The theme of Digitization and Documentation, which inevitably affects the fields of surveying and designing architecture/urban areas, is periodically innovated by the new digital technologies and new multimedia communication systems to acquire, analyze and disseminate the value of our historical heritage.
The research in this field pushes us to overcome the limits imposed by tested technologies in order to be able to extend the field of application in the surveying and representation of the increasingly complex challenges imposed by the needs of conservation and maintenance.
This volume, which follows the three previous conferences of the "Digital & Documentation" cycle in the respective locations of Padua, Turin and Rome,
brings together some of the most significant research experiences that have achieved very competitive goals and objectives by professors and industry experts.
The volume ranges from architectural surveys to 3D models, to photomodelling, from BIM to augmented reality.
Today's communication has almost completely entered the digital world as the only system of language, be it graphic, spoken or artistic. It is no coincidence that the architectural and cultural heritage, as well as the urban aspects of the city, could not avoid undergoing significant change caused by the influence of the digital transition which allows them to be safeguarded, documented and handed down.
Digital, through all its forms, is, today, not only the representation of the asset but also its management through BIM approaches.
The boundaries of representation, digitization and documentation open up and become ever wider, embracing greater goals and responding to growing needs.

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DIGITAL & DOCUMENTATION

Laura Inzerillo

PROSPETTIVE MULTIPLE

STUDI DI INGEGNERIA
ARCHITETTURA E ARTE

Laura Inzerillo
Francesco Acuto

edited by

DIGITAL & DOCUMENTATION

The new boundaries of digital & documentation

volume 4

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The volume consists of a collection of contributions from the seminar "Digital & Documentation: The New Boundaries of Digitizing", realized at the University of Palermo on the day of September 2[0h], 2021. The event, organized by the experimental laboratory of research and didactics MetaLab 3D of DIING- Department of Engineering of University of Palermo promotes the themes of digital modeling and virtual environments applied to the documentation of architectural scenarios and the implementation of museum complexes through communication programs of immersive fruition.

The event has provide the contribution of external experts and lecturers in the field of digital documentation for Cultural Heritage. The scientific responsible for the organization of the event is Laura Inzerillo, University of Palermo.

This publication is made with the contribution of DIING, Department of Engineering of University of Palermo.

University of Palermo

Dipartimento di
Ingegneria

The event "Digital & Documentation" has seen the participation of professors, researchers and scholars from University of Palermo, University of Pavia, University of Bolzano, University of Rome "La Sapienza", University of Roma3, University of Catania, Politecnico di Torino, Politecnico di Milano.

University
of Pavia

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University of Catania

Associazione
Italiana
Disegno

“Ogni uomo confonde i limiti del suo campo visivo
con i confini del mondo”

Arthur Schopenhauer

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Preface

Sandro Parrinello

University of Pavia

Associate Professor of University of Pavia, European Research Ph.D. in Representation and Survey Sciences. Since 2012, he is Visiting Professor at Perm National Research Polytechnic University (Russia) and in 2015 he receives an honorary degree from the State Academy of Civil Engineering and Architecture of Odessa (Ukraine). Since 2005, he is an expert of UNESCO; in 2011 he was appointed Expert and Voting member in ICOFORT as contact person for Italy. He is director of DAda Lab. - Drawing Architecture Document Action Laboratory of University of Pavia, and director of Joint LS3D Landscape Survey & Design laboratory of University of Florence and University of Pavia.

Drawings updating and languages rewriting for the structuring of knowledge

Now in its fourth edition, the conference on Digital Documentation demonstrates how the proposed topic is getting more and more relevant as time goes by. The identity of the digital world and its products are taking on new features.

For years now we have been witnessing a revolution in the procedures that had characterised the cognitive activity related to the science of representation for centuries. It is not just a matter of a "change of medium" or a change in the methodological aspects linked to the progress of technology, but a complete reinterpretation of human-space relationship that contaminates every cultural model. This change covers indeed, within the disciplines related to architecture and heritage, each characterisation of the creative process, outlining, via new configurations, opportunities that have yet to be explored and revealed.

The digital world breaks out of those gears and constructions where it has grown up until now to contaminate every aspect of life in the most profound way. The paradigm is that of Cronenberg's Videodrome, where media produce a dystopian evolution, i.e., the birth of homo videns.

In the film, this contamination between man and media leads to a renewed perception of the world among human beings, resulting in the total fusion of the digital and the flesh as a new way of existence. What is currently happening fortunately seems to have less tragic outcomes.

The digital that we experience on a daily basis does not manifest the horror of its distortion, as it does in the movie.

The process of approaching and seducing the digital is supported by a gradual entrustment of functions that trigger the illusion of a greater control over our thoughts, and thus produce a feeling of higher safety towards said relationship.

The digital is becoming more and more soothing and is gradually replacing interpersonal activities that concern more than just relationships between people, but the relationship between people, things and experiences themselves, which are themselves becoming increasingly digital. The digital experience is made of rhythms and times that differ greatly from the real one. Its immediacy is its strongest quality.

"All and now" should be the slogan for the user when researching online. Everyone can get answers and become something else when immersed in the net, just like in Spielberg's Ready Player One, even if these answers are not yet widely used through systems that provide immersive realities.

Apart from the digital interface, the media flood is producing, through the redundancy of continuous, homologated, standardised and incessant messages, a general disinterest in both the facts and possibly the actual matter. Let us just think of the new productive dimension that information has been experiencing for years now.

A piece of news that undergoes even the slightest critical process is born old and is probably similar to a thousand others being produced at exactly the same time. The proliferation of information causes a detachment resulting in a surrender to the digital world.

Weddings with holograms, digital works of art, cryptocurrencies, digital experiences more attractive than real ones, are just a few examples of what could be considered science fiction just a few years ago. In this panorama, the opportunities for rewriting messages, redefining ethical and cultural models, and conveying data within the digital dimension appear almost unlimited.

So, what is the role of digital documentation? I believe that the task of our generation in these times of great tension is to bring as many experiences as possible into the digital era. What will be forgotten, overlooked, or even accidentally not digitised will be lost forever.

