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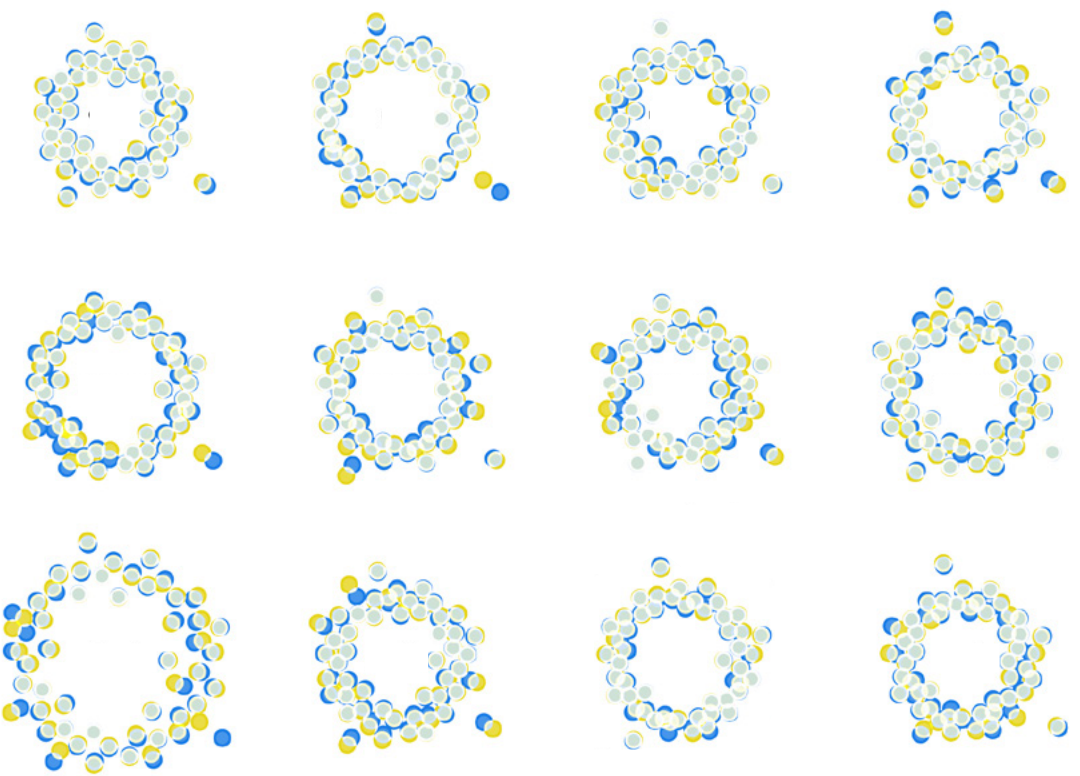

Colophon

diid
disegno industriale
industrial design
No. 75 — 2021

Year
XIX

diid is an open access peer-reviewed scientific design journal

diid is published three times a year

Registration at Tribunale di Roma 86/2002 (March 6, 2002)

www.diid.it

Print subscription (3 issues)
Euro 60,00
Subscription office
ordini@buponline.it

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Bologna University Press
Via Saragozza 10
40123 Bologna
Tel. (+39) 051 232 882
Fax (+39) 051 221 019
www.buponline.com
info@buponline.com

ISSN
1594-8528

ISSN Online
2785-245

DOI
10.30682/diid7521

ISBN
978-88-6923-991-5

ISBN Online
978-88-6923-992-2

Cover image from
Semantic proximity of the most relevant terms in *DRS Conference proceedings* and *Design Studies* articles by Steven Geofrey, Center for Design, Northeastern University.

