(FAB)BOTS CUSTOMISED ROBOTIC DEVICES FOR DESIGN & FABRICATION

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AA, IAAC

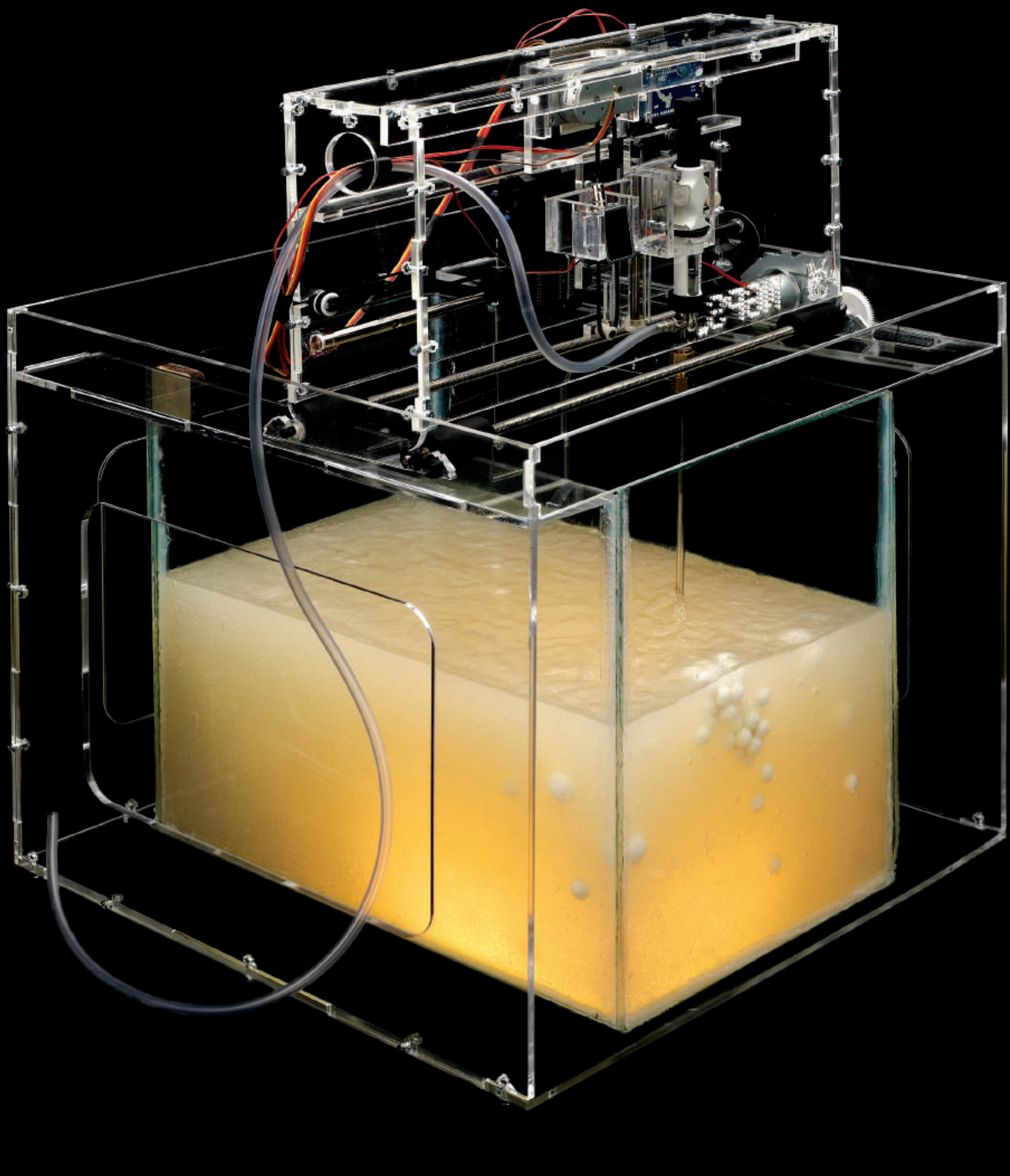
Digital design and fabrication technologies have given architects the means to invent new architectural languages and communicate them directly to production facilities, allowing for the construction of projects with unforeseen complexity. Yet the impact of digital fabrication goes far beyond the mere production of complex geometries.