This is a great responsibility if we think of the vastness and heterogeneity of cultural heritage. It remains very difficult to imagine how this can be read and interpreted in order to find a specific position within the complex but nonetheless ordered structure that configures the digital dimensions. I am thinking of the intangible heritage, of the sound of the many dialects, of tastes and smells, and of the many pieces of information that do not yet find a place in the digital dimension, but whose existence is linked to customs and traditions that are being lost.

But the same may be true for information held by a text or a manuscript stored in an archive somewhere remote and thus not easily accessible. The precarious nature of this information seems even too evident today; whatever will not be uploaded not only into the digital domain, but into the network in general, so as to acquire its own digital echo, will probably be forgotten.

All the research experiences presented in this fourth conference have a common denominator: proposing tools to convey information digitally in order to preserve its memory over time. In the first session, about BIM, the development of architecture information systems is focused on historical architecture and the improvement of the modelling processes with respect to the reliability and the compositional and technological interpretation of the historical artefact.

In the second session, the digitisation experiences concerning the drawing archives address the issue of data structuring when bestowing an infographic spatiality on historical memory. In the third session, on the parameterization of models, more heterogeneous experiences are described, which examine how to interact with digital representation and complex models.

Browsing through the pages of these proceedings, many faces of digital documentation emerge, such as many research trends, cultural interests, operational needs. This world rich in knowledge, through the definition of models and modelling procedures, affects the deepest areas of representation.

The volume therefore constitutes a fragment, which is added to the previous volumes, to the other experiences carried out during these study days, but also to other conferences.

It participates indeed in the process of media coverage to which even scientific research must now succumb.
Nevertheless, I am willing to believe that, as usual for the Documentation & Digital Study Days, these proceedings, which are published one year after the conference, let us look back and consolidate our knowledge. One year in the digital information field might well feel like an era.
A global pandemic and the beginning of a new war in Europe occurred in between the conference and the production of its proceedings, thereby making the future of all research uncertain. This is why this fragment, this piece of experience, seems even more important: because information systems, models and the digital world in general should be able to help the progress of human thought but never replace it.
Hence, in a historical moment torn between wars and pandemics, where social and cultural realities contaminate each other, in a process of accumulation and stratification of symbols and signs, we hope to create a language that respects this complexity and represents, protects and supports knowledge.

S. Parrinello

Laura Inzerillo

University of Palermo

Ph.D., Laura Inzerillo is Associate Professor at University of Palermo within the Department of Engineering. Graduated cum laude in Management Engineering at University of Palermo, 1995. Ph.D in Digital Survey and Representation of the landscape and Architecture at University of Palermo in 1999. She won a fellowship ata Columbia University in New York from 1999 to 2000 with the confirmation of researcher at Columbia University from 2000 to 2003 at MUD. She won a post PhD fellowship at Univesrity of Palermo from 2000 to 2004 when she became researcher. Her field of expertise are the digital survey, 3D representation, Descriptive Geometry, reverse Engineering, monitoring. She is editorial member of several International Journals, reviewer member in other several International Journals, chief in editor of a special issue in MDPI Journal. She is actually authors of about 150 paper, 3 monographies, 2 chief in editor books and she won a best award paper. She has been involved in several international and national projects. Actually she is involved in SMARTI ETN - Sustainable Multi-functional Automated Resilient Transport Infrastructures European Training Network HORIZON20-20; in REMED - Application de l'économie circulaire pour une construction durable en Méditerranée ENI CBC MED European Union.

THE NEW BOUNDARIES OF DIGITIZATION:
FROM BIM TO PARAMETRIC MODELLING

This conference was the first appointment held using an hybrid mode: the first after the pandemic period. For this reason it was characterized by a particular enthusiasm due to the beauty of the meetings in presence and not in a remote way. In this background of happiness, we held our meeting. Moreover, Palermo had not appeared on the international scene, in the scientific disciplinary sector ICAR 17, for several decades and this occasion represented an expected and hoped-for return from the scientific community of the sector. Why do we talk about new boundaries of representation? In what sense do we mean the boundary of representation? New technologies take over more, and more rapidly, over those just introduced in the world of digitization and acquisition. The experiments of young researchers reach such avant-garde levels as to constitute a new starting point. The experience of the less young researchers and the innovativeness of the most immature researchers become a perfect glue for an effective and accurate methodological approach. The D&D conferences were born with the aim of giving voice to the research of young researchers to open new horizons of investigation in collaboration with the professors of the area, engaged for years in the various fields of research.

The themes that go beyond the boundaries of one's knowledge to expand to those of the scientific community, have been addressed in this fourth edition of the international conferences D&D, Documentation and digitization. It was not only a presentation day but a training day where the experiences and the passion of the speakers guaranteed an active participation of the guests.
The scientific insights, the methodological rigor, the passion and enthusiasm, with which the research was conducted and, consequently, handed down to us, have been driving forces for the entire scientific community.

Given the extensive participation and, given the versatility of the research ideas, three sessions have been planned: the first relating to BIM, the second to the digitization of archive drawings and the third to parametric modelling and video mapping.
The first session saw, as protagonists, researchers from Turin, Milan, Naples, Rome and Pavia. Daniela Oreni focused the research on the question of the 3D modelling within the BIM structure, the HBIM for the conservation and restoration of historic buildings and their representation. The Building Information Modelling is going to cover all design all over the fields of interest, in these last years. It is a new methodological approach of digital modelling which, with its interoperability, uses the tools and methods between tradition and innovation of the representation of anthropized reality whether it already exists or is in the design phase. The practitioner who intends to use BIM as an operational tool, must have matured the essential concepts of digital modelling and interoperability

between architectural and structural design with particular attention to aspects not only stylistic-architectural, but structural and plant, etc. working on the built heritage and on the one to be built; he must be able to compare contents, tools and modelling methods for the interpretation of the typical complexity of the built and the under construction.

He must possess skills in the communication of information typical of advanced modelling, skills in relationships for teamwork, familiarity with BIM tools and methods, processing capacity of a BIM concept map, creativity in the preparation of technical data sheets that illustrate the theoretical contents for a more immediate and user-friendly approach. However, it often happens that the professional, by necessity, improvises himself as a BIM connoisseur, without having the appropriate skills, creating complex and difficult to manage BIM models. The role of the researcher is to experiment and propose new simplifying methodologies of the BIM model; to implement interoperable concept maps of great effectiveness and simplicity at the same time.