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The Cyclical Design Process in the 4.0 Era: Design Across Digitalization and Virtualization

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Abstract
Industry 4.0 comprises a number of technological transformations in the pre and post manufacturing phases. Enabling technologies such as Cobots, IoT, Big Data, Virtual Reality and Augmented Reality play a major part in the fourth industrial revolution and the reshaping of the design process. These changes elevate the role of the industrial designers while allowing them to work transversely within the design process. The aim is to encourage the use of virtual and digital tools, useful for data-driven design, as well as for technological innovation in the process of pre and post manufacturing phases. This study aims to investigate the development of the design process, in the Industry 4.0 context. It is supported by the results obtained from the analysis of four companies in the Veneto Region and illustrates how it is possible to represent the design process through a cyclic framework.

In conclusion, a critical review of this research will show the potential limitations and developments of this cyclic model.

Keywords
Industry 4.0
Digital and Virtual
Design process
Data-driven Design

Introduction

In the 4.0 era, industrial design is presented as a trans-disciplinary profession that harnesses creativity to resolve problems and co-create solutions[1], in order to be present in all phases of the design process, from the concept definition to the sales management strategy. Assuming that in an industrial context, the development of the design process can be represented by a horizontal line (Banathy, 1996), it is possible to divide it into three phases (Závadská & Závadský, 2018):

- Pre-manufacturing. The brief definition and design phases enable the production planning and scheduling phases. Digitization of the early decision-making processes facilitates the virtualization of tools and procedures for project definition.
- Manufacturing. A process characterized by a high presence of digital technologies for the virtualization and planning of production processes.
- Post-manufacturing. Virtualization processes through Augmented Reality and Virtual Reality are promoted by communication and sales strategies as factors of success. The collection and processing of data provides better management of customer care services.

1
From the 29th General Assembly in Gwangju (South Korea), 17-18 October 2015, the Professional Practice Committee unveiled a renewed definition of industrial design. https://wdo.org/about/definition/

Fig. 1
Linear Design Process. Graph by the Authors of the paper.

We observe that in this linear process Fig. 1, the role of the designer is only present in the phase of pre-manufacturing where he is engaged in the definition and planning of the product form, but it is not present in the phases of production development, commercialization and sales. The linear design process, defined by many (Banathy, 1996; Schuh, Rudolf & Riesener, 2016) finds its shape and development within the pre-industry 4.0 context.

It is defined by a series of iterative micro-processes that make product and process innovation complex. In the 4.0 era, this linear approach with internal iterative developments can no longer be considered as a standard.

Designers can trigger and sustain significant social and economic changes by focusing instead on emerging and innovative forms of collaboration between multiple figures who are all connected to the design process (Bertola & Teixeira, 2003). Indeed, the digitization and virtualization of processes and tools can benefit the connections and relationships between the different design phases.

Over the years the designer has played the role of *cultural translator* for technologies, giving them both an identity and value (Rampino, 2012, p. 44). It has thereby become a mediator and a

Doi: 10.30682/diid7521k

catalyst of interdisciplinary knowledge by working incessantly on the innovation of meaning (Celaschi, 2017), adapting to ever-changing contexts and renewing methods and tools (Lotti & Trivellin, 2017).

As the technologies used move towards increasingly digitized and virtual systems, the designer is tasked with making the centrality of the user explicit (Khanna & Khanna, 2013) in the constant interaction between man and machine, first triggering a change in perception and then of process. On the basis of these considerations and through a meta-design approach (Giaccardi, 2005), this paper suggests a cyclical design process framework in the context of Industry 4.0.

The main hypotheses that defined the objectives are:

1 The understanding and analysis of the product requirements during the early stages of ideation have a significant impact on the design and production of this product in terms of quality and cost.

2 The physical and digital levels are mixed in the design phase, leading to the emergence of systems whose physical and digital representation cannot be examined separately.

3 The need for the digitization and virtualization of communication systems, marketing, and development of the after-sales services will become increasingly relevant so as to bring significant improvements to the above-mentioned phases.

The Designer and the Cyclical Design Process Across Digital and Virtual

The concept of Industry 4.0 is in continuous development (Hermann et al., 2016): currently it consolidates the use of digital technologies to increase the interconnection and cooperation of different resources in the production process, starting from design through to production.

