ShOCK!

Sharing of Computable Knowledge!

eCAADe 35

20 - 22 September 2017 Rome

eCAADe 2017

ShoCK!

Volume 2

Editors
Antonio Fioravanti, Stefano Cursi, Salma Elahmar, Silvia Gargaro
Gianluigi Loffreda, Gabriele Novembri and Armando Trento
Faculty of Civil and Industrial Engineering
Sapienza University of Rome

1st Edition, September 2017

ShoCK – Sharing of Computable Knowledge - Proceedings of the 35th International Conference on Education and Research in Computer Aided Architectural Design in Europe, Rome, Italy, 20th-22nd September 2017, Volume 2. Edited by Antonio Fioravanti, Stefano Cursi, Salma Elahmar, Silvia Gargaro, Gianluigi Loffreda, Gabriele Novembri, Armando Trento. Brussels: Education and Research in Computer Aided Architectural Design in Europe; Rome: Dep. of Civil, Building and Environmental Engineering, Faculty of Civil and Industrial Engineering, Sapienza University of Rome.

ISBN
9789491207136
978-94-91207-13-6

ISSN: 2684-1843
Legal deposit: D/2017/14982/02

Publisher: eCAADe (Education and Research in Computer Aided Architectural Design in Europe) and Dep. of Civil, Building and Environmental Engineering, Faculty of Civil and Industrial Engineering, *Sapienza* University of Rome.

Cover Design: Ugo Maria Coraglia, Kareem Elsayed and Antonio Fioravanti.
eCAADe2017 Logo Contest winners: Mohamed Elgendy and Omar Hadid (1st prize); Valerio Perna (2nd prize).

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Theme

ShoCK! – *Sharing of Computable Knowledge!*

The theme of the 35th eCAADe Conference is *Sharing of Computable Knowledge! – ShoCK!* so, we have invited eCAADe community, members of Sibling Organizations and CAADFuture friends to face this exciting theme.
Why such a strong theme? Mainly for three reasons.
The first one, is that we live in a city that has been witness of several revolutions of the conceptions of architectural space: most turning points of space perception are present here by means of architectural masterpieces as Bruno Zevi stated. I like to quote Rem Koolhaas: "It is a platitude that the presence of history in Rome is detriment to the development and display of modern art. But if that were true, Rome – *a city of successive modernities* – would never happened.".
Secondly, as my DaaD research group states "Rome is an open-air museum of architectural avant-garde masterpieces of an *uninterrupted history* where styles are juxtaposed, intertwined and *stratified* other than culturally also physically…" This concept is very close to the modern concept of cognitive sciences: to think by means of several abstraction levels of intelligence.
And the third reason is that we live in a Faculty founded in 1817 – right two centuries ago - has always had a multidisciplinary approach to understand and solve problems: from the outset Architecture, Civil engineering, Bridge construction, Topography, Geometry and Mathematics subjects were present. As a matter of facts this approach it is not limited to technical aspects as – most importantly – the Faculty, now Civil and Industrial Engineering, lives in *Sapienza* University of Rome – established in 1303 – a university that pursuits the "universal" approach where each discipline enhances the others.

Going back to the theme, it involves in turn several subjects: Internet of Things, pervasive nets, Knowledge 'on tap', Big Data, Wearable devices and the 'Third wave' of AI, ... All of these disruptive technologies are upsetting our globalised world as far as it can be predicted henceforth.
So, academicians, professionals, researchers, students and innovation factories… are warmly invited to further shake up and boost our innovative and beloved CAAD world – we already are in the post-digital era – with new ideas, paradigms and points of view.
I said "*CAAD world*" as I think that it contains and involves several disciplines but it is a new subject it its own that overcomes the former ones.

The underlain idea of this International Conference is that as a catalyst of creative energy it pursuits with determination founders' purposes and to be a shocking vanguard, a melting pot of novelties, in words: to become an “incubator” of innovative and seminal ideas, to generate enthusiasm, to be an occasion for new friendships and to facilitate the establishment of effective researches' networks. The title of the conference reflects well these intentions:

Sh o CK! – Sharing of Computable Knowledge!