Pierpaolo D'Agostino

Marika Griffo focused her research on the semantics through models in their ex-ante and ex-post classification processes. The 3D survey obtained by a photogrammetric or laser scanner process has innumerable potentials. However, the point clouds obtained from data processing represent a single and indistinct object, deprived of any ontological structure. Therefore, it is necessary to perform a deconstruction and classification of the cloud in order to create a semantic and explanatory model. Thanks to this deconstruction, the final model is easier to read and interpret. How does all this intervene in BIM modelling? When should semantic classification be introduced in BIM? In reality, the semantic code is created ex-ante through the use of hierarchical models in BIM space. The model obtained contains ontologically defined objects which are grouped by analogy or equivalence or are separated by diversity. In both cases the system is built thanks to a semantic construct, which has the purpose of organising the data in such a way that their classification is truthful and effective. Ultimate and fundamental goal of modeling is the understanding of the object.

Laura Inzerillo

SESSION - III

Parametric modelling and Video mapping

Francesco Di Paola
University of Palermo

Francesco Di Paola is Associate Professor at University of Palermo within the Department of Architecture. Graduated cum laude in Building Engineering-Architecture at University of Palermo, 2003. Ph.D in "Representation and Surveying of Architecture and Environment" at University of Palermo in 2007. He is a member of the Scientific Board in the Interdepartmental Research Center "Coscienza" of the University of Palermo. His research mainly topics are in the field of Architectural Geometry, Algorithms Aided Design, Survey, Cultural Heritage Fruition in VR/AR. He is a member of several area research associations, he is member of scientific/technical committees of international conferences, he is reviewer member in several International Journals and guest editor of a special issue in MDPI Journal. He has been involved in several international and national projects. He is actually the author of more than 110 publications in scientific journals, proceedings of national/international scientific papers and monographs. He won a best paper award and, in 2007, he was awarded the UID Silver Targa by the Association of Italian Unity of Design (UID)

Graziano Mario Valenti
University of Rome "La Sapienza"

Graziano Mario Valenti is an associate professor, afferent to the Department of History, Design and Restoration of Architecture at the University of Rome "La Sapienza".

In 2014, he was awarded the national scientific qualification for the role of full professor. His research activity - articulated in the study and development of theory, conception, realization and testing of experimental models - is focused on the application of new digital technologies to support the design, construction, knowledge and communication of industrial and architectural products, with particular regard to cultural heritage and with the specific objective of anticipating future operational scenarios and solving current application problems. An expert in computer science, since the origins of his research activity, he has directly designed and implemented, using multiple programming languages, numerous procedures and applications for sharing, integrating and representing data of a heterogeneous nature distributed over a geographic network. A particular object of study that cuts across all of his research is the definition and representation of integrated and dynamic digital models that take on the role of both a container and a processing unit for heterogeneous information.

From 2000 to the present, he has participated in numerous university research projects funded by "La Sapienza" University and MIUR, frequently assuming the role of scientific coordinator.

Author of monographs and numerous scientific papers, he has spoken as a speaker or reviewer at international congresses and conferences.

INTRODUCTION

Virtual representation, free-form surface modelling techniques and numerical control manufacturing, with their intrinsic dynamic and interactive capabilities, have profoundly expanded and enriched the repertoire of geometric shapes, generating innovative design skills and creative languages.
There is no doubt about the opportunities for exploration, contamination, relationships and overlapping of ideas, measurements and information, which the continuous evolution of expeditious, parametric and automatic procedures brings to the use of the many products of the information age.
Adopting computation as a form of design is profoundly different from simply using tools geared toward increasing the productive capabilities of the designer. This approach implies first of all an extension of design actions to techniques and strategies, whose main strength is measured in the ability to promote new and different ways of thinking.
The added value of digital culture is rooted in the complementarity and synergy of all graphical and expressive methods of architectural language, hinging on the foundations of Scientific Representation. The latter play a basic role for infographics, constitute an essential cultural baggage and enrich the researcher with the awareness of possessing the tools of knowledge and governance of the geometric properties that regulate space, in order to be able to both read and communicate the design.
In computational design, the programming and the design domains come together to identify a form of creativity capable of interpreting information into procedures and rules for the project. In this field, new research perspectives declined in the specific contexts of the project (architecture, design, representation, territory, technologies, communication interfaces) integrate digital and emerging technologies in the elaboration of a product. The computation is seen as the process that regulates the information and the interactions between the elements involved in the definition of the design of the form, its responsive reactions to the context and the application of the same digital technologies to the production.
The emerging techniques of parametric and generative modeling, algorithmic-visual and computational programming, the methodology of “form-finding” and optimization processes with genetic algorithms constitute the tools of geometric-formal control that, in addition to bringing a methodological and applicative renewal, connects and hybridizes fields, processes and disciplines.
In Industrial Design, as in multi-scale architectural design, the explication of algorithmic thinking promotes research directions based on the centrality of the concept of code-procedure for building geometric- informative models. The parametric and semantic digital three-dimensional model simulates, collects and manages not only geometric data, but also structural, energy related and construction aspects of the work, putting them in relation with each other and thus

improving the interaction and dialogue between the design figures involved in the process. Furthermore, in the field of Design, generative and pre-figurative systems are now often associated with new production processes that are no longer of a "mechanical" type (cutting, turning, milling) but "plastic", linked to the additive modes of digital fabrication. In the near future, most industrial processes will have a digital matrix as a generator of governance and production control. The generative approach is useful for the designer to translate even the most complex visions into tangible signs, conceiving objects that can significantly adhere to the specific needs of people, contributing to the construction of unprecedented and fruitful design paths.

The contributions explore the themes of digital design and, specifically, the systematic aspects central to the relationship between computation and design.