In order to discuss this issue, we reviewed the design process through the steps of brief definition, prototyping, communication/sales and finally the subsequent marketing and customer care management.

The decision not to consider the manufacturing phase in this research is justified by the fact that it does not actively involve the designer in research related to technical, engineering and logistical innovations. The analysis reported in the next section, allowed us to collect data for each design phase and synthesize their interaction in a cyclic model Fig. 2.

The cyclical shape demonstrates the interconnection of the design phases. The digitization and virtualization of post-manufacturing support and optimize the brief definition phase, which in turn benefits from the analysis of data collected from the products in use.

A structured and digitized brief facilitates design virtualization and therefore production planning. Data and information generated in the pre-manufacturing phase allow for successful communication and marketing of the product.

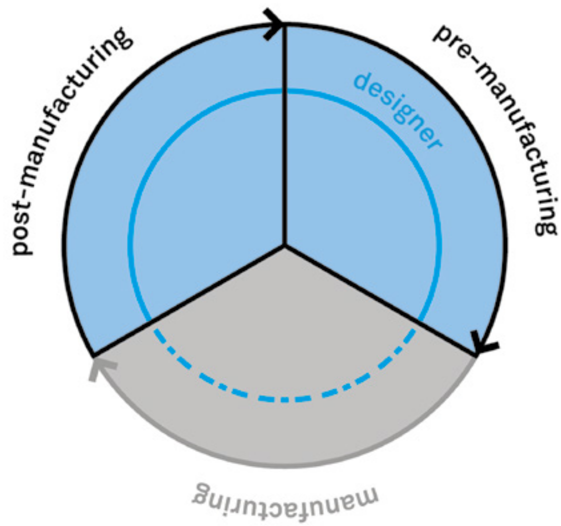

Fig. 2
Cyclical Design Process. Graph by the Authors of the paper.

Furthermore, this research aims to construct a new archetypal design process model that is balanced between the physical, the virtual, the digital spaces and the tools. This allows designers to balance all of these elements with the intent of furthering both process innovation (Carullo, 2017) and product innovation.

The Meta 4.0 Project

The conceptual framework was developed using the results from a wider research program[2] that explores the issues of Industry 4.0 and the related digitization and virtualization of design, production, communication and sales processes of a given product. In the context of Industry 4.0 we analyzed how designers could partake in all the phases including brief definition, product development, communication, sales and after-sales services.

Moreover, the theoretical research comes from an amalgamation of four companies in the Veneto Region, partners of the project[3], whose very different realities have in common recognition of a high level of technical and engineering expertise.

Four main phases were analyzed to define the evolution of a cyclical design process, containing two pre- and two post- manufacturing phases. Each main phase has a reference and was applied within a specific scenario with a partner company:

1 Brief definition.
2 Product development.
3 Communication and sales.
4 Monitoring, maintenance and customer care.

2
The study, conducted within the research unit FIND (Future, INNovation and Design) at the University Iuav of Venice, was funded by the Operating Program FSE of the Veneto Region for the project *Meta4.0 — possibilities and potential of design for Industry 4.0: new challenges starting from metalworking*. Researchers: Luca Casarotto and Pietro Costa with Francesco Baldassarra, Lisa Casula, Antonio de Feo, Ernesto Zamborlin. Project partners: Baxi, Delka, Italcab, MasRoof.

3
MasRoof is a start-up characterized by a B2B business model. It designs integrated and modular solutions for anti-seismic and solar roofing and structures. Italcab S.p.A. is a SME characterized by a B2B business model. It designs and produces cabins for earthmoving and industrial machines. Baxi S.p.A. is a large B2B company. It is active in the design and production of boilers and high technology heating systems. Delka s.r.l. is a SME that works in the realization of interior furnishing systems mainly for office spaces.