So the aim of the Conference was to knock our habitual design activities out, to compare the various methodological and technological trends and to disseminate the latest research advances in our community. Will our fine buildings and design traditions survive? Or, will they ‘simply' be hybridized and enhanced by methods, techniques and CAAD tools? Obviously, computation is needed to match the ever-growing performance requirements, but this is not enough to answer all these questions we have to deal with the essence of problems: *improve design solutions for a better life*!
Obviously, ***computation*** is needed to match the ever-growing performance requirements, but this is not enough... As life is not a matter of single individuals, we need to increase collaboration and to improve ***knowledge*** and ***sharing***. This means going back to focusing on human beings, and involves the humanistic approach, and the long history of architecture... from handicrafts to thinking to technology... to handicrafts again.
A large spiral of the *architectura* as *eternal* as our city.

A.

Antonio Fioravanti
eCAADe 2017 Conference Chair

* This second volume of the conference proceedings of the 35th eCAADe conference contains 81 papers grouped under 14 sub-themes; both volumes contain altogether 155 accepted papers. The Conference was held at the Faculty of Civil and Industrial Engineering, *Sapienza* University of Rome, Rome, Italy, in via Eudossiana 18, Rome, on 20th – 22nd September 2017.
In addition to the accepted papers, the first volume contains *Keynote* speakers' contributions concerning the themes of their keynote lectures and the *Workshop Contributions* including the contents of workshops given; the second volume furthermore includes the *Poster Session* contents.

All the papers of these proceedings will be accessible via CuminCAD - Cumulative Index of Computer Aided Architectural Design, http://cumincad.scix.net

Acknowledgements

Authorities, colleagues, researchers, professors, students, professionals all of you are welcomed to the 35th eCAADe conference, in Rome the *eternal city*.

It has been a long time ago – 31 years – since the previous eCAADe conference was held in this Faculty, hosted by our University - “La Sapienza”.
That time, Gianfranco Carrara, one of the eCAADe founders, chaired the 4^{th} eCAADe conference in 1986. That time on, there was only one eCAADe conference in Italy precisely in Palermo in 1995 chaired by Benedetto Colajanni and Giuseppe Pellitteri. This Faculty – now Faculty of Civil and Industrial Engineering – inspired by Parisian and Austrian models, is quite old as it was funded by Pope Pius VII in 1817, so now it celebrates its Bicentennial!

But it is quite young compared to our mother University “La Sapienza” that was established by the Pope Bonifacius VIII in 1303.

The original idea of bringing the eCAADe conference back to Rome goes rather back in times, I remember it was in 2009 at eCAADe conference in Istanbul. You know things take their time in Italy, so only in 2013 my Faculty approved and on 21^{st} March 2015 eCAADe Council granted us the permission to organize the 35^{th} conference. Over the last years several people have helped us to make this conference happen. We thank the former Dean of Civil and Industrial Engineering Faculty, Prof. Fabrizio Vestroni and especially the present Dean, Prof. Antonio D’Andrea for their supports.

During the process of organizing the eCAADe 2017 we have had the privilege to experience the supportive, collaborative and frank atmosphere of eCAADe Council, whose members, no one excluded, have helped us with all organizational aspects.

Let us be touched in remembering for his humanity the former eCAADe President, Johan Verbeke, who recently passed away. We all are sad in this moment thinking is no more physically with us now, but at the same time we are grateful to have met him and exchanged ideas on equal terms as his habit. In spirit, he is present so we can tell him: Johan, special thanks for your open-minded support, we warmly thank you! We miss you, and we do not forget you!

How cannot we mention Joachim Kieferle a friend, who is also the eCAADe President, for his encouragement and unswerving support during the last years and his ability to cut up dead-

locks into pieces. A special thanks to the great Bob Martens for his ability in organizing complex tasks and simplifying processes – Dutch origin helps – his daily support was precious and helped us relentlessly. And a "suuppper" thanks to a "super" friend as Gabriel Wurzer for his optimism and silent help in difficult issues.

