Publishing Series on PROJECT | Essays and Researches

Pro-Innovation | Process Production Product
vol. 02 | 2019 | paper 15 | pp. 207-226

ISBN (print): 978-88-5509-052-0
ISBN (online): 978-88-5509-055-1
ISSN (print): 2704-6087
ISSN (online): 2704-615X

ADDITIVE MANUFACTURING
DESIGN OF FUTURISTIC ARTIFACTS

Benedetto Inzerillo [a]

section
Design

typology
Essays & Viewpoint

DOI
10.19229/978-88-5509-055-1/2152019

Abstract
Industry 4.0 is making its contribution to changes in the structure of the world economy to such a considerable extent that there is talk of a new industrial revolution. For some years now all the great business enterprises have possessed costly 3D printers that can create any artefact or component with little effort. This paper deals with the applications of additive manufacturing as part of the transversal processes in the field of design in research and concrete actions by design-oriented firms intending to invest locally. Among the projects developed in Palermo mention should be made of two interesting cases, where the innovation is geared towards the market of carbon-reinforced plastic and the integration of digital production processes.

Keywords
flexibility, personalization, technological, digital and robotic innovation, additive manufacturing

Ever since the crisis at the beginning of the 21st century a new industry called Industry 4.0 has gradually emerged. The process of transformation that has shaped it boasts a technological set-up, with an ever more significant impact, not only on the manufacturing sector but also on services, ranging from business to personal welfare and to services devoted to the community. Industry 4.0 is making its contribution to the changes in the structure of the world economy in such a decisive manner as to provoke talk of a new industrial revolution (Anderson, 2010). The inter-connection of technology in terms of the internet of things, artificial intelligence, robotics, additive manufacturing, virtual reality, digital traceability, self-propelled vehicles and drones, is now altering our lives (Schwab, 2016). For some years now, all the great firms have possessed large and costly 3D printers, which, by means of CAD programmes, and with little effort, can manufacture any object or component (Anderson, 2013; Sposito and Scalisi, 2017). Applications of additive manufacturing represent a principal goal, as part of the transversal nature of the field of design, from research to the tangible actions of design-oriented firms intending to invest locally. These artefacts are not the simple product of a practical function, but incorporate an infinite number of 'ways of being', giving rise to feelings, relationships and explanations of our world.

In the words of Maurizio Vitta, things have a voice and portray a world of meaning to those who have ears. «Whatever, at first sight, looked like an inert 'thing', a fragment organized from material which embodied a precisely defined and infinitely repeated function (something static, therefore, fixed once and for all on the stage of motionless daily life), reveals itself to become […], all of a sudden, a shape-shifting body, which then finds its place in time no less than in space, which takes on various features and physiognomies in accordance with the situations in which it is to act, and which is a generator of energies of disparate kind: semantic, symbolic, aesthetic, technical, ergonomic, cultural and so on. Whatever presents itself in this perspective is no 'object'; it is an event that comes alive through its process, which unravels itself before our eyes in continuous transformations, and which still remains inflexibly identical to itself and faithful to the task assigned to it from the very first moment» (Vitta, 2016, p. 6).

New Industry 4.0 – In this new open and competitive, global context, as intimated by Patrizio Bianchi, «an ever greater authorising element in the new industry is represented by the continuous inter-connection of every single individual, of every single business enterprise, every research structure in relational planetary networks. The real value added is identified more and more often in research products, which themselves become proto-types for industrial development, the cost of production of which proves to be much lower than the cost borne in achieving its initial formulation» (Bianchi, 2018, p. 66). An obvious example might be that of software, the duplication of which sustains marginal costs compared to those required to achieve its initial definitive form. With these prerequisites, the difficulties in entering the market for new competitors are subject to significant changes, moving from the dimension of production plants of large factories to the organization of laboratories in which prototypes are created, within the actual firm itself, or in research structures that are part of, or linked to, the University. The development of digitalization consents the continuous inter-connection between productive systems and, above all, between individuals belonging to populations a long way from each other, in terms of history and tradition; therefore, it is no longer only the development of telecommunications and informatics that are at the basis of the new industrial revolution, these having characterized the phase of the third industrial revolution (following the long Fordist period).

Patrizio Bianchi continues: «This hyper-connection, with the relative exponential data production, not only generates the possibility of responding to demand deriving from individual needs, but must also become a tool for tackling the large global challenges, such as water shortages, sustainability of life in large cities, famine and social inequality, which today represent new public assets at the global level» (Bianchi, 2018, p. 66). The social changes that have taken place over these years of global interconnection are consenting the development of abilities and skills essential for applying all the available technology, which over the next few years, will play a part in responding to the demands that characterize this historical period. The integration of different productive and scientific systems represents the new approach that enables us to tackle and handle the issues and the complexity of the contemporary world, but is also decisive in the organization of cyclical global production chains. Many firms have relocated the various phases of production to more competitive contexts, whilst maintaining the research, planning and control structures of the productive cycle in those countries in which science and technology are on a more solid footing o the systems of production.

Industry 4.0 is not only a moment of considerable technological advance, but also represents the capacity to put together science, technology, skills and social contexts, so as to respond to both general global issues and the demands of the individual (Lombardi and Rossi, 2017). It is worth making a few considerations: Industry 4.0 production has the aim and the capacity to introduce differentiation without interruption, in an industrial productive cycle, ending with personalization of the final product (generated, however, in series). As claimed by Adam Smith (1973)[1], there arises a problem of coherence between organization of production and the size of the market. The possibility of producing enormous volumes of personalized goods is today linked to the possibility of selling these very goods on the world market. Artisan production is an example of the advantages deriving from the utilization of the same skills and the same machinery for the production of various goods; the tailor can create both ceremonial and sports clothing, incorporating all the work-phases, because he has the skills and equipment that enable him to move from one product to another uninterruptedly.