Brief Definition: How Digitalization of Processes Improves Project Planning

A brief is defined by customer requirements, market information, investment planning, form development and core product functions. The data collected generates value and opens up new opportunities to improve design quality, manufacturing efficiency, and marketing competitiveness (Zwolenski & Weatherill, 2014). Data-driven design is a method that could provide essential support for designers to connect both to the real physical and the virtual digital world. In fact, by collecting and analysing Big Data, it is possible to obtain information and create digital models of reality to support the ideation and production of more defined and clearer design briefs. This information could come from social networks, sensors, web or other unstructured sources. The capabilities of these 4.0 tools and processes make it possible to consider data both as a way to monitor the product and as a source to foster new application possibilities. Data-driven design means, first of all, to try to understand the context in which the data is generated, thus understanding people's needs, necessities and requirements. This data-driven human-centred approach (Celaschi et al., 2017) aims to extract information by placing the data within an organized system, which, seen in relation to other data, can assume relevance and add value. The triangulation of the quantitative and qualitative data, which is generated in each design phase can induce interesting prompts for brief generation. BIM (Building Information Modelling) systems, which collect and analyse large quantities of different types of data, seem to be the ideal tool to optimize the use of Big Data. Widely used as a design software in the architecture, engineering and construction industries (AEC), the BIM system aims to create a collaborative design and construction process that visualizes the physical and functional aspects of a building. It is focused essentially on the design and construction of an artifact. The Mas-Roof analysis focuses on validating methods to determine how the efficient use of BIM as a collaborative data processing tool can have a significant impact on generating new briefs.

Collecting information in a virtual model simulation, on how products interact within different situations can be valuable for physical product management and optimization (Tao et al., 2018). Digitalization of data connected to the physical product can provide faster, more transparent communication between customers and designers. It can also create digital support for design planning and drive a new design product by utilising the feedback provided by customers using past editions of this product.

Product Development: How Virtualization Could Support Prototype Production

In this step, product development teams would complete the product design work collaboratively through the exchange and sharing of data and ideas. Product design data includes information collected from the previous brief definition phase: the description of a product's form, function and configurations, and data from tests, prototypes, etc. In addition, past data related to similar product defects is consid-

ered to improve the design of future products.
At these stages, designers are expected to complete the development and manufacturing of the prototype, as well as focus on the development of useful tools and equipment for product validation and production planning. The prototyping phase requires repetitive simulation testing to ensure that the product can achieve its target performance level. This phase may be slow and complex due to a lack of real-time data and digital user test feedback. It's appropriate to use results from experimentation with a VR tool Fig. 3 to support prototyping, as this virtual tool can accurately anticipate the real performance of physical products by making virtual simulation test scenarios.

Data generated during the brief definition phase and from 3D CAD models enables a virtual simulation of the appearance and performance of the prototype, optimizing the duration and quality of the process. As demonstrated in the case of Italcab, using a virtual prototyping tool helps designers to perform testing and error analysis processes more efficiently. It also allows them to start usability studies and verification of regulatory constraints (such as ISO standards on visibility and workplace safety).

Fig. 3
Example of Virtual Reality prototype for usability and standards testing. Picture by E. Zamborlin.

The information received from the prototyping department goes directly to the manufacturing departments (e.g. welding and assembly). Here the employees can use the same tool to virtualize and test the process, while collecting important data that will be used to avoid future errors, and to make the process qualitatively better and faster. The same virtual models have the capability to facilitate engineering and manufacturing processes (Hermann et al., 2016).

Communication and Sales: Augmented Reality

The introduction of Augmented Reality (AR) in communication and marketing could improve the presentation of product information by facilitating cognitive processing by the buyer. Currently, even if not widely used, AR is utilized in the areas of product communication and marketing (Smink et al., 2020) because if the product — search product and experience product (Fan et al., 2020) — is placed inside their home, the consumers learn about the technical and dimensional specifications of the product and are able to experience it in context, which could potentially push them to buy (Fan et al., 2020).