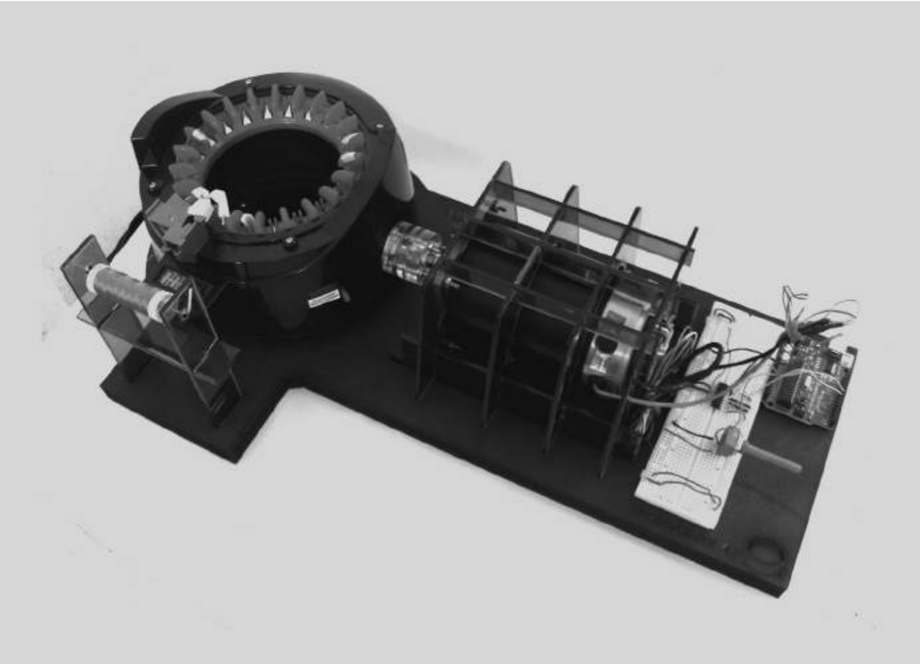
A growing number of architectural practices and academic research groups are exploring the new-found freedoms in the close connection between digital design and production, inventing new design processes, material applications and building scenarios based on opportunities found within the use of digital fabrication technologies.[1]

The work presented in this article fits within this context, but it also explores which opportunities lie beyond the use of existing CAD/CAM technologies borrowed from other industries. Focusing on technologies and workflows that are specifically designed for architectural production, it considers the design and operation of custom fabrication devices as an integral part of the design process. Exploring new scenarios for the creation and inhabitation of architectural structures, it experiments with flexible, mobile and low-cost fabrication machines. This allows the work to speculate about projects that are site-specific, customised and adapted to local climatic conditions, in areas and communities that traditionally have limited access to new technologies and infrastructure.

This article presents a collection of ten projects that investigate the workflow between computational design and material production methods, through the invention and development of customised, numerically controlled fabrication devices, software protocols and material solutions.

The ten projects are conceived by master students in the DRL graduate programme at the Architectural Association (AA) and the MAA programme of the Institute for Advanced Architecture of Catalonia (IAAC). They were developed in two design studios tutored by Marta Malé-Alemany, in collaboration with Jeroen van Ameijde (London) and Victor Viña (Barcelona).[2]





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1: Non Gravity Printing Systems: machine prototype.

2–4: Dreamweaver: hacked household knitting machine, knitted tube typology studies, structural prototype.

METHODOLOGIES FOR EXPERIMENTATION

Using introductory tutorials focusing on scripting and machine building, the design studios encourage students to formulate a critical position towards the characteristics of existing digital fabrication technologies. The studios develop early prototypes of custom-designed fabrication systems, using techniques such as the 'hacking' of standard CNC machines, consumer devices or electronic toys. These 'quick and dirty' tests help to explore the behavioural properties of the proposed hardware solutions, opening up new lines of research and discussion, and provide the basis for successive generations of system designs. Emphasis is placed on the different nature of the abstract machinic models of the proposals to their implementations as prototypes, discussing the economy of means in applications at a larger scale.

Developing devices in combination with specific methods of material formation, the studios explore integrated design and production methods that are specific to a particular application scenario. Suitable for deployment on-site, these methods are potentially more viable to be used in architectural projects than standard digital fabrication technologies, which are designed for the mass production of a generic range of products in an industrial setting. The students' prototypes of fabrication devices deliver proof of concept for the possible implementation with a small investment of time and resources. The limitations of the relatively simple machines are regarded as an opportunity to develop new architectural languages, emphasising the scenario as an optimisation between the characteristics of specific materials, tools and design.

As the studios emphasise the testing of deployment scenarios through material and mechanical testing and digital simulations, students are asked to reflect on the implications of their tools for the nature of the architectural design process itself. Several new processes of conception and production are emerging within the work, ranging from methods of direct control – in which digital fabrication comes after a customised design process – to methods of indirect control, where the final product emerges out of the interaction between fabrication devices, material behaviour and environment.