On the other hand, Fordist production is an example of efficiency based on specialization on a single product, which is built by dividing up the production cycle into successive phases so as to optimize the skills and equipment regarding a single productive activity. In the first case, if one wishes to increase production, one has to arrange the workers in parallel formation. In the second case, however, the workers are arranged in line and are specialized in one single operation; in this way they increase the speed of execution, but inevitably miss out on other skills required to construct the final product. In the first case we might have personalized products for an individual, but at high cost; in the second case, the price will be lower for a standardized product.

In conclusion, Industry 4.0 is endeavouring to overturn the order of things, by changing the way of working and the nature of the organizations by means of a process of digitalization of the manufacturing sector and the refurbishment of the chain of values (Cipriani, Gramolati and Mari, 2018).

Generative Design – Among the most exciting issues linked to the manufacturing industry of Industry 4.0, we certainly find Generative Design, which can be described as a method of planning in which the output (be it an image, a sound, an architectural model, an animated object) is generated by a set of rules or an algorithm, thanks to the utilization of software (Wikipedia, 2019). In brief, the designer, thanks to this software, by inserting the structural limits of a project, is able to try out thousands of different solutions simply by pressing a key, and thanks to the results of these simulations, he can choose the best configuration possible for the desired artefact, with less wastage of time, material and money. This revolution is today already providing considerable feedback

(Bohnacker, Gross and Laub, 2012). Apart from being used on a daily basis in the design of industrial constructions of every kind, it is also utilized in futuristic projects, as in the construction of the first stainless steel bridge in the world, created entirely in 3D by the robotics company MX3D, or, the design on the part of Autodesk for Nasa of a lander, in the shape of an ultra-light spider, for the landings of space-vehicles.

As Beth Comstock (2018), author of the book Imagine It Forward, explains, generative design can be applied everywhere: from the design of houses and hospitals to the design of cars and motorcycles and, why not, for space travel. Let us imagine we need a chair and so establish certain parameters: it has to bear a determined weight, it has to be made of plastic and metal, its cost must not exceed a certain figure. So, we try to imagine applying these parameters and pressing a key; in a few minutes we shall see on the screen thousands of possible variations of the chair, each of which responds to the parameters demanded. Generative design is a sort of invisible revolution, difficult to understand for those not working in the field, but crucial for companies in reducing costs, the choice of materials and production techniques, and for improving the quality of the project, its efficiency and performance at all levels. The process is complex, almost handcrafted; there are thousands of algorithms that are continually being mixed around. These are hybrid technologies and methods, with nobody using algorithms in exactly the same way. Recently, at General Electric, an aeroplane engine was designed using generative design. Its predecessor was made up of nineteen pieces whereas this one, designed by applying generative design and additive manufacturing, was a single item weighing about a third. In the same way, Airbus designed a panel separating the part of the cabin where the cabin crew operate from the part where the passengers are seated; thanks to the algorithms this panel weighs 55% less than its predecessor. It was designed commencing from the growth-structure of mammal-bones and manufactured additively, because the forms created by generative design cannot easily be produced using traditional methods.

In all probability, with several constraints, this represents the future. Generative design will shatter all paradigms and consent the completion of designs outside the traditional framework. At present it is easier to design than to produce, because, given the parameters, the algorithm aims to construct an infinite number of versions of a product that complies with these paradigms. The problem, if any, is placing new forms on the market; it is easier to build more efficient and cheaper variations with the technology we already possess. A few examples: the insides of aeroplane wings are completely different from how they were ten years ago and, in many cases, have already been designed using and applying the thousand variations that generative design consents, but looking at them they seem the same. If they had a completely different form it is probable that nobody would trust them. Innovation is often disguised, since the general public is not always ready to understand it. Therefore, we must not imagine bold new forms; the aeroplane of tomorrow will be very similar to the one of today, but it will be lighter and might also fly a little more slowly. Reducing cruising speed is the best way to permit passengers to pay less and reduce costs with regard to weight and structure. The passenger might not like spending a longer time on his/her flight, but will appreciate the cheaper ticket. In other cases, it will be different; the key issue for generative design will be to remove material from a product to make it more efficient, lighter and less costly. This is actually already happening in the field of product design. An example for all is the new Illy moka pot, where the internal pressure and other parameters have been established and software has generated an infinity of variations. On the inside it is the computer that produces the moka, on the outside it is Alessi.

Additive Manufacturing and Generative Design – It is in this field that particularly significant projects are emerging. Among others, it is worth mentioning the experiences in the field of Generative Design of Francis Bitonti, who, in 2014, in collaboration with Michael Schmidt Studios and Shapeways, created the first Unibody parametric item of clothing, produced with additive manufacturing (Fig. 1), and in 2015, Molecule Shoe, a model of shoe created with Game of Life, an algorithm conceived in 1970 by the English mathematician John Conway, which generates clusters of three-dimensional pixels (Fig. 2). In 2016, the American studio Nervous System created a new type of sole for personalized running shoes, for the footwear company New Balance, with a foam structure constructed on the basis of the client's physical characteristics (Fig. 3). One of the main advantages of parametric additive manufacturing processes is being able, layer by layer, to add forms continuously characterized by extremely complex geometrics.