AR adds a new dimension to the product experience thanks to two different characteristics:

- With the display of a device there is an overlay of virtual content (3D or infographics) to reality.
- Virtual objects are interactive and displayed in real time. AR technology is able to generate positive attitudes towards the brand by stimulating the buyer to purchase (Wedel et al., 2020).

Moreover, it was possible to critically reflect on the users' perceptions of AR technology, identifying the perceived factors of spatial presence and virtual intrusiveness (Smink et al., 2020).

Certain technologies, which are defined as transformative (Riva & Gaggioli, 2019) were capable of changing the user's experience, pushing them to make purchases. The connection between the virtual and the real components plays a central role within the theoretical analysis. There must be a continuum between what is around the user and what the software overlays on reality (Maldonado, 2005, p. 174).

Fig. 4
AR application prototype for Delka Srl. Picture by A. de Feo.

During the initial stage of the theoretical research, a series of design activities was structured within the partner company Delka srl using AR technology as a communication and marketing tool for its products. Starting from the specific analysis of Delka srl Fig. 4, three hypothetical company profiles were generalized, that would use AR technology: to sell for B2C, to communicate for B2B and to virtualize user assembly manuals.

Maintenance and After-sales Services: The Digitalisation of Customer-care

The customer can make the best possible use of the product using the information in the user manual. A large amount of data is generated during this usage, e.g. about the state of the product, the operating environment, user behaviour. This data can be used not only for maintenance and repair of the product but also to improve the product development (Bertoni, 2018). Information collected with the support of the partner company Baxi shows us how services related to the after-sales phase (call centre and FAQ) help to manage the maintenance, service and repair phases of the product. The analysis of the Baxi thermostat made it possible to identify the main problems in the usability of the product to define new after-sales support tools. Then the collected data was used to improve the user experience through communication tools such as video tutorials or dedicated sections on the website.

The appropriate maintenance and assistance solutions are generated and transmitted to the manufacturer according to the data collected from the products in use.

Therefore, efficient and accurate services are provided to users. In this process, information and causes of failures such as maintenance and component quality data are recorded and analysed in order to predict product lifespan and implement proactive and non-reactive maintenance. Data collected and then analysed by the product in-use should be considered as a success factor that gets a maximum return from this cyclical process.

The Framework Application

As the previous investigations show, the evolution of a cyclical design process, accelerated by the progress of Industry 4.0, equally involves SMEs and large companies with different business models (B2B and B2C).

Even if each reported case is different in type, size and product characteristic, all scenarios can be described using the same cyclical framework. However it is possible to identify a divergence in the extension of the three macro processes that characterize them. This is clear from a schematic representation of a cyclical design process Fig. 5.

1. In the MasRoof case, design is constrained by the standardization of modular products and determines a higher interest in the pre-manufacturing processes. Therefore, post-manufacturing management is not considered a success factor that brings value in the business process.
2. Italcab focuses on high customization which obviously has an effect on the management of its design processes. Control of the post-manufacturing process is negligible and the optimization of pre-manufacturing is highly relevant in order to propose solutions designed and realized ad-hoc, to satisfy the needs of each individual customer.
3. Delka builds its sales strategy of digitization and virtualization of communication (post-manufacturing process) in order to improve its position in the market.
4. Baxi considers the control of customer care services (post-manufacturing processes) to be key factors in implementing business strategies for company success.