PROTOTYPING ARCHITECTURAL MACHINES

Design and build processes using direct control take advantage of the possibility of traditional numerically controlled devices to activate a number of motors with high precision using relatively simple code. A number of student projects have started with the adaptation of the components of a CAD/CAM system and its computational workflow, which translates parametric coordinates to digital signals, which in turn drive electromechanical actuators. Instead of using the motors to drive linear axes in a way that is standard in two- or three-axis CNC machines, they can be used to drive rotational devices, allowing to design custom machines with a more simple mechanical layout or to connect the motors directly into other mechanical devices.

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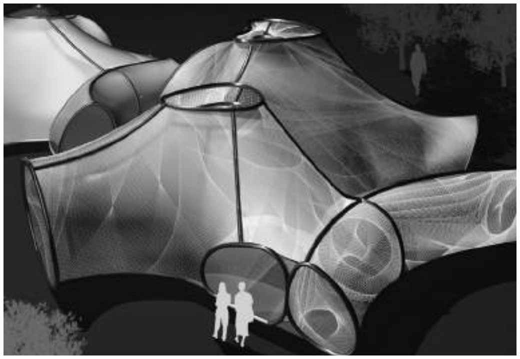
Dreamweaver departs from hacking existing circular knitting machines with numerically controlled plug-in devices. The project's aim is to create alternative patterns, which serve to produce multiple variations of the common tubular knitted profiles. Using the variations in knitting patterns to produce structural elements for architectural applications, the machine is regarded as a part of a high-speed, on-site construction system.

Learning from typologies of branching propagation and hierarchical clustering, the project is developed as a computational and material model that operates at multiple scales. Using the precision made possible by the machinic system, the system is able to create varied structural typologies on a macro level by programming material patterns at the knitted micro-scale.

Fibr(h)ous(e) also uses CNC technology at its basis. Envisioning a foldable machine that can easily be transported on-site, a tabletop proof of concept machine built by the students is used to demonstrate the principles of filament-winding and explore the potential of using parametrically generated patterns of thread by driving the machine in various sequences of movements over time. Conceived as a combination of scaffold and skin, the project speculates on a fast deployment system for lightweight, self-sufficient living units that could be built in one day. Driving differential fibre patterns through structural, programmatic and climatic parameters in accordance with the required performance criteria for each living unit, Fibr(h)ous(e) proposes an efficient building technology based on the use of minimal material and an intelligent distribution logic.

PROTOTYPING WITH MATERIAL BEHAVIOUR

Taking advantage of the capacity of numerically controlled devices for the precise implementation of large datasets of machine instructions, a number of projects are also relying on complex material behaviour in the realisation of their final structures. Using both conventional and unconventional materials in innovative applications, these projects question the necessity to control all aspects of the material formation with the same precision, accepting the inherent limitations of a material or using its potential to self-compute for the benefit of the final structures.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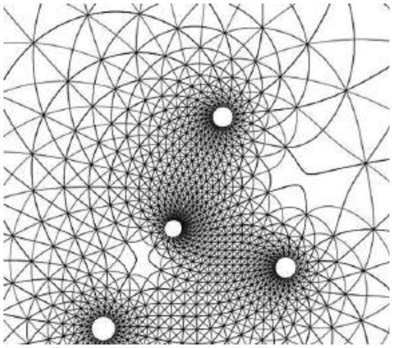
Sandbot explores low-cost casting processes using sand as recyclable formwork to produce building components. It is conceived as a portable device with multiple tools to carve and press sand that is available on-site into complex moulds, in which different materials can be cast such as plaster and cement. Within the constraints of the material and the tools the system is capable of infinite variation, as the mould is essentially scale free and completely reusable.

Non Gravity Printing Systems (NGPS), uses a multi-material deposition machine that releases small drops of paste-like materials into a chemical solution that causes the deposited liquid to form into perfect spherical droplets. The concept of the project grew out of the 'Molecular Gastronomy' experiments by Ferran Adrià, the famous head chef of El Bulli restaurant. NGPS operates in an environment that is nearly gravity-free because drops of material remain suspended until solidification is completed. This process of fabrication, based upon aggregation of small material deposits, allows for the combination of different materials according to performance criteria, resulting in highly complex structures with intricate material combinations.

PneuMorphosys explores the possibilities of incorporating air into the construction process as a structural optimisation, material distribution and morphing agent. The project uses a flexible formwork and a system of digitally controlled valves to regulate the flow of air into a series of discrete pockets, located inside and outside the structure to define both internal chambers and the external shape of the cast. A series of sensors serve to control the material pressure, allowing the optimisation of material distribution within complex formations.