In the words of Dario Scodeller and Emilio Antinori (2017, pp. 34, 35), «much of the technology applied at the end of the 1970s in the field of rapid prototyping, has today become an actual production process for finished products. In this design process, via so-called slicing software, the virtual model generated in nurbs or mesh and then codified in a binary file, is subdivided into horizontal planes connoted by specific characters, such as density and filling form, thickness of leather, intensity of layers of horizontal subdivision, speed of growth, variation and positioning of diverse materials in the same component. In contrast to other traditional processes that subtract or conserve mass, this method of construction through aggregation of materials leads to a better management of the geometric complexity and, consequently, the possibility of combining functions and components».

In the field of additive manufacturing a new development in innovative processes is emerging, with the combining of robotics and materials (as in the case of the Sicilian start-up Ocore, which we shall be looking at later). One of the first to use an anthropomorphic arm for the extrusion pf thermoplastic polymers, was the Dutchman Dirk Vander Kooij, who, in the last few years, has created a great number of self-produced objects (Fig. 4). Fashion designers such as Iris Van Harpen and Anouk Wipprecht, creator of the spider-dress (Fig. 5), have collaborated in the production of artefacts created in 3D printing and electronically controlled kinematic motion. The artefacts designed by Joris Laarman, on the other hand, are the result of research combining generative modelling

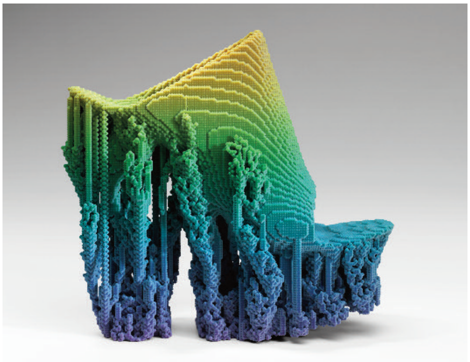


Fig. 1 - F. Bitonti and Micheal Schmidt Studios, Parametric Unibody dress, *New York 2014.*

Fig. 2 - F. Bitonti, Molecule shoe*, New York 2015.*

Fig. 3 - New Balance, Soles for personalized tennis-shoes, *Boston 2016.*

Fig. 4 - D. Vander Kooij, Endless Chair, *Zaandam 2010.*

Fig. 5 - A. Wipprecht, Spider dress, *Amsterdam 2015.*

and additive construction of Unibody products; one example is the Starlings Table, created using a 3D flight simulation programme, based on Craig Reynolds's boids algorithm, with which Joris Laarman simulated a flock of birds frozen in a given moment of generation and converted into a self-supporting, three-dimensional structure (Fig. 6).

Additive technological processes have made it possible to broaden the project's horizons, especially in the 'vision' of the near future (Autodesk, 2017). The first generative design products were developed in the bio-medical sector, and the aeronautical and aerospace industries, which demand important technological performance; studies have recently been added in disciplinary areas such as architecture, lighting design, product design, fashion design and all those sectors in which the potential to create forms via these new instruments, appear compatible with their main lines of aesthetic research. In this new design context there are basically two types of approach: either the creation of a totally new algorithm geared towards a final product, or, alternately, the utilization of an existing algorithm, modified and adapted in function of the artefact to be produced. The relationship between formal research and structural research in this field does not have a clear boundary and the established computational design strategies, which are aimed at improving structural performance, are supplemented by form-finding strategies that have been developed through intuitive processes (Figliola and Battisti, 2017). The innovative aspect of this new area of design consists in the absence of a predefined goal as regards the formal result; to this end, the statement by the computational designer Alessandro Zomparelli is interesting; he considers generative products as 'fossilizations of the digital world', and, therefore, signs of an algorithmic process that produces a flux of forms that are nothing but a progressive stratification of solutions.

Fig. 6 - J. Laarman, Starlings table, *New York 2010.*

The Generative Design of Philippe Starck – In the world of design, Stark is one of the creative spirits with the most success and the greatest impact. The long list of his iconic creations seems to have no end, but in his long career there is still something he has not achieved: to work alongside an intelligent machine in a process of co-creation. At the Salone del Mobile, Starck and Kartell presented A.I., a chair produced with an algorithm that emerges from simple inputs (Fig. 7): it has to be comfortable, to have the structural requisites of resistance and solidity necessary in order to obtain certification, and to comply with certain aesthetic canons of simplicity and clean lines.

Philippe Starck, Kartell and Autodesk asked A.I. to study how to help the body relax using the least quantity of material; A.I., with no culture, no memory, no influences, responded using only its intelligence. A.I. is the first chair designed outside our actual brain, a long way away from our habits and our way of thinking. A.I. is different from any other previous project by Starck; in fact, it has been conceived by a human being but was co-designed with a computer using generative software. In order to carry this out, Autodesk provided Starck with access to a research prototype of his generative design software. The software proto-type used by Starck includes functionality that is still in the process of being developed by the Autodesk Research team. Furthermore, this was the first project in which injection-moulding had been defined as a production stricture in Autodesk generative design technology. The project lasted two years, and at the beginning of the collaboration there was an evident gap between the designer's expectations and the level of creativity exhibited by the software and what the software was capable of producing on its own.