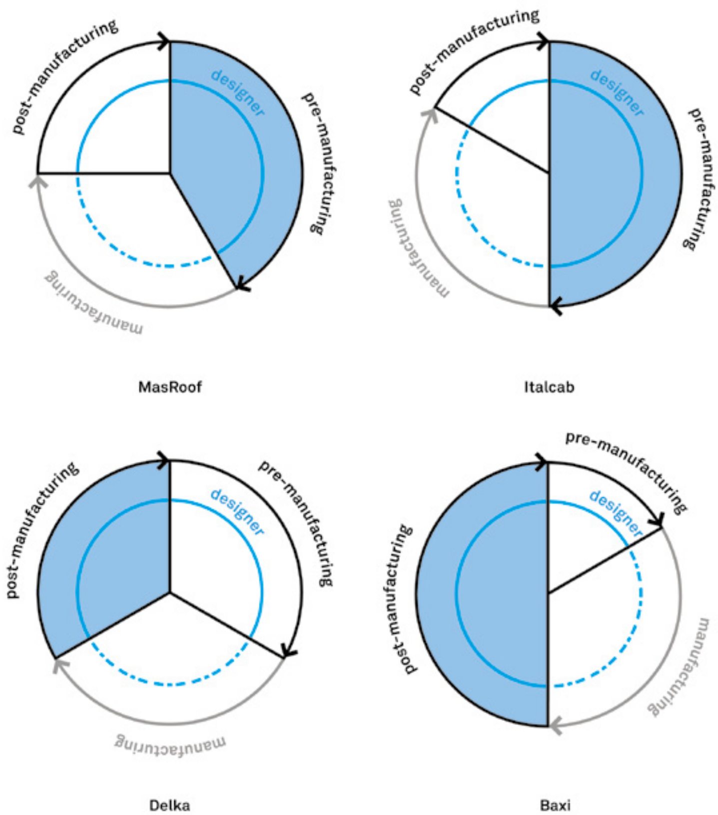

Fig. 5
Representation of a Cyclical Design Process: MasRoof (1), Italcab (2), Delka (3), Baxi (4). Graph by the Authors of the paper.

Conclusion

In the 4.0 era, data-driven design generates value for companies. Collecting and analysing these huge amounts of data is as important as understanding who will use it, how it will be applied and what kind of value it brings.

In this sense the necessity to define a set of concepts and potentials becomes clear, taking advantage of the information provided by this research project:

1. Using the potential of big data and getting the most value from digital tools leads to a more accurate and efficient brief definition.
2. Digital technologies for virtual prototypes optimize the quality of product development and engineering.
3. Product communication is almost as important as product development itself. The designer must be able to highlight and communicate the achieved innovation.
4. Data-driven design could become a useful tool for designing new features, new products and defining new briefs using the information that is collected from marketed products and maintenance services.

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It is interesting to understand how the processes, analysed through the framework, could become a source to stimulate continuous process innovations, in which the industrial designer can better connect and move between the various stages of the design process with ease. Today, the digitalization of post-manufacturing processes occupies a much larger section of the entire process. On the other hand, in business contexts (such as Italcab case), the high customization of the product generates an increased value in the pre-manufacturing phase. Due to the availability of an exchange with the companies who carried out part of the applied research, this study aims to demonstrate the complexity of standardising the design process model.

Future developments would involve further experimentation, starting again using this framework, to understand how a dimensional balance of the phases can optimize the processes, or if just more commitment to the elevation of current models could guarantee business success. Certainly, in both the first and the second scenario, continuous and desirable technological innovations (AI, CPS, Big Data, IoT, etc.) will be the main proponents of the new paradigm shift with a data-driven design perspective.

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The guest editor for this issue No. 75 guides us through the *Galaxy of Design Research* into the international debate with eminent figures who help us, as if we were at a telescope on a spaceship flying through astral space, to plot routes, establish certain points, set goals, in a horizon that the scientists of anticipation call T^2, in the contemporary era but just a little beyond, to become aware of the direction we are moving in.

A heartfelt thanks goes to the design community which responded to our call by submitting over 110 scientific products so far from a total of 142 authors. Many more than we were expecting and that, in the best of cases, we will be able to spotlight, but which bear witness to the need to open the scientific debate at the international level and to do so within the rules of the scientific community.

Flaviano Celaschi

No. 75 — 2021
Anno XIX
ISSN 1594-8528
ISSN Online 2785-2245

Bologna University Press

Euro 27,00

ISBN 978-88-6923-992-2