Digital Vernacular is based on the use of a numerically controlled device to deposit paste-like materials such as clay. Following the geometrical rules dictated by material behaviour, a layered process of deployment is integrated into the design and construction strategy for housing units on-site. Adapting each design to the specific characteristics of its site, the project uses variable



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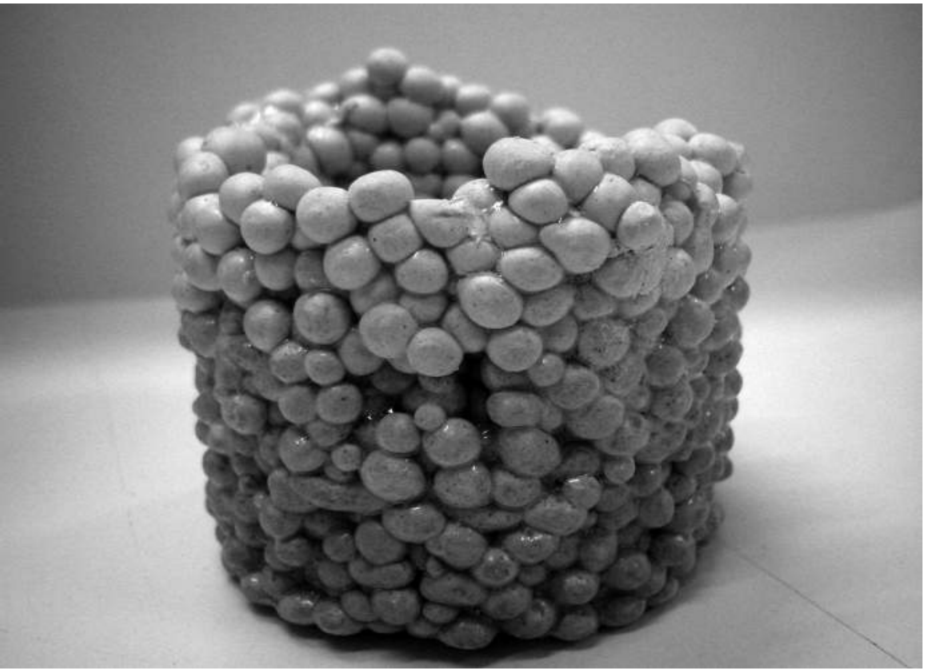

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5–6: Fib(h)rous(e): prototype detail showing scaffold and skin, housing scenario rendering.

7–8: Non Gravity Printing Systems: printed materials tests, multi-material printing logics.

patterns to incorporate openings for ventilation, circulation and views. In an on-site machine deployment scenario, the self-same rules that govern the construction sequence of co-dependent spaces is also be applied at the scale of a community, delivering vernacular housing environments at an equilibrium between materiality, fabrication and design.

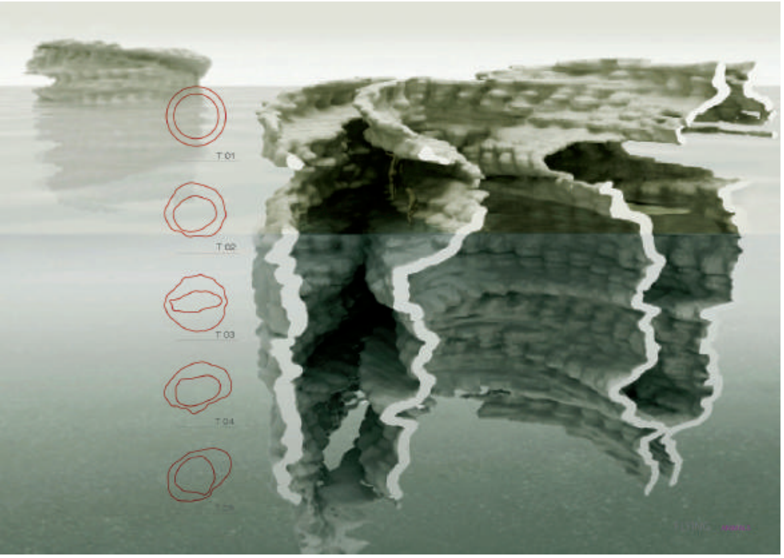
PROTOTYPING EMERGENCE

A number of projects investigate the emergent nature of decentralised computational models and their ability to perform according to intelligent behaviours, often mimicking processes of self-organisation as observed within nature. Providing an alternative approach to the design of custom hardware solutions, by using external sensorial inputs to adjust their fabrication process in real time, these proposals are based on adaptive, dynamic processes reacting to environmental conditions in order to construct highly performative and site-specific formations.

Fab(a)thing is developed as an instantaneous on-site design and fabrication process, using an infrared input device, a 3D positioning system and a deposition nozzle for PU foam, a material that solidifies almost instantly. Using an infrared distance sensor attached to the dispenser head to dynamically autocorrect its path, the system can respond to design changes or material deformation during construction. Conceived as an interactive CAD/CAM process that allows the end-user to sketch on-site in an augmented reality interface, the project opens up new paths to explore the application of emergence, decentralisation and adaptivity in alternative construction processes.