Fig. 7 - P. Starck, A.I. seat Kartell, *Noviglio 2019.*

Starck expected the system to follow his initial directions and then to generate a chair that resembled, as far as possible, what he had imagined. However, the A.I. assisted system behaved in a way very similar to that of a child in his early learning phase. In the course of time, Starck became more attentive to his ways of describing what he wanted; the perfecting of the requisites allowed the software to better understand his design intentions and, in the end, to become more efficient. The process evolved into creative conversation very similar to what might happen between two human beings; Starck conveyed to the system his design intentions, whilst the A.I. tried to learn as much as possible, in order to be as useful as possible. As the relationship between the two matured, the system became a much stronger collaborative partner and started to anticipate Starck's preferences and understand the way he preferred to work.

Ergonomic and made-to-measure seats – Among the projects carried out in Palermo by design-oriented firms over the last two years, two of the most interesting cases are, without doubt, those of the chairs created in additive manufacturing. The chair can be personalized on the basis of postural requirements with a precise medical approach. In direct contrast to the words of Le Corbusier, we humans are different from each other, not only spiritually but also physically or, at least, dimensionally. Contrary to the object-type strategy, conceived precisely for a need-type, which does not really exist, design research here focuses on the configuration of a chair based on the person and on correct posture, with primary regard for health rather than ergonomics, using additive manufacturing techniques as leverage, characterized by building piece by piece, and bringing into play skills of a medical basis (orthopaedics, physiotherapy, motor science etc.).

The ergonomic and made-to-measure chair project originated in Palermo from research work and experimentation carried out over the years by the group Associazione IDEA (Innovazione e Diffusione per lo sviluppo Economico e Ambientale; lit. innovation and diffusion for the economy and environment), set up in 2003 by the architects Fausto Giambra and Fabrizio Fiscelli in collaboration with the Laboratorio di Disegno Industriale, run by Prof. Dario Russo (2016), as part of the degree course in Industrial Design at the Department of Architecture. The work is based on previous experiences in the same field emerging over the years, which provided useful input from projects that had been carried out and completed. There have been many projects emerging from this significant collaboration over the last few years: additive manufactured chairs, personalized and corrected ergonomically in order to prevent postural problems, orthopaedic shoes constructed with a foot-scansion to endure the correct posture, lamps and furniture of various kinds.

As a result of the experience obtained in the sector, IDEA is today one of the few in Sicily capable of organizing courses for designers and technicians operating with additive manufacturing, leading to highly-specialised qualifications that provide young people with new employment openings; from digital craftsmanship to restoration of cultural assets, from design to the orthopaedic sector. From these considerations and links with the University, IDEA set up a Maker Agency, becoming a place where firms can develop their innovative projects through collaboration with talented young people, qualified in the utilization of new technology (Magone and Mazali, 2016). IDEA has thus become a network geared towards innovation through the abilities and creativity of its young people, which bring them into contact with the world of work. Collaboration with the association IDEA has led to the creation of a web-site that connects on-line makers, users and additive manufacturing. Through this on-line portal it will be possible to select the chair-model from those in the catalogue and personalize it in accordance with specific ergonomic parameters (Lupacchini, 2008) and preferred colours.

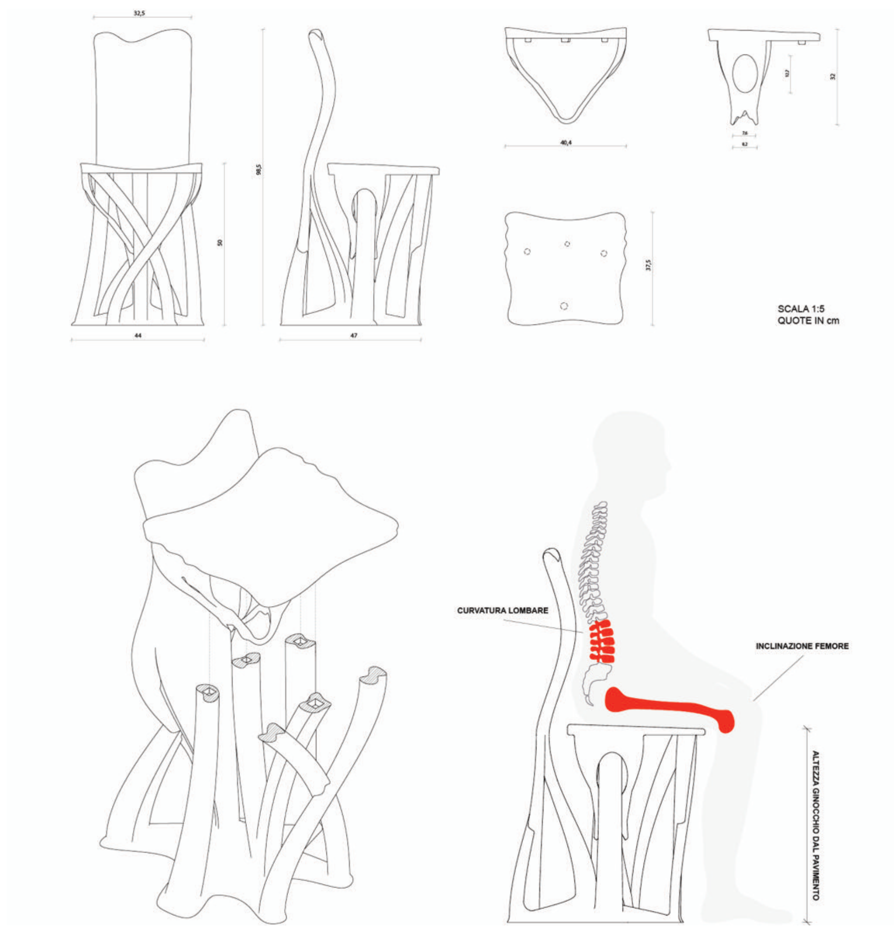
Flux: project for an ergonomic additive manufacturing chair – «The design method is simply a series of required operations, set out in a logical sequence dictated by experience. Its aim is to achieve the maximum result with the minimum effort». These were the words of Bruno Munari (1981, p. 16), who revealed himself to be a problem-solver many years ago and ahead of his time. Human Centered Design methodology, indicated as Design Thinking, was applied in the project, drawing inspiration from the Munari method, and simplified in certain phases. The process proceeds from the requisites of the people to whom the project is addressed; the project's key-points are defined and then one proceeds to the conception and, finally, the creation of the proto-type and the tests. In approaching the theme the designer Daniele Ficarrasi wondered, first of all, to what extent additive manufacturing technology had actually been exploited up to that point; this technology consents the construction of extremely complex forms with relatively swift modalities, costs and times and with solutions that cannot be accomplished with traditional techniques. Moreover, analysis was carried out on all the dynamics of parametric modelling that come into play when artefacts for FDM (Fused Deposition Modeling) additive manufacturing are designed.