Also, we wish to thank all the other previous conference organizers, Henri Achten, Rudi Stouffs and Emine Mine Thompson, for sharing their experience and knowledge. A special thanks to more recent conference organisers Bob Martens, Gabriel Wurzer, Thomas Grasl, Wolfgang E. Lorenz and Richard Schaffranek together with Aulikki Herneoja, Toni Österlund and Piia Markkanen!

Quality is the vital issue concerning conference proceedings.

To improve it we used different means: *OpenConf* conference management system that easily ensured that none of the reviewers came from the same institution as the authors; through special relationships between Liverpool University and eCAADe thank to Martin Winchester's support we were able to overcome program bugs; a second and handcraft check of interest conflicts among authors and reviewers was made during the reviewing phase; a double-blind peer review process; and an accurate reviewers' selection. The selection was fair, and only extended abstracts with high grades were admitted to full paper phase.

Quality means also typographic quality control in two ways: for printing results and for respecting author's layout; so, thanks to the well-known *ProceeDings* formatting management system eCAADe could fulfil these two needs.

Authors uploaded their extended abstracts (length of 1000 to 1500 words, two optional images, 5 to 10 references) by 1st of February 2017; each abstract was evaluated anonymously.

Altogether, we received 309 extended abstracts from 46 different authors' countries, shortly after 5 were withdrawn. Each extended abstract had three blinded peer reviews so 912 reviews were accomplished in a short time and 165 papers were accepted for full paper submission, 21 of these were withdrawn and eventually 154 papers were published in eCAADe 2017 Proceedings.

Let us express our very grateful appreciations for all the 132 reviewers from all over the world for their constructive and thorough comments for each author. A special thanks to reviewers who spent their time to review more than 8 extended abstracts – Joachim Kieferle and Anand Bhatt - not to mention members of "Joker Reviewers' Team": Stefano Cursi, Salma Elahmar, Paolo Fiamma, Silvia Gargaro, Gianluigi Loffreda, Wolfgang E. Lorenz, Davide Simeone, Gabriel Wurzer and me that were able to review abstracts during the last days to accomplish missing reviews on time.

We thank and congratulate all authors for their hard work and support on using the ProceeDings tool and finalizing their full papers carefully in time. In this last phase of editing full papers we want to thank for his "extra-ordinary" work Gabriel Wurzer, the Master of the ProceeDings and Wolfgang E. Lorenz and Ugo Maria Coraglia, who with high sense of responsibility worked with us and to successfully produce high quality proceedings.
We also continued the practice started in eCAADe 2015 conference in Vienna of having all the session chairs to give prospective comments of the papers and to evoke the discourse at early stage between the author and session chair for the 27 sessions of the conference. All the session chairs also participated the peer review process of the extended abstracts.

We owe great gratitude to the session chairs for their commitment and their long-term contribution to the process until the final paper presentations.
We thank the keynote speakers and their contribution of writing the keynote papers concerning their lecture themes: Gianluca Peluffo, Chair in *Exhibition Design* and *Art & Architecture*, IULM - International University of Language and Media; John Gero, Research Prof. in *Computer Science and Architecture*, University of North Carolina at Charlotte and Krasnow Institute for Advanced Study George Mason University; and Gernot Riether, Director of *School of Architecture*, NJIT – New Jersey Institute of Technology, Editor of *DCA Journal*.
Workshops are part of eCAADe conferences, so we thank all the organizers for their workshop and for their contribution of short papers (non-peer reviewed) about the contents of their own workshop.

We are also grateful to Wolfgang Dokonal and the eCAADe Council for organizing the traditional PhD workshop for young researchers and supporting the grant winners with a subsidy for traveling to Rome.

We recovered an old tradition of previous eCAADe Conferences bringing poster session to life again, so during the conference we had 4 free lectures on interesting themes.