9–11: Fluid Cast: digitally simulated formation of a floating structure, prototype machine for plotting wax in water, numerically controlled printed wax prototypes.

12: HelioBot: mechanical prototype.



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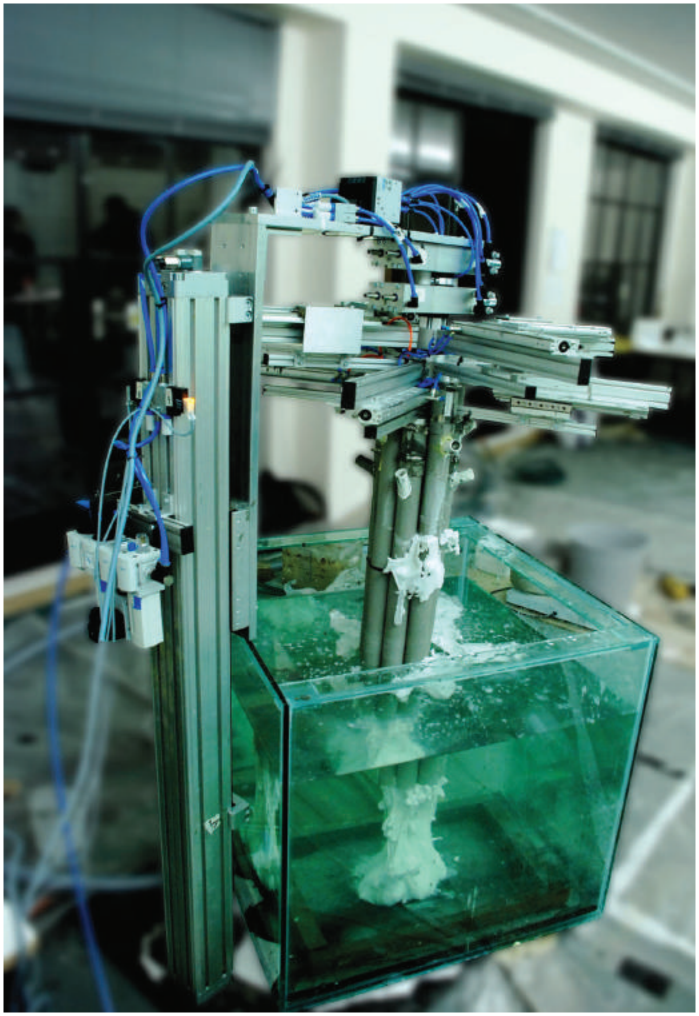

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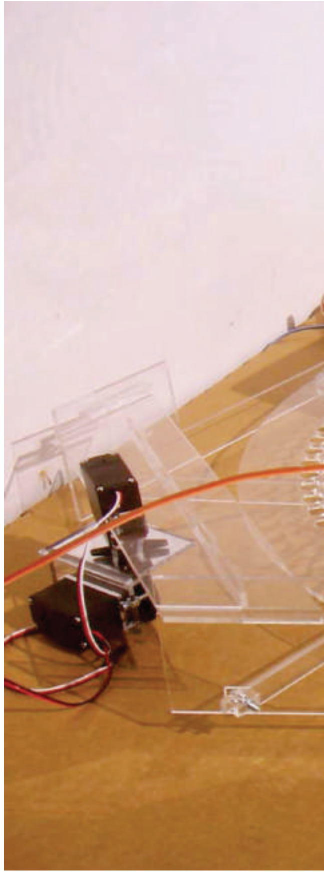