The first models were produced by tracking sections perpendicular to the floor, which did not distance themselves from what already existed, appearing over-conditioned by the technological component; in fact, applying additive manufacturing in accordance with sections orthogonal to the buttressing surface, the supports are eliminated and production is facilitated. Furthermore, this modelling technique, to a certain extent restricts the possible results that can be obtained with additive manufacturing; as with all relatively new technology, additive manufacturing needs more research and closer examination in order to show off its real potential. Furthermore it was not easy to parameterize the model, the structure of which had to be redesigned entirely whenever the initial design was modified. The work of refinement on the completed project commenced, working continually on the section, with the aim of streamlining and lightening the load of the chair. The first checks were carried out using Grasshopper, Rhinoceros plug-in, gen-

Fig. 8 - Next page. *D. Ficarra,* Flux seat*, Palermo 2018*

erative design software and continued using Fusion 360 and Print Studio additive manufacturing software, with which the feasibility (of that which was being modelled) was verified step by step. The first forms, inspired by the branch-work in Mother nature, emerged, as often happens, almost by chance; through a system of optimizing forms (present in the modelling software), commencing from full profiles, applying their loads and utilization strictures, a model was generated that took into account the material and the maximum values of the activity. In this way forms began to appear that were more streamlined than those originally conceived, the development of which adhered to a logic of branch-work that put together and, at the same time, stressed the structural and aesthetic functions that the designer had been seeking.

After this initial phase the work proceeded with a further modification, which proved to be fundamental for the definitive project (Fig. 8); the model was conceived starting from its base and then following the line of planes parallel to the horizontal plane. This



meant being able to take a risk with even more sinuous forms, also satisfying the demands of the clients, who, with great enthusiasm, received the idea of producing an ergonomic chair that was totally different, in terms of form and function, to anything produced hitherto. The result obtained by tracking parallel sections proved to be the right choice, even though new problems arose with regard to that part of the seat, since this system generates a number of supports that are wasteful in terms of time and material costs (Fig. 9). Finally, from these considerations, the idea emerged of a structure that could be assembled in post-production, rather than produced as a single item, and this allowed us to resolve the previously-mentioned problems, by manufacturing separately the complete seatback support and the actual seat. Thus, several more models were produced, some of which were discarded due to purely stylistic imperfections and others that did not adequately pass the test of stability. The final configuration was obtained after further modifications that were not substantial but regarded small details (Fig. 10). The dimensions of the chair varied in accordance with the posture requirements of the ultimate user. Comparisons with experts in the sector enabled us to optimize the configuration of the chair by working on crucial points, such as the lower lumbar area and the incline of the seatback.

Figg. 9, 10 - D. Ficarra, Flux seat*, Palermo 2018: phase of production and final product.*

Sedia Reale (lit. Royal seat), made-to-measure, postural, on demand – After checking out developments, limitations and potential offered by this new technology and, after analysing many existing chairs, the designer Antonino S. Riolo chose four as reference-points for the project. He examined various aspects, including: ease of production using additive manufacturing technology, constructional stability, efficiency from the economic point of view, postural potential and, above all, ease of parameterization in adapting to the body of every user smoothly. The four project reference-points chosen were: the Endless Chair, that was built using additive technology, and thanks to the recovery of a re-adapted, old industrial robotic arm, took its shape from a continuous extrusion of recycled plastic; the Panton Chair was the first chair to be injection-moulded in a single block, with a profile that lent itself to swift additive manufacturing, since it consisted of a single continuous line; the Makerchair Puzzle was generated from a single form divided into 202 jigsaw puzzle pieces, enhancing the possibilities for small-time additive manufacturers in the construction of small or large furniture at accessible prices; lastly, the chair manufactured additively and designed by Zaha Hadid, was conceived as something lightweight but resistant, the design of which demonstrates the intelligent use of different densities of material in function of structural requirements.