The researches of Giorgio Buratti, Domenico D'uva, Marco Filippucci and Mirco Cannella provide a significant contribution to this scenario, describing a vast applicative and theoretical panorama, which ranges from the small scale of the industrial product to the large scale of territorial analysis, at the same time offering useful conceptual connections, which consolidate the general and increasingly shared theoretical apparatus of digital work, both for research and for the project.

Giorgio Buratti experimentally demonstrates how, through the coding of generative procedures, it is possible to investigate and use morphologies typical of the natural world for design, functional and manufacturing optimization purposes. His applications concern articulations of minimal surfaces and fractal geometries, whose parametric and generative definition must necessarily find its foundation in theoretical knowledge and critical capacity, useful for identifying and describing its formal genesis step by step.

Domenico D'Uva's research concerns the territorial scale, addressing those situations defined as "fragile", whose analysis and mapping, due to the complexity of the landscape and the scarcity of pre-existing information, require an unconventional approach based on integration of heterogeneous sources. The problem highlighted in the illustrated case study finds a solution in the definition of an optimized workflow that systemize various digital technologies.

Marco Filippucci, retracing a vast repertoire of exemplary case studies, emphasizes some critical issues and solutions that have profoundly transformed the meaning of design and model; focusing in particular on the problem of the explication of the process of representation, he emphasizes the temporal separation - postponement - of the representative result with respect to the act of drawing, which he pertinently associates with the renewal of the ancient discipline of descriptive geometry.

Finally, Mirco Cannella, delves into aspects that are different in type to the previous ones. The researcher discusses the potential and criticalities of augmented reality systems used for fruition purposes in architectural and archaeological contexts. In particular, his contribution focuses on procedures for georeferencing digital models in the real context, determining solutions that overcome the operational difficulties of current systems on the market.

The researches illustrated here, in their diversity and in some ways complementarity, are indicative of a mature thematic area, of great potential and rapidly developing: a resource of opportunities that will certainly be able to inspire and motivate future young researchers.

Giorgio Buratti

Polytechnic University of Milan

Giorgio Buratti is Ph.D. at the School of Design in Politecnico di Milano (Italy), where he graduated in 2000 with full marks. In the same year he obtained his master's degree in Ergonomics and he is teacher assistant in several courses. From 2008 to 2010 he is Temporary professor at Design course at Linguistic center of Basel. From 2015 he is adjunct professor in Politecnico di Milano. He focused his research in defining generative algorithms and parametric modelling system to generate articulated surfaces and high level complexity geometry. He is interested on relations between Nature and Design, in design development of biological patterns and formal structures and in digital fabrication technologies. He collaborates with several important companies such as Saint Gobain, DHL, Brembo, Luxotica in innovation and development.

COMPUTATIONAL DESIGN IN THE STUDY OF FORMS OF NATURE

Abstract

The increased level of computer literacy that has characterized the last few decades has led designers to investigate processes that underlie the used daily Computer. This interest has promoted a new type of modelling focused on the formulation of algorithms, systematic procedures based on a uniquely interpretable succession of instructions, which explain how to achieve a goal. Used in the drawing discipline, the computational process opens to a new research direction based on code concept: if a problem resolution can be described by a finite number of steps, in the same way the shape's identity is a consequence of the set of discrete rules that define it. In synergy with the digitization of production processes capable of constructing complex morphologies starting from the numerical model, algorithmic modelling has allowed the morphological freedom that distinguishes recent design or architecture productions. This paper investigates the reciprocal link between computational modelling and digital fabrication in studying morphologies typical of the natural world, searching for a new formal language based on efficiency and functionality.

L'accresciuto livello di alfabetizzazione informatica che ha contraddistinto gli ultimi decenni ha portato i progettisti ad indagare i processi che sottendono il funzionamento dell'elaboratore quotidianamente utilizzato. L'interesse ha promosso un nuovo tipo di modellazione incentrata sulla formulazione di algoritmi, procedimenti sistematici basati su una successione di istruzioni univocamente interpretabili, che spiegano come raggiungere un determinato obbiettivo. Utilizzato nella disciplina del disegno, il processo computazionale apre ad un nuovo indirizzo di ricerca basato sul concetto di codice-procedura: se la risoluzione di un problema può essere descritta da un numero finito di passi, allo stesso modo l'identità di una forma è conseguenza dell'insieme di regole discrete che la definiscono. In sinergia con la digitalizzazione di processi produttivi capaci di costruire morfologie complesse a partire dal modello numerico, la modellazione algoritmica ha permesso la libertà morfologica che contraddistingue le recenti produzioni nel mondo del design o dell'architettura. Questo scritto indaga il legame di reciprocità tra modellazione computazionale e fabbricazione digitale nello studio di morfologie proprie del mondo naturale, alla ricerca di un nuovo linguaggio formale basato sull'efficienza e sulla funzionalità.

Introduction

The complex morphologies today realized in the design or architecture sector are possible thanks to the intended use of the digital medium, no longer bound by assisted design software. The study of computer processes that underlie the form generation has equipped the designers with an alternative approach capable of developing ad hoc tools used in unique design and research experiences. The process is based on the possibility of controlling the geometry by studying algorithms, logical procedures based on a succession of uniquely interpretable instructions that explain to the computer how to achieve a specific goal. Any problem solved in these terms is said to be computed. Used in the drawing, it promotes a research direction based on the centrality of the concept of code- procedure: if the resolution of a question can be described by a finite number of steps, in the same way, the identity of a shape is a consequence of the set of rules discrete that define it. For the design disciplines, the study, comparison and reasoning of the morphological properties are fundamental for the effectiveness and efficiency of what is conceived. The result of any project depends, in fact, on the ability to respond to project requirements related to the timing and resources necessary to achieve a goal. This leads to a formal simplification, which adapts to the tools and manufacturing processes since for design purposes the possibility of designing articulated geometries would be useless without the opportunity of a realization. Technological evolution has today expanded production capacities thanks to construction processes, summarized by Digital Fabrication definition, able to interpret the digital model and translate it into different levels including the exact modelling of the parts, assembly and construction, defined both in the components and systems, whether in the process leading to production or construction. For the first time in the project's history, the information necessary for the design and production of artefacts is summarised by a single representation, in a paradigm that allows the creation of hitherto advanced morphologies.