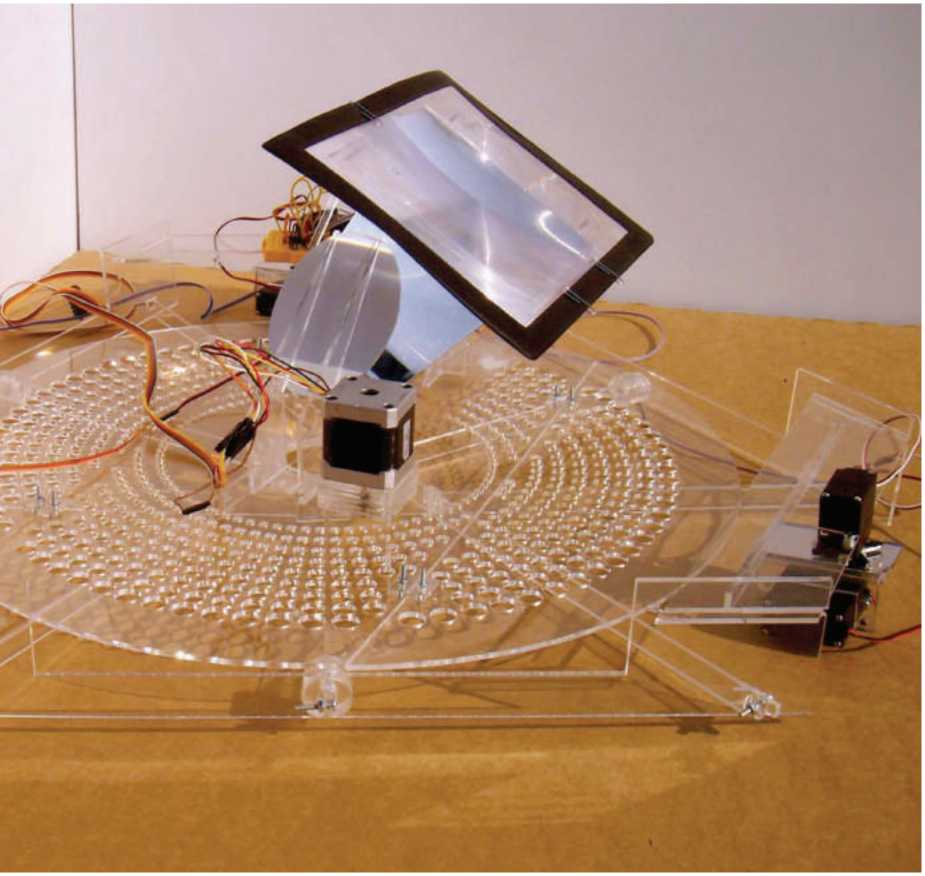

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Heliobot is a full-scale prototype of a solar-powered machine for on-site fabrication, capable of operating autonomously. It utilises no additional energy other than that gained from the sun and operates by concentrating solar energy for burning, heating and cutting in the preparation of materials for future assembly. The device operates as a mobile robotic system using light sensors, DC motors and simple analogue electronic circuits based on differential behaviours (as in Mark Tilden's BEAM robotics[3]). A sun-tracking system, comprised of four independent sensing and actuating modules, is able to align a Fresnel lens in order to achieve maximum solar concentration.

Mimicry is a project that explores the nature of flocking behaviour and swarm intelligence, using both software and hardware prototyping tools to explore computational models (as in Braitenberg's Vehicles[4] or Craig Reynolds' B.O.I.D.S.[5]). It simulates the collective result of a number of actuating agents over different lapses of time, generating material formations dependent on light conditions within a specific environment. The project speculates on new fabrication processes that simultaneously design, optimise and fabricate, producing emergent material patterns from simple governing rules as the machines operate over time.

Fluid Cast investigates complex material behaviour of phase-change materials as well as construction technologies using multiple material deposition agents, speculating on highly innovative fabrication scenarios for water-based structures. An extensive series of material tests is used to inform agent-based digital simulations that demonstrate how complex structures can be formed as a result of interactions between multiple machines and a dynamic 3D environment such as the sea. The emergent properties of these structures are generated through the method of controlling the devices, programming specific behavioural rules that are aimed towards performance criteria of the resulting structures within the environment in which they operate. The project tests the implications of behaviour of the deposition nozzles moving in-between short and longer distances from each other, creating instant networked structures that can be applied in various water-based and inhabitable applications, at a range of different scales.

DIRECTIONS FOR FUTURE RESEARCH

Through the development of innovative material processes, devices and computational methods, the students' projects speculate on application scenarios that distance themselves from current processes that are based on linear file-to-factory methods and industrialised modes of production.

The work employs high-tech software and hardware applications to enable deployment in relatively low-tech environments and communities, considering energy use and the economy of materials in using local resources in designs that are adapted to local contexts and climate.

Continuing to pursue a sense of realism through the demonstration of working machinic prototypes, rigorous material testing and digital simulations, the studios are currently developing new projects that cover a range of interests. Aiming for the construction of larger prototypes that test real architectural performance, the studios continue to set up design processes that are aimed at producing structures with a built-in intelligence, helping to address some of the new and pressing challenges of our time.

AUTHORS/ ACKNOWLEDGEMENTS/ PROJECT CREDITS

RESEARCH PAVILION ICD/ITKE

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Responsible for the scientific development were Moritz Fleischmann (project management), Simon Schleicher (project management), Christopher Robeller (detailing/construction management), Julian Lienhard (structural design), Diana D'Souza (structural design) and Karola Dierichs (documentation).

PROJECT CREDITS
Institution: University of Stuttgart. Department: Faculty of Architecture. Institutes: Institute for Computational Design (ICD), Prof. Achim Menges, and Institute of Building Structures and Structural Design (ITKE), Prof. Jan Knippers. Project Team (Concept and Realisation): Andreas Eisenhardt, Manuel Vollrath, Kristine Wächter and Thomas Irowetz, Oliver David Krieg, Ádmir Mahmutovic, Peter Meschendörfer, Leopold Möhler, Michael Pelzer and Konrad Zerbe. Scientific Development: Moritz Fleischmann (project management), Simon Schleicher (project management), Christopher Robeller (detailing / construction management), Julian Lienhard (structural design), Diana D'Souza (structural design), Karola Dierichs (documentation).