This year for the first time we launch an international competition linked to the Conference, the "eCAADe2017 Logo Contest" that helped in disseminate the spirit and values of eCAADe in new areas. We thank the International Jury that was made up by Antonino Saggio (President, Chair in *Information Technology applied to Architecture and Urban and Architectural design*), Eleonora Fiorani (Vice president, Chair in *Cultural Anthropology and Sociology of Innovation*),

Henri Achten (former eCAADe President, Chair in *Computer Aided Architectural Design*), Maria Argenti (Chair in *Architectural Composition* and Editor in chief of *Rassegna di Architettura e Urbanistica*), and Antonio Fioravanti (Chair in *Architectural Engineering*). Two Winners and three Honourable mentions were awarded (see on website https://www.daadgroup.org/result/).
We would like to express our gratitude for the administrative help in organizing this conference to eCAADe council and especially Nele De Meyere that has provided us valuable input and lessons learned from past conferences.

We have also had support from DaaD*group* for managing the conference services, ranging from the registration process to the actual on-site registration services. A big thank you goes to PhD students Ugo Maria Coraglia and Francesco Rossini for their extra-work in critical situations.

Thanks to the sponsors we were enabled to organize an international conference as eCAADe is. Financial supports, apart Sapienza University of Rome, was generously provided by A-Sapiens, AT Advanced Technologies, Autodesk; 3TI Progetti and Bentley Systems International Ltd. Technical support was provided by Epson Italia, Gangemi Editore, Geores, it solution, Noumena and ProceeDings.

We wish to also thank Gangemi Editore in person of Giuseppe and Fabio Gangemi for their very fast and accurate printing process and the high quality of both volumes.

As a special form of sponsorship, all members of the Organizing Team and students of Architecture-Building Engineering M. Course that donated their time to help prepare and organize this conference. Thank you all !!!

Rome, 1st September 2017

Antonio Fioravanti

Conference Chair

Angelo L.C. Ciribini, Gabriele Novembri and Armando Trento

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Contents

Tangible Computing

Manufacturing of Intertwined Logics

Andrea Quartara[1], Angelo Figliola[2]
[1] Department of Architecture and Design, dAD, University of Genova [2] Department Planning, Design and Technology, La Sapienza, Rome
[1,2] {andreaquartara|angelo.figliola}@gmail.com

This paper explores the process of digital materialization through robotic fabrication techniques by presenting three wooden projects. The analysis of the case studies is oriented to underline the impact that computation had on architectural construction due to its methodological and instrumental innovations over the last decades. The absorption of computing and digital fabrication logics within the discipline is explored from either an architectural point of view and from the improvements related to automation of the constructive process. On the one hand the case studies are caught because of the desire to expand material complexity and, on the other hand because of the integration with other technological systems. The narrative allows gathering pros and cons in three different investigative macro areas: material culture, methodological oversights, and operative setbacks coming from digital machine and communicational constraints. This analytical investigation helps the definition of a new pathway for future researches, looking forward the assimilation of digital materiality learning in building construction.

Keywords: *computational design, file-to-factory, large-scale robotic woodworking, new production methods*

COMPUTING OF DIFFERENTIATED LOGICS

This paper explores the seamless control between design and materialization of form made available to architects by recent developments in the fields of computational design and digital manufacturing. Beside a brief theoretical background, the paper considers the impact of computation on the architect's design mindset highlighting different case studies to discuss the thesis: they are effective proving grounds considering different approaches at different scale of the "new digital continuum" (Kolarevic, 2003) that has entered in academic research.

Over the past decades, computation has entered in the common designing approach and architects have started to develop ways of thinking divergent from the deep-rooted and demiurgic practice, by borrowing from other disciplines promising logics. Historical and epistemological roots referred to linguistics, sociology, physics, and biology laid the basis to put forward an understanding of computation not as a marginal remedy to architectural design, but as a methodical vehicle. The teleological studies on *gestalt* (form) and *bildung* (formation) epitomise the founding factors of the theory of morphology: this discipline has a major impact on architecture inasmuch it regards the evolution of form. This pivotal but general concept that is mainly borrowed from exact sciences reveals its operational potential in architectural design when paired with cybernetics. On a theoretical standpoint, first designing episodes started to embed the theories of formation, transformation and of growth of form within the project path and resulted instrumental to promote cybernetics concepts in the architectural investigative agenda.