Some of these have long been known as they can be found in biological systems. The natural world was, in fact, the first model of design inspiration since man began to represent natural organisms and phenomena within caves to understand their principles. Although the functional efficiency observed in nature has constantly stimulated equally effective solutions in the world of artefacts, abstracting and transforming natural principles into technology is a discontinuous process linked to the theoretical tools and technologies available. The modern world of design is thus adapting scientific culture trend that abandons the deterministic vision of reality to embrace a model more consistent with the real world, admitting that all phenomena, even if to different degrees, are characterised by nonlinear processes. Below are examples of how this approach reveals its potential in studying and formalising morphologies typical of the natural world that open to a new language and to innovative solutions.

Triply Periodic Minimal Surface

A minimal surface is a surface whose mean curvature is always zero. This definition answers to Plateau problem: if a closed polygon plane or oblique is assigned, then there is always a system of surfaces, including all possible surfaces that touch the frame, which can minimise the area.[1]

The most interesting geometric shapes for the research are the Triply Periodic Minimal Surfaces (TPMS), three-dimensional symmetry surfaces, invariants for translation in Cartesian space. This property allows periodic replication of the single surface in space to form a new modular structure, seamlessly and without intersections, in which the physical iteration between the modules (a polyhedron called Fundamental

Cell) causes a compensatory effect that significantly increases their structural efficiency while maintaining minimal use of material[2]. These characteristics are known because triple symmetry minimal surfaces are widespread in nature and are studied by different disciplines in numerous systems. The objectives of those researches[3], and this study too, lie in understanding the principles on which the remarkable properties depend and then transfer them to technological applications. The solution proposed concerns the safety of construction workers. The investigation showed how many bricklayers did not wear helmets due to weight and amount of heat, especially in the summer period[4]. The TPMS's characteristics to create stable morphologies are therefore functional to realise a resilient but lightweight, protective helmet with a breathable structure capable of solving the user problems detected.

The first problem to solve is the digital control of TPMS. It has already been written that minimal surfaces are characterised by zero mean curvature. The peculiar property of these loci is, however, not easily usable in their digital generation.
A method is based on Karl Weierstrass's[5] parametric equation, which expresses every minimal surface as holomorphic functions. This equation, however, is characterized by a complex formulation that makes the computation process complicated. The most effective process is the implicit formulation that describes a surface through a linear function of three variables, f (x, y, z) = 0. The trigonometric form is appropriate to the digital description because it allows the large number of elements that characterize TPMS without overloading the calculation process and does not allow self-intersections. Using Grasshopper, a visual programming language that works in Rhino 3d (CAD) environment, it