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THAW IMAGINING A SOFT TECTONICS

AUTHORS
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Thaw was exhibited as part of the digital material exhibition at R.O.M Gallery for Art and Architecture, Oslo, in May 2010. The exhibition was kindly supported by the Nordic Culture Foundation and Henrik de Miniassen, director of R.O.M. Thaw was further developed as a larger-scale installation for the Lisbon Architecture Triennale as a 10-metre-high installation Thicket.

Thaw was further supported through the collaboration with Behnam Pourdeyhimi, NC State University College of Textiles.

(FAB)BOTS CUSTOMISED ROBOTIC DEVICES FOR DESIGN & FABRICATION

Design Studio: 'Machinic Control 1.0': Tutors: Marta Malé-Alemany, Jeroen van Ameijde. Architectural Association School of Architecture, Design Research Lab (DRL) Graduate Programme (2009–10). Projects: DIGITAL VERNACULAR: Shankara S. Kothapuram, Mei-ling Lin, Ling Han, Jiawei Song. FIBR(H)OUS(E): Amrita Deshpande, Saahil Parikh, Akhil Laddha. FLUID CAST: Ena Lloret, Maria Eugenia. Villafañe, Jaime De Miguel, Catalina Pollak. Design Studio: 'Digital Tectonics RS3', Tutors Marta Malé-Alemany, Victor Viña, César Cruz Cazares (assistant), Lluís Fraguada (collaborator). Institute of Advanced Architecture of Catalonia (IAAC), Master in Advanced Architecture (2009–10). Projects: SANDBOT: Joel Letkemann, Viraj Kataria, Fabio Lopez. HELIOBOT: Felipe Pecegueiro, Jorge Orozco, Kfir Gluzberg. FAB [A]THING: Jun Huang, Jessica Lai, Asim Hameed. DREAMWEAVER: Melat Assefa, Brian Peters, Joao Albuquerque. NGPS: Ali Basbous, Miquel Lloveras. PNEUMORPHOSYS: Natalija Boljsakov, Brian Miller, Carlos Naranjo. MIMICRY: Mia Gorretti Layco, Georgia Kotsari, Tomasz Starczewski. Exhibition: (FAB)BOTS, Customized robotic devices for design and fabrication, 16 June to 12 September 2010, Disseny Hub Barcelona (DHUB). Curator: Marta Malé-Alemany. Coordination: Catalina Pollak.

LOGIC MATTER

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CNCATENARY TOWARDS A DIGITAL FABRICATION METHOD FOR CATENARY SYSTEMS

This research was realised as part of the Master of Science in Adaptive Architecture and Computation at the University of London Bartlett School of Graduate Studies. It was carried out at the facilities and workshops of The Bartlett School of Architecture and under the supervision of my tutors, Ruairi Glynn and Marilena Skavara.

SCANLAB

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FREE-FORM METAL INFLATION & THE PERSISTENT MODEL

Anders Holden Deleuran (research assistant, CITA) for his persistent and skilled attempts at modelling the metal inflation process using Autodesk Maya. My colleagues at the Centre for IT and Architecture (CITA) and Institute 4, Kunstakademiets Arkitektskole, for their continued encouragement and support of this work.

Persistent Model #1 was an exhibit in the show entitled *digital.material* which showcased four recent works by CITA. The exhibition ran from 23 April to 23 May 2010 at the ROM Gallery, Oslo.

MATTER & MAKING

PERISCOPE FOAM TOWER

AUTHORS
Brandon Clifford and Wes McGee

PROJECT CREDITS
Design Team: Matter Design – Brandon Clifford, Wesley McGee. In collaboration with Supermanoeuvre – Dave Pigram. Structural: Simpson Gumpertz&Heger – Matthew Johnson. Build Team: Matter Design – Brandon Clifford, Wesley McGee, Johanna Lobdell, Deniz McGee, Kris Walters, Maciej Kaczynski. Rigging: Boutte Tree – TiersonBoutte. Fabrication: University of Michigan Taubman College of Architecture and Urban Planning.

WAVE PAVILION

Designer/Fabricator: macdowell.tomova. Consultants: Wes McGee, Matter Design; Dave Pigram, Supermanoeuvre.