The idea behind the design of the Sedia Ideale (lit. Ideal chair) was to produce a chair that can be configured by the user thanks to the utilization of a web-based configurator and can then be produced using FDM additive manufacturing technology, with the aid of PETG as a base material. The form is defined by two different profile curves, one for the external profile of the chair and the other for the central profile - three curves, in all, that generate a surface linking all three. This configuration is very efficient; one needs merely to move the two external profile curves apart or bring them closer together to modify the width of the chair. These curves are drawn with dots that, if positioned strategically, are joined together to form lines; laid out in continuous sequence, these lines form an entire profile curve. This enables us to choose the dots that, thanks to a simple translation, modify the height and depth of the seat. A lumbar cushion in TPU (a semi-ellipse, the minor axis of which measures 6 cm) is added to the configuration, which is positioned on the seatback by means of magnets sunk during the manufacturing phase, both in the seatback and the cushion. Finally, several furniture feet in TPU are fixed into the base of the chair.

The CAD project was conceived to be interpreted by a product configurator, which, by means of simple inputs, enables one to modify the height, width, depth of the seat and other personalized factors of an aesthetic order (Fig. 11). The Sedia Ideale is basically composed of two materials: PETG and TPU, to which one other element is added, in the form of neodymium magnets, which allow the cushion to be fixed to the seatback. PETG is a thermoplastic resin; it is a material resistant to bumps and chemical agents, is easy to mould and has a low withdrawal coefficient, which makes it ideal for large-size additive manufacturing, and suitable for moulding this chair. On the other hand, the lumbar cushion and furniture feet are made with a pre-formed elastomer

Fig. 11 - A. S. Riolo, Ideal seat*, Palermo 2019.*

Fig. 12 - Next page. *F. Belvisi and D. Cevola,* Mini 6.50*, Palermo 2018.*

called TPU, which is highly resistant to abrasions or ripping. The process of production begins with the slicing phase; the model is placed on its side on the additive manufacturing plane; in this way supports are not needed and the layers are oriented in the direction of maximum pressure. Once the production has begun, thanks to the interaction between additive manufacturing and robot, the process is interrupted automatically for magnets to be inserted, and subsequently starts up again and continues until the completion of the process. The same operation is repeated for the cushion and furniture feet. Being a parametric object, the measurements are not static, but vary within precise parameters defined by the designer; it will be the end-user who will bring his/her own chair to completion.

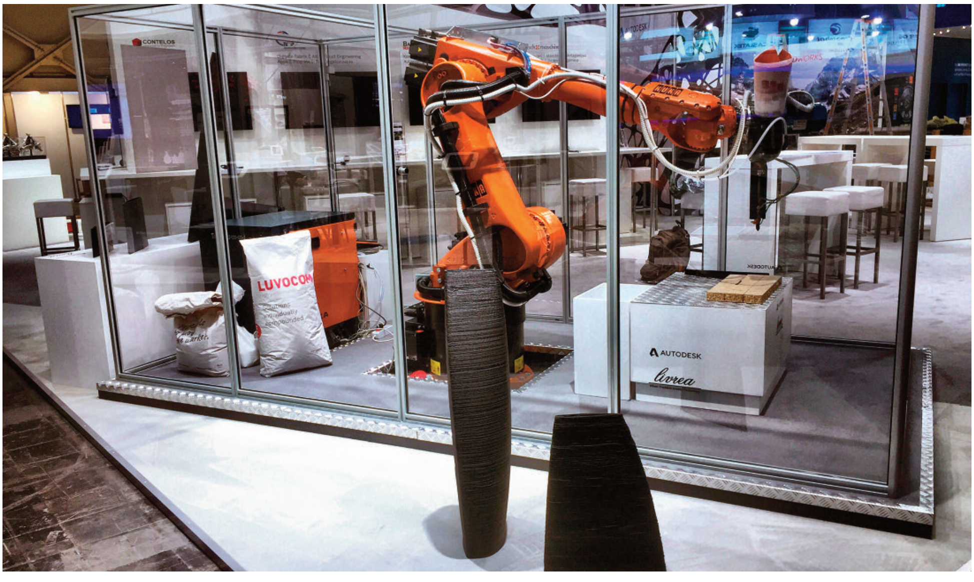
Ocore: the additive manufactured mini 6.50 – The ambitious project by two Sicilian designers, Francesco Belvisi and Daniele Cevola, was to build the first racing sailing-boat in the world, made almost entirely using additive manufacturing technology. The boat was a Mini 6.50 and was designed to participate in the Mini-Transat, a trans-Atlantic regatta (Fig. 12). The project was begun in 2014 originating in research into numerical modelling; in fact, certain civil engineering studies into the fractal behaviour of soil could be applied to large-scale additive manufacturing structures. Fractal structures are hierarchical and are commonly found in nature; the mathematics that defines them is usually a simple algorithm of easy computation, which can be used to generate complex and efficient structures. The intrinsic simplicity of fractal structures offers great advantages, both in generating additive manufacturing files and in simplifying models with regard to the structural and thermic properties of the object. A study was carried out together with Autodesk regarding the creation of structural elements based on fractals for boats; although many of the limitations imposed by conventional production techniques could be overcome, it was immediately evident that, in any case, the project would require the development of new tools, materials and design techniques.