The word cybernetics stems from Greek *kybernetike*, meaning governance: although it is referred to conceptions that appear far apart from architecture - namely control systems, or logic modelling - the intellectual domain of cybernetics advances the research of the "goodness of fit" (Alexander, 1964) by augmenting its transdisciplinary value. Cybernetics, defined "as a field that illuminates the concepts of adaption and control by way of abstraction" (Riiber, 2011), specifies that systems are built on regulation, adjustment and purpose. The advent of computational design, thanks to its generic and flexible nature, constitutes a convenient platform in matching the growing body of available information. It steers the generation of mutual interactions among constituents while the computed agent (the object) is distinguished from the computational process (the method). Rather than implying cybernetics as the oversampled way to control an architectural system by using technology (i.e. hardware or software technology), the most effective value of computational design arises from the opportunity to arrange manifold focuses, which are decoded and conceptualized as iteration, generation and variation of geometric formation. As consequence, the attention of a common digital approach is focused on the shift from a "pre-emptive act" (Sheil, 2012) towards a procedural process that implements performances relying on shapes validating innovative spatial configuration.

The relentless digital enhancement in architectural design has progressively transformed the architect's drafting board into a software ecosystem, and has made the sequential separation between modeling, optimization, analysis and fabrication processes more evident. While strengthening further the separation between design and making already theorized centuries earlier by L. B. Alberti, the "computational fallacy" stated by S. Kwinter (2003) demands the seamless correspondence between original ideas and material fabrication as a resolving answer to a jammed computational scenario. Architects have already realized that computing is not only a convenient gizmo for formal and aesthetic investigations, but it inaugurates an operative dialogue with the digital manufacturing lattice on which the project can be based. Therefore emerging frameworks and techniques in the fields of design and construction are contributing to a disciplinary revolution due to the progressive convergence of computation and materialization.

Thus the recent achievements demonstrate the impact of IT on both the ideation and the digital manufacturing of unconventional prototypical architectures. A profound upheaval has been put in place by avant-garde academic and professional practices since the introduction of tailored CNC and robotic fabrication systems, mainly borrowed from automotive. In particular, the narrative traces different ways through which digital fabrication technologies are simultaneously developing and expanding the role of computation as interface between the digitally computed design and the physical world.

COMPUTATIONAL AND MATERIAL COALESCENCE

The digital turn has definitely triggered a considerable symbolic and systemic revaluation in architectural design; by the same token the digital manufacturing of material space has been introduced as one of the computational parameters. Once the mindset about forms that "are no longer designed but calculated" (Cache and Speaks, 1995) has been en-

Figure 1
Overall view of the Landesgartenschau Exhibition Hall. © Miro Bannwart

compassed, the focus of the research shifts from the computable abstraction to the tangible computing of its manufacturing process. The same transdisciplinary key concepts - such as automation, adaptation, emergence, convergence, communication, efficiency, efficacy, and connectivity -, that have been the foundational thoughts for the transfer of cybernetics' logics within the architectural designing flow, are now becoming paradigms addressed towards fabrication. Thus, the project conceptualized as a computational system transfers its rule-based design in criteria involving both digital machineries and materials. The spread of digital fabrication facilities in architecture activates the "new digital continuum" (Kolarevic, 2003) inasmuch capabilities like standardization or automation don't represent simply practical solutions, but they become design parameters in assuring architectural qualities.

Three wooden structures are showed as representative of full-scale implications; they outline part of the evolving array of interoperable tools and processes that allow the design-to-production chain of non-standard outcomes. As matter of fact architects have developed pioneering and innovative material fabrication setups, which purposefully allow the transfer in actual-size constructions of essentials from manifold branches of knowledge as well as from different craft expertise. Material, manufacturing constraints and assembly logics become designing parameters proving that file-to-factory is not a process as linear and reductive as some detractor may claim (Sheil & Glynn, 2011). As M. Burry suggests, the digital fabrication advent has taken the credit of blurring the model and prototype boundaries (Sheil, 2012), focusing on a discipline that intertwines design and production.