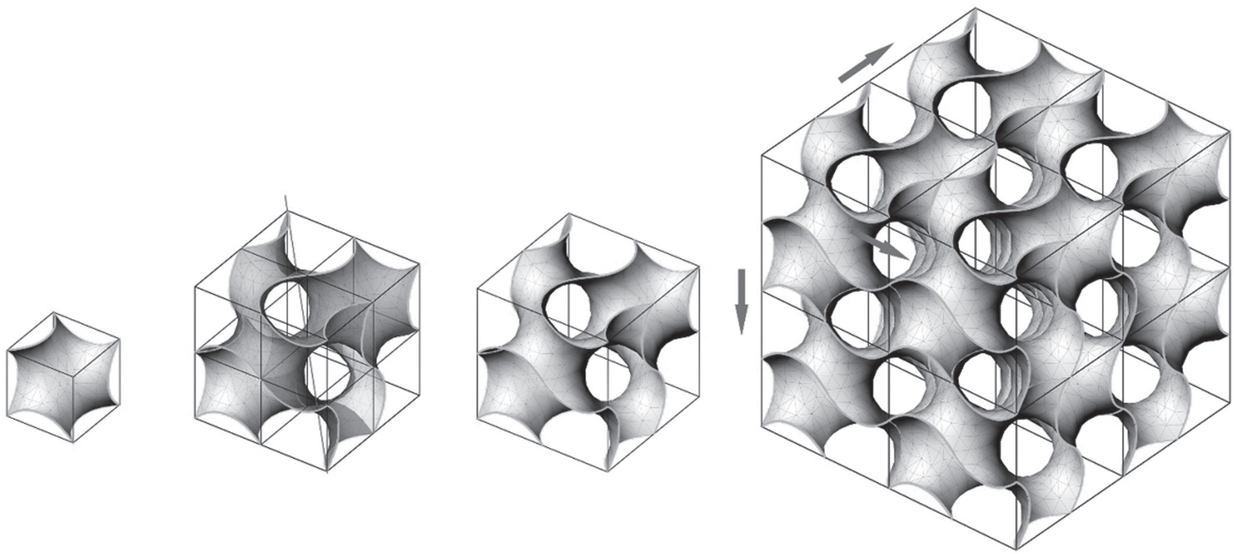

Fig. 1 - TPMS based on Gyroid principles of construction

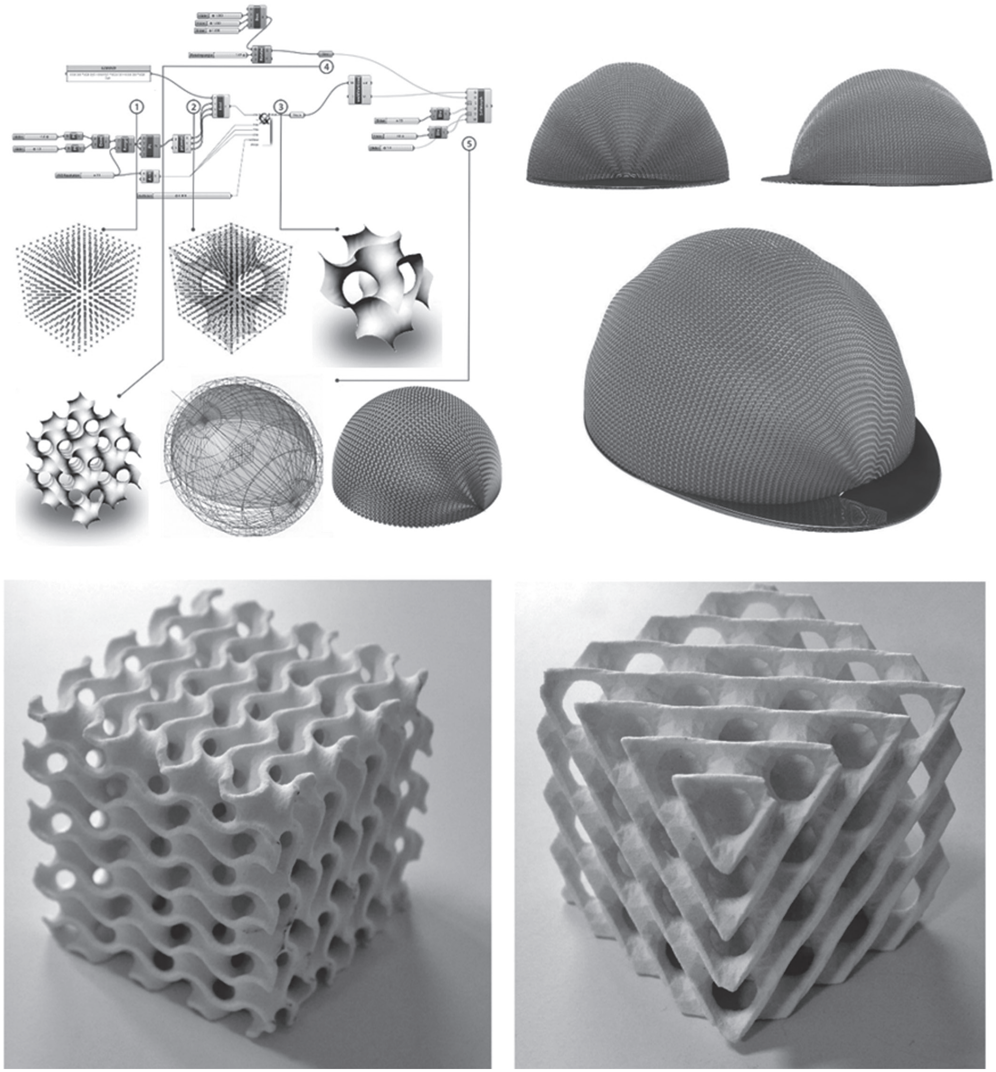

Fig. 2 - Step of the algorithm: 1) Definition of points in the fundamental cell; 2) Triangulation creates the surface; 3) Gyroid surface; 4) Invariant translation to create a TPMS based on Gyroid; 5) Discretization of the Hemispherical dome to obtain a safety helmet composed by Gyroid. Below TPMS based on Gyroid and Diamond Surface manufactured by 3d printing process.

is possible to define algorithms that describe the minimal surfaces expressed in the implicit formulation with good approximation. We can observe the construction example of a TPMS derived from Gyroid. This surface is generated exclusively by curves and distinguished by the absence of reflection symmetry between the eight fundamental units. It does have C3 axes of symmetry (along one diagonal of the unit cell) and 4-fold rotoinversion axes. In other words, the fundamental units are placed at 120° intervals along a diagonal, while the rotoinversion operation rotates them by 90° and performs the inversion through the centre of cube. This creates a morphology that separates the space into two enantiomorphic regions, which are specularly symmetrical and overlapping with a plane outside them, but not by rotation (Fig.1).

In nature, these structures are present where one needs strength and lightness, such as in the sea urchin exoskeleton or butterfly wings. In addition, the morphogenesis processes take place for stratification, similarly to what happens in manufacturing through 3D printers. These features make Gyroid particularly interesting for the design purposes proposed.

The algorithm translates the algebraic equation into a finished form that can be studied, manipulated and replicated. The process can be conceptually simplified, imagining that the equation “selects”, in the domain of Cartesian space points, those belonging to the surface to represent. The following algorithm’s instruction connects by triangulation the points creating the surface. It is now possible to exploit the symmetry characteristics of the single unit by replicating it and studying adaptation processes to the considered morphology. The example in figure 2 shows how, via computational modelling, it is possible to integrate the properties of the minimal surfaces into a protective artefact. The digital helmet model was solved with a NURBS surface, discretized in parallelograms coinciding with the lower base of the pyramid trunk in which every single Gyroid will be recalculated.

The only technology available today for the creation of such a digital model is 3D printing. After assessing the cost-benefit ratio and research intentions, the first experiments were conducted with the Zcorp Spectrum Z510 plaster-based 3D Printing. Regardless of the software that generates the format needed for 3d printing (stereolithography) is. STL, which describes the model through a triangular mesh. If in a digital domain a surface is an ideal geometric object without thickness, its translation into the physical world requires specifications:

1 Correct topological relationship among the mesh triangles, which must not have discontinuities or overlays.
2 Clarify the perpendicular to the triangles to allow the machine to recognize the interior and exterior of the artefacts.
3 Optimizing printing speed concerning material and geometry.
4 Considering that printers deposit layered material, moving vertically, it is necessary to provide the correct arrangement to support the protruding parts to prevent the structure from collapsing during printing.

Broccoli, lungs and geometry

The following examples investigate how a conscious use of computational processes in design can describe and control the complexity factors of the biological reference model. The first example concerns a vegetable that has always fascinated scholars of different disciplines for its morphological characteristics: Roman broccoli[6].The reputation is probably due to the broccoli’s “rosette” (the small cone) fractal arrangement, which reproduces the same geometry on different scales following the rules of internal homothety. In other words, each broccoli’s cone generates a succession of other cones on its lateral surface in a continuous sequence. Another interesting aspect is that this sequence can be expressed as a quotient of the Fibonacci sequence, or rather, as the ratio between this sequence's numbers in which each quantity is the sum of the previous two. The algorithm first describes a logarithmic spiral belonging to the XY plane. This spiral is defined algebraically so that the vector radius r is a continuous and monotone function of an angle q, describable in the Cartesian plane by polar coordinates such that x = r cos q and y = r sin q, where r is the distance of a generic point P from the origin of axes (considered as the spiral pole). The angle q indicates the inclination of OP with respect to the polar axis. The curve projection on the cone lateral surface allows obtaining a three-dimensional logarithmic spiral in which the polar axis OZ coincides with the cone height.