One of the team's first tasks was to develop a range of thermoplastic materials for additive manufacturing, which would enable one to produce advanced structural components capable of resisting enormous stress. The materials for additive manufacturing were provided by the LEHVOSS Group and were based on high-performance thermoplastic polymers reinforced with carbon fibre, which means the artefacts are more resistant, more rigid and lighter. The additive manufacturer is fed with material in granule form, instead of the filament used for most FDM machines, since the pellets maintain good performance characteristics with a higher level of carbon fibre when compared to filaments. The first step was to create Ocore (www.ocore.it), a start-up with the task of developing additive manufacturing technology geared towards direct extrusion and to creating the design tools to support it. Instead of using the modality on which most additive manufacturing operates, Ocore positioned the head of the extruder at one end of the arm of an industrial robot (of 6 axes), produced by KUKA (Fig. 13). This provided

the additive manufacturer with a large volume of work. The robot's agility also gave the extruder greater liberty to manufacture than other conventional machines that can only deposit material along the vertical axis. Moreover, Ocore developed a new strategy for depositing material using an algorithm inspired by the fractals, with the aim of manufacturing the hull, deck and structure in a single piece (Fig. 14).

Almost all FDM additive manufacturers built today are run on software that generates instructions for manufacturing by slicing a mesh that defines the outline of the object in question resulting in a polygonal geometric shape. On the other hand, Ocore perfected a programme that translates the surfaces of Bezier, which outline the hull directly in the robot KUKA's native programmed language. This approach allows the arm to move very smoothly at a greater speed and precision when compared to the conventional control algorithms. The utilization of additive manufacturing enables one to create a structure that integrates films and reinforcement oriented perfectly with regard to the stress; then they are covered by a layer of carbon films that supports most of the boat's torsional and shear stress load. This approach enables us to achieve an excellent relationship between performance and weight and reduces the wastage of material to a minimum (Goldberg, 2018). The boat is designed to be constructed in transversal sections without solutions of continuity and then assembled longitudinally. In conventional sailing boats the hull and deck are usually built separately and then assembled subsequently (Larsson and Eliasson, 2014). On the other hand, in additive manufacturing construction it is more practical to manufacture the boat in transversal sections so that the hull and deck are manufactured as a single piece (Fig. 15).

The Mini 6.50 hull is manufactured in four segments, joined together with structural



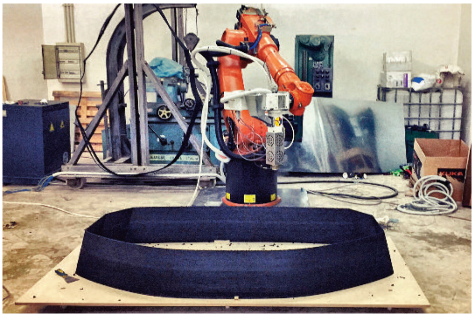


Fig. 13 - Previouse page. *The industrial robot Kuka, used in additive manufacturing.*

Fig. 14 - Construction in a single unit of hull, deck and structure of the Mini 6.50*.*

Fig. 15 - The working plane of Kuka.

Fig. 16 - Mini 6.50 *made entirely with additive manufacturing, Palermo 2018.*

adhesive and covered with a skin of epoxy and carbon resin (Fig. 16). A considerable advantage of this method is that it enables one to initiate production simply with a CAD file, without the need to build the required moulds in the traditional production processes of a boat, and with much shorter construction times. The other components of the boat built applying conventional methods also derive benefits from additive manufacturing technology. For example, the keel, which needs to be particularly sturdy, is made from carbon fibre and epoxy resin on an additive manufactured spindle. The rudders were also built using additive manufacturing, with a material base of polyamide loaded with 25% of carbon fibre, and with a notable reduction in production time (as much as 70%), whilst respecting weights and characteristics of equivalent rudders in composite material and with the possibility of trying out various configurations in order to speed up the process of refining the details of the boat; the costs are much lower than those for traditional systems (Luzzatto, 2018). Thanks to automation the production process is reduced to a few days.

Conclusions – The three experiments described above are, of course, not without limitations and critical points. In particular, in-series production of a project such as the one for the two chairs will require further trials, time and investment before it can be launched; production systems for complex objects utilizing additive manufacturing are still slow and clumsy, and do not result in large-scale production at accessible prices. On the other hand, it has proven to be a very effective solution for the experimentation of products of a high technological content. The case of Ocore does however open up new scenarios in the production of proto-types and components in the sector of racing boats and custom-built boats, but not without difficulties due to the structure verification complexity of a boat made from totally new materials and constructional techniques. Nonetheless, in both cases the utilization of additive manufacturing seems particularly effective, resulting in a significant reduction of costs and production time when compared to the technology applied hitherto (models, dummies, moulds).

The chair designed by Starck, in the same way as the projects presented above, provides food for thought regarding automatic learning and technology. Although creativity will probably never find its niche with robots, a programmed machine today can actually work out a project; the present level of quality of the above-mentioned experiments is in certain ways still rather unpolished, but from these examples it may be hypothesized that Man-driven machines will become ever more effective in creating products emerging from the human genius. At this point one might wonder what the role of the designer will be; in fact, his/her role in this phase is actually decisive for defining and applying the correct use of new technology, as well as protecting and maintaining his/her own position. One possible scenario sees all of us one day as designers. This process has been initiated over the last few years, also thanks to the accessibility of additive manufacturing, which potentially permits almost anybody to model and give shape to ideas, to create a proto-type and sell it on one of the numerous on-line market-places. Creativity is inborn in Man and in a scenario in which artificial intelligence is destined to replace certain skills, anybody will be able to start grappling with software and additive manufacturing. It is also true that, in the face of technology, in the last few years, we have not all suddenly become designers, and only those who have the right qualifications for creating and developing products can assume the role of designer. The designer's mission, therefore, will be to emerge from this new generation of makers and creators and become a mentor of machines (Gatti, 2018).

