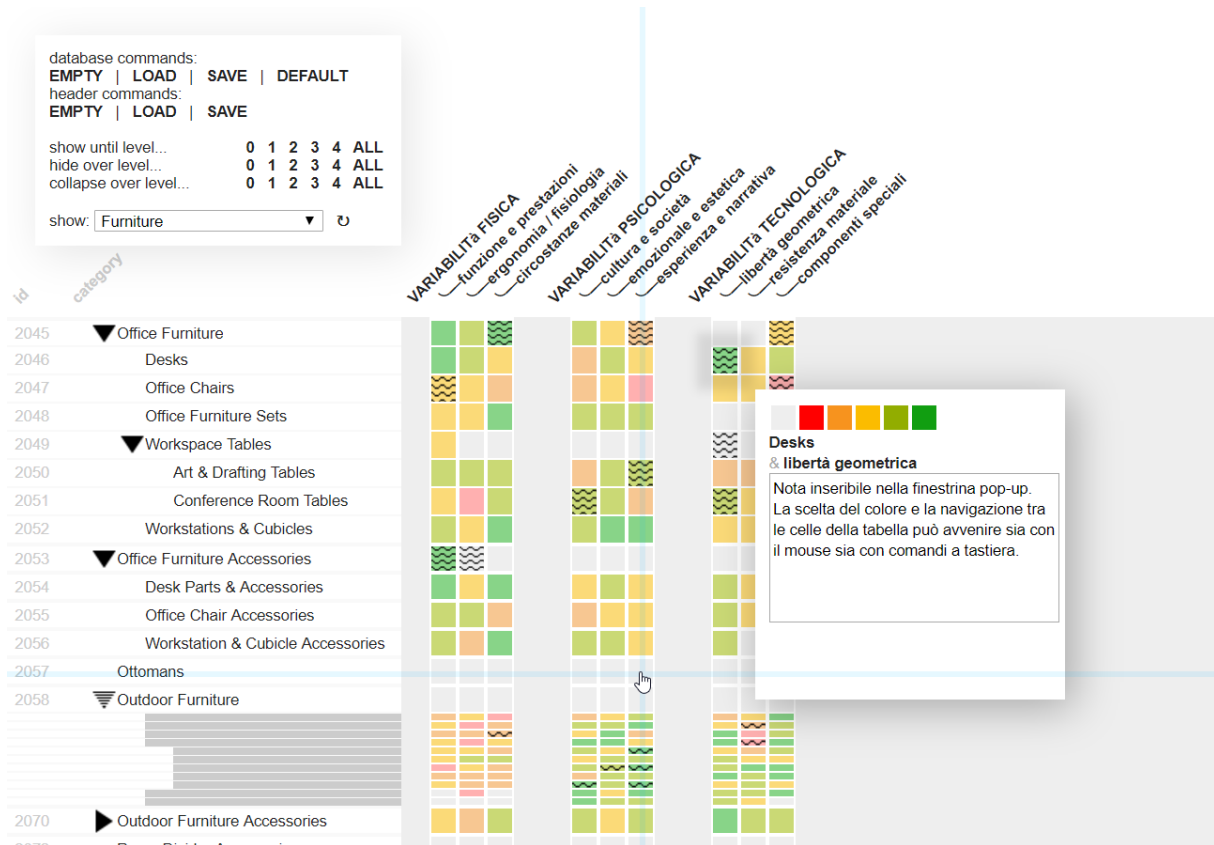
However, we can observe that none of these tools is particularly adequate for the handling of a unknown mass of elements. The product category list could contain hundreds or thousands of elements, each of which should be evaluated according to the previously described system of 9 criteria in order to discover relevant correlations and identify promising points of intervention. This suggests the necessity of a specific tool capable of facilitating the mapping workflow, including the compilation and analysis of the matrix.

Therefore, the author has developed an experimental web tool with the following functionality:

- construction of a hierarchical list of product categories
- importing product categories from existing classifications
- variable visualisation of the hierarchy (complete, minimised or hidden levels) for a useful perception
- rapid investigation of product categories by the one-click convocation of Wikipedia, Google or Pinterest research
- possibility of constructing a hierarchical list of evaluation criteria
- rapid insertion of evaluations and text notes (keyboard shortcuts)
- organisation of the rows (product categories) according to the evaluation score of any given criteria (columns)

The mapping tool has been experimented starting from the Google Product Taxonomy as objective external database. Completing a few chosen macro-categories have resulted a series of interesting product ideas but it has also surfaced some functional shortages of the tool, for which this is not yet ready for public use, only for use in controlled environment (alpha version).

Naturally mapping the possibilities is only the first step towards valorising a new technology. In the specific case of promoting Digital Fabrication and Computational Design, for the following steps the author has developed another graphical tool inspired by the Business Model Canvas, allowing designer to develop a concept design with the consideration of the peculiarities of DF and CD. However, in this paper we have limited the discussion to the mapping tool, which demonstrates a potentially useful approach for various fields of contemporary design.



## 5. Conclusion

Starting from the acknowledgement of Digital Fabrication’s potential as a transformative force of the Next Economy, we have observed certain obstacles for its diffusion and identified personalisation through Computational Design as a strategy which could facilitate the valorisation of DF. In order to overcome the difficulty of finding solid starting points for the DF&CD concept ideation, we have proposed a web-based tool for mapping efficiently the characteristic advantages of these technologies to a wide range of product categories. This tool targets designers and organisations that want to benefit from their DF and CD related skills and resources, and, on the other hand, companies that want to improve their offerings through personalisable products. Operating on a web-based platform, the future evolution of the tool could enable the collaborative compilation and verification of the matrix map with a crowdsourcing approach in order to obtain comprehensive idea banks. While the structured elaboration of matrices might not feel natural for some designers, adopting such a rigorous approach can result a valuable comprehension of the realistic possibilities and the mental flexibility that is necessary for the creative use of new technologies in unexpected contexts – a competence that may raise the strategic value of the designer.

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