The next step divides the curve according to the Fibonacci sequence, obtaining proportional segments. The extremes will correspond to the base centres of cones that will constitute the new peaks. The algorithm constrains the cones height to the radius and the radius to Fibonacci sequence so that, depending on the point of generation, it respects the tangency condition with the bases of the adjacent cones that lie on the same curve. Like this, the size of the "rosette" decreases proportionally as the spiral approaches the cone apex. It is sufficient to repeat the process n times to obtain a geometry that approximates the existing vegetable precisely (Fig.3).
The geometric study also reveals the phyllotaxis reasons: the angle of 137.5° that accurately distances the cones base

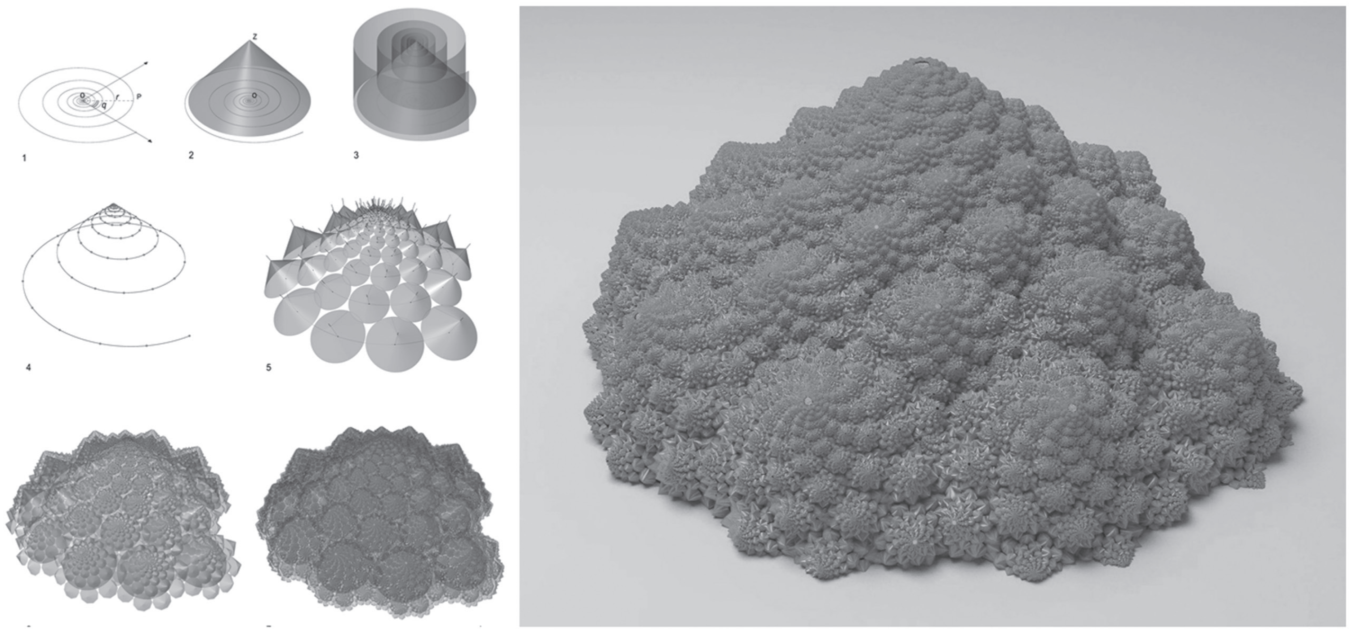

Fig. 3 - Algorithmic development of a Roman broccoli

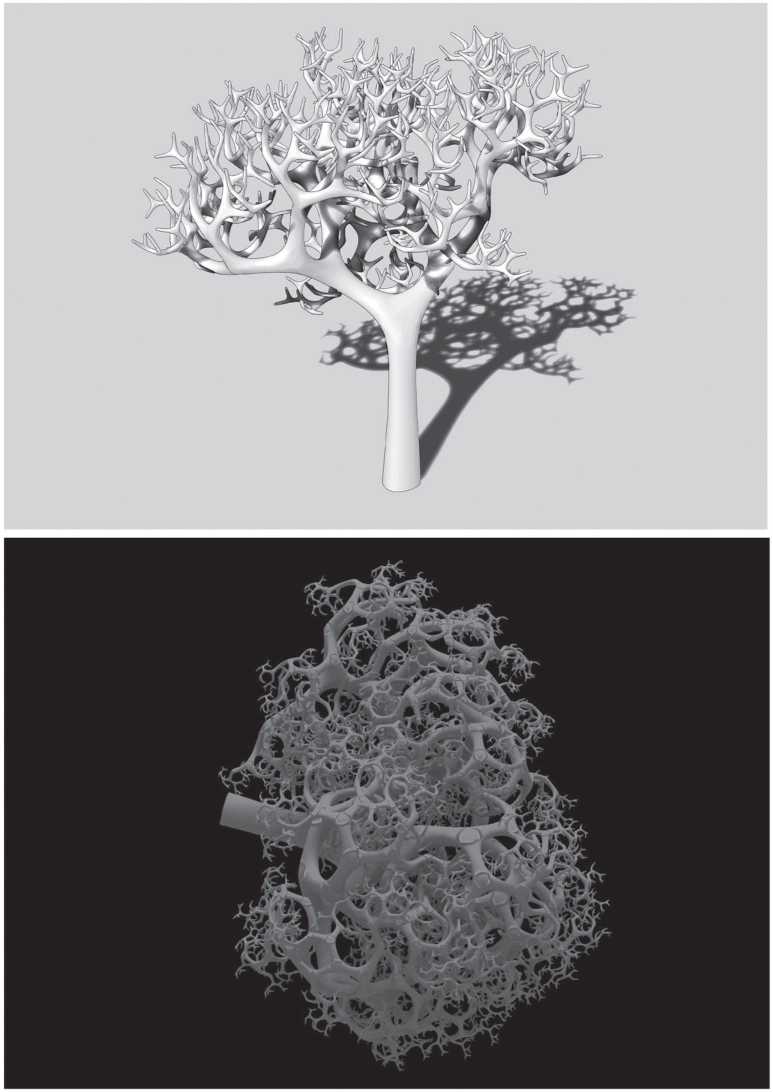

Fig. 4 - The same algorithmic description, by parameters variation, can generate a tree morphology or the articulated distribution of the pulmonary circulatory system.