CASE STUDIES

Amidst the broad array of digital fabrication applications, the dissertation chooses wooden structure as case studies in order to investigate theoretical statements. Architects are honing robotic and CNC fabrication techniques for manufacturing purposes reconsidering wood and its derivatives as suitable building materials for the experimental design researches at an actual scale and no longer as an out-of-date material. Recent years have seen unprecedented innovation of new technologies for "advancing wood architecture" (Menges et al., 2016).

The selected case studies - the Landesgartenschau Exhibition Hall (University of Stuttgart, 2014), the Woodchip Barn (Architectural Association, Design&Make, 2015), and the Digital Urban Orchard (Institute for Advanced Architecture of Catalonia, OTF, 2016) - bring forward different achievements and perspectives on digital fabrication in architecture to illustrate the interplay between the virtual design and the virtue of material.

Figure 2
Left: robot milling from the public information panels. Right: internal view of the plate outlines that visually reflect the changing of Gaussian curvature. © Miro Bannwart

As a prime example, the Landesgartenschau Exhibition Hall (LaGa from here on) largely demonstrates the efficiency of the "machinic morphospace" (Menges, 2012) first applied at a building size. The applied morphogenetic process explores the multifarious advantages arising from the reciprocal influence between the rationalization of biological rules, the material fabrication requirements and from the multiple performative applications. The entire constructive principle of this exhibition hall is based on the large-scale application of the robotically fabricated finger joint system, developed in the previous biomimetic research of the Research Pavilion 2011 by ICD and ITKE.

The LaGa's final morphology results in a permanent, fully enclosed, insulated and waterproof building (Figure 1), which uses beech plywood plates as the primary load bearing elements. The resulting three layers' sandwich dome-shaped shell considers solutions to the programmatic requests (two functional zones were required: a reception and an exhibition area) while applying a form-finding strategy oriented to generate a lightweight structure. In fact the implemented Agent-Based Modelling (ABM) algorithm allows the discretization of the doubly curved surface through planar subdivision accordingly to the Tangent Plane Intersection (TPI) strategy. Each individual and unique polygonal plate interacts with its neighbours ensuring the structural stability through the distribution of in-plane shear forces along the plate edges. The computed plate outlines visually reflect the changing of Gaussian curvature between the two computed synclastic main areas. Besides the programmatic, geometric and structural focusing, the plate-structure and the relative three-dimensional finger joints have been generated following also other parameters. For example the robotic workspace, the angle variety achievable by the robot-arm equipped with the spindle and paired with the turntable, and even assembly-related functionalities or material conditions, such as the stock material size (Figure 2).

This comprehensive computational approach, in making every detail adaptable to local and global geometric parameters, represent a valuable proof of concept of the integration of innovative constructive process and technological system - e.g. load-bearing structure and insulated sealed shell - within a computational protocol. However the resource-efficient lightweight structure and its corresponding fabrication procedures reveal minor cons. They directly arise from the high level of specialization in the study, limiting the conception stage of the design process and consequently the spatial configuration of the final shape.

The large-spanning and unprecedented Vierendeel-style truss built by the Design&Make team (Figure 3), while been focused on the evolutionary metaheuristic optimization placement technique, considers the substantial material parameter

Figure 3
Overall view of the Wood Chip Barn with perimeter walls and roof on top of the truss. © Andrea Quartara

in robotic fabrication as strength of the applied research. The Woodchip Barn project is entirely built with non-engineered wood and thoroughly relies on a data-driven process coming from the survey of the tree forks' digital catalogue.

An ambition of the project is achieving a structural diversity not only thanks to the differentiated robotic processing, but also directly from the natural conformation of the 25 selected forks (Figure 4). Each one of them is wholly unique by nature and the shape is optimized by itself: the capacity of carrying "significant cantilevers with minimal material" (Self and Vercruysse, 2017) is exploited by a customized robotic fabrication setup that augments its inherent structural and geometric qualities. A 6-axis robot arm equipped with a routing spindle has machined each tenon-mortise connections; they were defined between each root and branch of the forks as volumetric subtraction of geometric primitives - e.g. cuboid, cylinder, truncated cone - correctly aligned. The tolerances management was a key point in the whole computational process, highlighting the consistent system of geometric references developed to ultimately achieve the maximum construction precision with irregular natural round-wood. The connection strategy designated the use of "steel bolts and split rings to provide tension and shear capacity" (Mollica and Self, 2016) to the compression transfer through timber-to-timber joints.