From the romantic point of view, one might consider transforming the relationship between designer and robot into one of craftsman and apprentice. By managing to educate and guide artificial intelligence in accordance with our skills, processes and creativity, the machine will be able to process an enormous quantity of data and tests that will provide feedback, subsequently recommending improvements and modifications for the success of a project. Collaboration between designer and machine might give rise to what Margaret Andersen, in an interview with the designer Anastasia Raina, defines as 'post-human design'. A design produced from a purely human perspective can be distinguished from an impersonal one produced via collaboration with a machine, by an element of unpredictability and controlled error. This element will be the strongpoint for post-human aesthetics and will result in emotional production, with Man still at the centre, even with the possible ingress of a new designer, who might analyse a number of possible solutions in a short time. We must, therefore, start to take into serious consideration the integration between Man and machine in such a way as to be able to develop and manage a new aesthetic understanding, which will be the result of combining thousands of possible options with choices still dictated by our purely human and emotional side.

NOTES

1) In his work (1973) Adam Smith claims the existence of two types of opposing and fundamentally successive economic organizations: one based on production for direct consumption in which each one produces for consumption whatever he has produced, and the other based on specialization o work, and as a logical consequence, on sale or trade via a product market of specialized work.
2) Bruno Munari, in his book *Da cosa nasce cosa* (1981), with a light-hearted approach renders the complex activity of the designer as something simple, trying to understand which are the most effective approaches for tackling a product design-project «Designing is easy when you know how to do it. Everything becomes easy when you know how to proceed in order to reach a solution to the problem [...]. The design approach does not change much; the skills change. Instead of solving the problem on one's own, in the case of a large-scale project, it will be necessary to increase the number of competent persons and collaborators and adapt the method to the new situation» (Munari, 1981, p. 8).

REFERENCES

Anderson, C. (2013), *Makers. Il ritorno dei produttori. Per una nuova rivoluzione industriale*, Rizzoli, Milano.

Anderson, C. (2010), *La coda lunga. Da un mercato di massa a una massa di mercati*, Codice Edizioni, Torino.
Autodesk (2017), *Making the unmakeable. Combining additive manufacturing with proven metalcasting processes.* [Online] Available at: https://www.autodesk.com/campaigns/additive/making-the-unmakeable [Accessed 20th July 2019].
Beltrametti, L., Guarnacci, N., Intini, N. and La Forgia, C. (2017), *La fabbrica connessa. La manifattura italiana (attra)verso Industria 4.0*, Guerini e Associati, Milano.
Bianchi, P. (2018), *4.0 La nova rivoluzione industriale,* Il Mulino, Bologna.
Bohnacker, H., Gross, B. and Laub, J. (2012), *Generative design: visualize, program and create with processing,* Princeton Architectural Press, New York.
Cipriani, A., Gramolati, A. and Mari, G. (2018), *Il lavoro 4.0 La Quarta Rivoluzione industriale e le trasformazioni delle attività lavorative*, Firenze University Press, Firenze.
Comstock, B. (2018), *Imagine it forward: courage, creativity, and the power of change,* Virgin books, London.
Figliola, A. and Battisti, A. (2017), "Post-Industrial Robotics Paradigmi progettuali della seconda era digitale, Design & Industry 4.0 Revolution", in *MD Journal*, n. 4, pp. 14-25.
Gatti, R. (2018), "Il nuovo ruolo del designer", in *3D Print Creative*, n. 22, pp. 36-39.
Goldberg, L. H. (2018), "Lighter, stronger, faster", in *Product, Design & Development*, n. 3, pp. 5-7.
Larsson, L. and Eliasson, R. (2014), *Principles of Yacht Design*, Adlard Coles, London.
Lombardi, M. and Rossi, M. (2017), *La fabbrica digitale. Guida all'industria 4.0,* Tecniche nuove, Milano.
Lupacchini, A. (2008), *Ergonomia e design*, Carocci, Roma.
Luzzatto, G. (2018), "The structure of an ocean racing boat printed in 3-D", in *Nautech*, n. 4, pp. 44-47.
Magone, A. and Mazali, T. (2016), *Industria 4.0. Uomini e macchine nella fabbrica digitale*, Guerini e Associati, Milano.
Munari, B. (1981), *Da cosa nasce cosa*, Editori Laterza, Roma-Bari.
Russo, D. (2016), "IDEA. Quando la stampa 3D incontra il design medicale", in *Siciliainforma*, n. 5, pp. 22-27.
Schwab, K. (2016), *La quarta rivoluzione industriale*, Franco Angeli, Milano.
Scodeller, D. and Antinori, E. (2017), "Design generativo e additive manufacturing, Design parametrico", in *MD Journal*, n. 3, pp. 28-41.
Smith, A. (1973), *Indagini sulla natura e le cause della ricchezza delle nazioni*, Isedi, Torino.
Sposito, C. and Scalisi, F. (2017), "Strumenti per la fabbricazione digitale in architettura", in *Agathón*, n. 1, pp. 143-151.
Vitta, M. (2016), *Le voci delle cose. Progetto, idea, destino*, Einaudi, Torino.

[a] *Benedetto Inzerillo, Architect and PhD in Industrial Design. He has been teaching since 1998. He has taught Methods and Systems of Production in Sicily, Nautical design and Laboratory of industrial design. He has been a lecturer in Laboratory of industrial design II, in the degree course in Industrial Design at the Department of Architecture, University of Palermo (Italy). Mob. +39 340/19. 76.188. E-mail: benedetto.inzerillo@unipa.it*