centres, corresponding to the peaks, allows the space to be exploited with excellent efficiency. If the divergence angle had, for example, an amplitude of 120°, or any other rational product of 360°, the cones would align radially, leaving a large amount of unused area among them. At this point, one may wonder why Roman broccoli develops cones starting from a circular base rather than using another polygon capable of seamlessly tessellating the surface, such as a square or a triangle. The finished model analysis seems to provide some explanation: it will be noticed how the self-similar principle orients the cones in every space direction. The continuous cone curvature allows for maximum exposure to light rays regardless of incidence[7].

The second algorithm computes a particular type of branched structure typical of some tree families and found in many living beings' respiratory vascular systems. The study is a three-dimensional development of a fractal known as the Pythagorean tree. It is based on a binary iterative procedure structured on the well-known relationship between square and triangle a2 = b2 + c2. Each square has one side in common with a triangle, which in turn has the other two sides in common with two other squares and so on, in a succession of rotations and homotheties which, despite their simplicity, generate branched structures of great complexity. The three-dimensional construction follows the same rule but requires replacing the cube or parallelepiped with a triangular-based prism.

Three-dimensional triangle equivalent is, in fact, the tetrahedron, which, having triangular faces, does not allow the construction of polyhedrons characterized by four faces. Solids characterized by square and triangular faces, such as the square-based pyramid or the cuboctahedron, could be used, but the binary relationship that distinguishes the morphology growth would be lost.

Each branch is divided into two parts that follow the face perpendicular, halving in section, in a repeated process that allows adequate coverage of the space without interference among one branch and the other. The algorithm then transforms the polyhedron into cylinders to better simulate the studied natural shapes. In this case, it is also possible to experiment with different parametric variations, realizing why the dichotomous subdivision of the trachea into bronchi and the bronchi into bronchioles, similar to the branching of many plants, is the simplest way to occupy a volume (Fig.4). While breathing, the lungs inhale oxygen (O2) and exhale carbon dioxide (CO2), while chlorophyll photosynthesis reverses this process. In both cases, the exchange efficiency improves as the surface increases, so that the continuous branching of the structure in constant proportions allows to have in a relatively small volume such as that of the lungs variable surface between 50 and 100 m2, equivalent to a tennis court. The specific relationship between the bifurcation angles then guarantees the maximum space coverage avoiding the branches overlapping.

Conclusion

This paper illustrates how computational modelling allows the representation of complex natural morphologies and sufficiently precise control to make them available for production purposes. The synergy with new machine tools is a decisive factor. However, technology does not guarantee the development of a coherent project because the form is not only a result of software or production technology. The main characteristic of the new approach is that conceiving a form algorithm forces one to systematize the design. The critical issue is not the knowledge of the programming language: a computational process can be separated from the computer, but a forma mentis capable of decomposing and analysing the steps that lead one to the outcome. Although able to manage and optimize thousands of data related to a problem, the computer cannot determine the generation rules that the designer must formulate. To prepare the form for computation, it is necessary to know the geometry. In a process where the digital model directly informs the machinery capable of producing it, the role of the design is not only a descriptive and planning tool but, today more than ever, to shape the material.

Bibliography

Ball, P. (2012) Pattern Formation in nature: physical constraints and self-organising characteristics in Material Computation, AD Architectural Design n. 216, edited by Achim Menges.

Bar-Cohen Y. (2011) Biomimetics: nature-based innovations, CRC Press, Boca Raton.

Bovill, C., (1996) The Fractal Geometry in Architecture and Design, Birkhäuser: Boston: France.

Buratti G, Santini M., Dellera L., Mosconi G., (2010), "La valutazione del rischio da sovraccarico biomeccanico in edilizia: preliminari di uno studio in corso" Giornale Italiano Di Medicina Del Lavoro ed Ergonomia, Centro Studi Fondazione Maugeri.

Buratti G.,(2013), Superficie minimi periodiche La geometria dell'apparente casualità. In: (a cura di): Andrea Casale, Geometria descrittiva e rappresentazione digitale-Volume 2. p. 133-140, Roma:Edizioni Kappa.

Buratti, G. Computational Process and Code-Form Definition in Design. In: (a cura di): P. Magnaghi- Delfino, G. Mele, T. Norando, Faces of Geometry. From Agnesi to Mirzakhani. p. 31-40, Springer.

Emmer M., (2009), Bolle di sapone. Tra arte e matematica, Torino, Collana Nuova cultura, Bollati Boringhieri.

Greenough, H., (1957) Form and Function: Remarks on Art, Design and Architecture, H. A. Small, University of California Press, Berkley and Los Angeles.

Hensel, M., Menges, A., Weinstock, M. (2010) Emergent Technologies and Design. Towards a biological paradigm for architecture, Routledge, New York

Iwamoto L.(2009), Digital fabrications -Architectural and material techniques. New York: Princeton Architectural Press.

Rossi, M.; Buratti, G. (2018) Computational Morphologies. Design Rules between Organic Models and Responsive Architecture, Springer Verlag. DOI:10.1007/978-3-319-60919-5 - ISBN:978 3 319 60919 5

Steadman, P. (1988) L'evoluzione del design. L'analisi biologica in architettura e nelle arti applicate, Editore: Liguori.

Notes

[1] See Buratti G., 2013, pag. 133.
[2] See Emmer M., 2009.
[3] See Bar-Cohen Y., 2011.
[4] See Buratti G, Santini M., Dellera L., Mosconi G., 2010.
[5] Karl Theodor Wilhelm Weierstrass (1815 –1897) German mathematician, also known as the father of modern analysis.
[6] Brassica oleracea italica.
[7] In fact, Roman broccoli is a cauliflower variety with a medium autumn-winter cycle.