Besides the uniqueness and the noteworthy of the truss, the final result totally relies on the algorithmic process of metaheuristic repositioning of the forks selected from the photographic campaign done in the forest of Hooke Park. Whenever this process would be applied in another place, the structure will be limited to the configuration and size of natural material available on that specific site.

Figure 4
A tree fork before been machined. © Andrea Quartara

The Digital Urban Orchard research project (DUO) involves the construction of a functional prototype to be implemented in urban public spaces within the self-sufficiency programme of the city of Barcelona. The OTF pavilion stems from the relation among form, function and application context for a new concept of socialization space and food production (Figure 5). As subsidiary section of the study, the built prototype hosts a hydroponic farming system and a opening silicone skin able to ensure the indoor comfort conditions for plants by natural ventilation. The simultaneous concerns on designing a stable yet iterative structure and on the solar gain have required

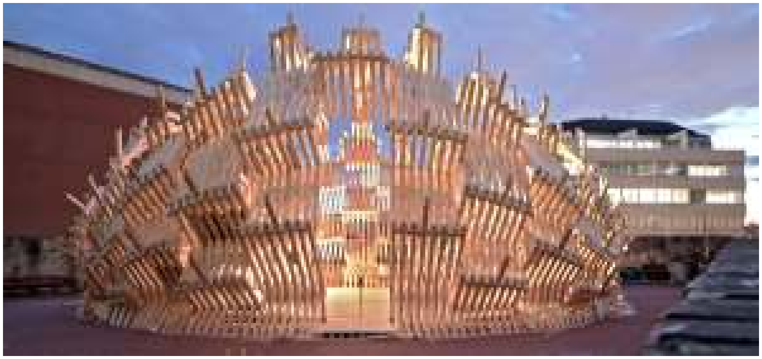

Figure 5
DUO: overall of the wooden structure, without the silicone skin. © Andrea Quartara

multiple design expedients in complying each one of the functional, structural and environmental performance criteria. In order to inform the genetic optimization of the shape (i.e. genotype), a data-driven strategy was set: the multiple phenotypes, among which the designer has found the final form, were generated through the progressive modification of environmental, geometric and manufacturing parameters.

The adopted hyper static structural system is generated from a pantograph-like pattern: the repetition of diagonals elements at differentiated angles ensures the structural rigidity. Despite the fact that at first sight the structure is an undifferentiated set of stick nailed to each other, each Redwood stick of Flanders, according to its position performs diversified tasks. Through the adaptable pattern of angled end-cuts, the stick-assembly alternately offers flat supporting areas for the hydroponic pipes, or it constitutes space-functional furniture or either some extended sticks are designed as holder of the silicone skin. The density of the structural pattern also responds to optimization logics for solar gain and considers almost total transparency at the top of the pavilion. The final shape has been discretized according to robotic fabrication constraints and manual assembly logics in 6 types of sections, for 12 components in total.

Three manufacturing strategies have been defined depending on the size of the sections. They involve the robotic processing of the entire section or of two halves or of three parts of the final arc section with 30 assembled parts in total. 2,524 shank nails were used in order to maximize the joints resistance. The collaborative fabrication process between robotic manufacturing and manual finishing was implemented starting from the achievements of the previous Fusta Robòtica Pavilion (exposed at the Setmana de la Fusta, Barcelona, 2015). Implementations concerned all stages in order to reduce material consumption and expand the range of achievable geometry within a non-industrial working setup. Furthermore the customization concerns also the hacking of standard woodworking tools placed on the rotary table, such as the miter saw which allows 3-dimensional angled cuts, or the pneumatic gripper fixed on the robot flange used as end effector, and also the sticks supplier which provides wooden profiles in three different lengths in order to reduce waste material (Figure 6). Realized with 1682 sticks, the pavilion is the result of a fast process of a design-to-production chain; 52 hours of production in the robotic room and 36 hours of unskilled manual assembly have ensured the custom digital design workflow completed in a rapid and automated production process, with only 2% of scraps from the material supply. While the OTF project involves different implications then the ones of the previous renowned design experiences, such as the environmental optimization of shape and the mass-customization advantages, its

Figure 6
Left: robotic fabrication process. Right: DUO's inner view. © Andrea Quartara

working setup opens up the debate around the fabrication's tolerance: the integration between technical/technological systems and low-engineered setup produces variances between the virtual design and the material actual size pavilion, due to high tolerance.

In different ways the three structures demonstrate the computational path, previously theoretically introduced, actuating the digital chain and materializing it through a collaborative robotic-human production process, customized from time to time. Within this design cycle forcefully emerges the need of taking in account of the material features, not as a final add-on of the architectural process, rather as part of the required informative loop. For the final implementation of complex design programs, the development of digital fabrication facilities constitutes the essential requirement allowing the production of individually differentiated geometries. In improving one single full-scale design-to-production workflow, critical points and advantages of the bi-directional digital and physical design process arise.

DELINEATING HORIZONS

The analytical interpretation of these case studies introduces different macro areas of intertwining limitations and potentialities arising directly from an experienced computational mindset and also facets linked to fabrication facilities, or to material properties involved in the digital fabrication. Indeed the material culture brings a projective capacity within the computational workflow, breaking the conceptual separation between the processes of design and the physical making of a built architecture. In stark contrast to precursors linear and mechanistic modes of digital making, the digital manufacturing implemented in the case studies assists the computational work progress, giving rise to an explorative "cyber-physical" (Menges, 2015) process. The material- and fabrication-aware design are reawaken not in the sense of the tenet "truth to materials" of modernist attempts, but rather as truly new design paradigms for vernacular materials by intertwining material computation, digital fabrication facilities, cybernetics and optimization. As counterpart the prediction of material behaviour, especially for natural materials and low-engineered components, is an entire field of research to be investigated in order to overturn material hurdles in material facilitations.

When architectural implementations are decidedly oriented to digital machineries they express a contrived mechanical commitment, which leads to "a lack of architectural taste", as G. Scott states in his work *The Architecture of Humanism: A Study in the History of Taste* (1914). This definition, borrowed from a context far apart from the digital fabrication's background, properly describes the risks that may occur when designers emphasize a proactive approach while embracing industrial technologies.

However, the actual change comes from adoption and adaptation of advanced production tools, complying choices for architectural space. In regards to architects, one of the most valuable features established is the management of the whole process from design-to-production, relying on a data-driven process that embed different kind of parameters and customised fabrication tools since the early design stages. Although the "new digital continuum" (Kolarevic, 2003) could be carried out within a single virtual environment, the high level of interoperability required between different programming languages can produce communicational constraints between different machine's protocols. Given the fact that the high specificity of the case studies activates remarkable accomplishments, it means also that bespoke tools and fabrication equipment are not aimed to work for any other project and remain exclusive to only a particular design. In this sense, wider applications "related to the precise working of CNC-controlled machines [...] led to irreparable production errors" (Kloft, 2009). However some of these limitations become marginal in a trial-and-error approach; conversely their spread use in the building industry would amplify their relevance.

Another category of limitations and potentialities woven together can be described as a combination of methodological oversights and benefits. In fact, besides technical difficulties, which are inevitable during applied researches, this last group of failures is centered less on the characteristics of the machinery and more on the nature of the design process. Multifarious research projects demonstrate the sought changes in the fields of software, hardware, and mindset above all. However it is useful reinstate the difference between computerizing a design process and computing material spaces. Sometimes they can be defined as mistaken perspectives arising from emphasized fascination for computational and Computer Numerically Controlled capabilities exceeding architectural design interests. One of the most insidious attitudinal fallacies occurs when authors attribute more value to the enticing and streamlined virtual flow, rather than to the underlying opportunities of novel tangible formations to be transferred to the building industry by means of "digital materiality" (Gramazio et al., 2008).

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Y

Z

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