BENT

Kendra Byrne and Nick Rebeck: www.b-e-n-t.com

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MATERIAL ANIMATION A NEW INTERFACE TO CUSTOM FABRICATION

Work developed on robotic folding methods was done in collaboration with Robofold Ltd., Gregory Epps. Field Condition is supported by the University of Kentucky College of Design – School of Architecture, College of Engineering – Dept. of Computer and Electrical Engineering, and the Institute of Sustainable Manufacturing. The team for Field Condition is Anton Bakerjian and Ian McHone.

MINIMAL COMPLEXITY

The Minimal Complexity prototype was developed during the Certificate of Advanced Architectural Research Postgraduate Course at The Bartlett,UCL, between 2009 and 2010, and it has taken part in 'Constructing Realities', the final exhibition of the Course's research work between July and October 2010.

The theoretical paper 'Minimal Surfaces as Self-Organizing Systems' describing the computational framework for generating the final prototype was developed as part of the MSc. Adaptive Architecture and Computation Course at The Bartlett, UCL, 2009, and has been presented at ACADIA Conference, in New York, in October 2010.

The Minimal Complexity structure winner of the TEX-FAB REPEAT Digital Fabrication Competition was built in Houston, Texas, in February 2011.

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INVESTIGATIONS IN DESIGN & FABRICATION AT HYPERBODY

PROTODECK

AUTHORS
Marco Verde Eng, MArch, MarkDavid Hosale, Ph.D.

PROJECT CREDITS
Property Developer: Hyperbody | TU Delft. Direction: Prof. ir. Kas Oosterhuis. protoDECK system development and manufacturing engineering: Marco Verde Eng, MArch. protoNODE system development and manufacturing engineering: Dr MarkDavid Hosale. Digital Fabrication: NEDCAM, HYPERBODY CNC DIVISION.

PROTOSPACE 4 MOCK-UP

AUTHOR
Jelle Feringa, PhD candidate, co-founder EZCT Architecture & Design Research

PROJECT CREDITS
Design of the protoSPACE 4 pavilion was completed in the context of the MSC2 spring 2009 design studio. Hot-wire manufacturing: Jelle Feringa & Haiko Dragstra (Komplot Mechanics). Components connections: Owen Slootweg. Final Assembly: Owen Slootweg & Chris Kievid & Jelle Feringa. Project managment: Chris Kievid.

PROTOTYPE FOR A SPATIALISED INSTRUMENT

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www.mishasmith.com

VILLA NURBS

City: Empuriabrava. Country: Spain. Construction: started 2003. Office: Cloud 9 (Barcelona, Spain; est. 1997) Architect: Enric Ruiz Geli. Collaborators: Felix Fassbinder (Project Architect), Jordi Fernández Río (Project Architect). Arquitectos Técnicos: Daniel Benito Pò (Architect), Xavier Badia (Architect), Agustí Mallol (Architect), Víctor Llanos (Collaborator [office]), Miguel Carreiro (Collaborator [office]), Emmanuel Ruffo (Collaborator [office]), Rosa Duque (Collaborator [office]), André Macedo (Collaborator [office]), Ura Carvalho (Collaborator [office]), Hye Young Yu (Collaborator [office]), Marta Yebra (Collaborator [office]), Mae Durant (Collaborator [office]), Angelina Pinto (Collaborator [office]), Randall Holl (Collaborator [office]), William Arbizu (Collaborator [office]), Max Zinnecker (Collaborator [office]), Laia Jutgla (Collaborator [office]), Manel Soler (Collaborator [office]), Megan Kelly-Sweeney (Collaborator [office]), Alessandra Faticanti (Collaborator [office]), Susanne Bodach (Collaborator [office]), André Brosel (Collaborator [office]), Konrad Hofmann (Collaborator [office]), Nora Graw (Collaborator [office]), Cricursa/Vicky Colombet (Glas Manufaturer), Toni Cumella Ceramic Manufacturer), Frederic Amat (Ceramic Artist), Industrias de la Fusta (IFV) (Corian Manufacturer), Covertex (ETFE Manufacturer), BOMA SL (Engineering), Obres i Construccions Joan Fustè (Construction), Diorama (Wood), Calderería Delgado (Steel Framework), Ramón Presta (Hydraulics), Industrias BEC (Tensile Structures), Aiterm, PGI, Reindesa (Installations), Aislater, Inoxcolor (Installations), Estudi Ramon Folch (Construction), Emiliana Desigestudio (Graphic Design), BAF (Audiovisuals), Led's Go (Illumination). Client (Private): Family Emilio Gallego. Programme: housing.

C-STONE & C-BENCH

This project is dedicated to Christel Vandewaerde (4 December 1963 – 18 December 2010).

GALAXY SOHO LARGE-SCALE CLADDING CONSTRUCTION IN CHINA

Client: SOHO China Ltd., Beijing, China. Architect: ZAHA HADID ARCHITECTS. Design: Zaha Hadid with Patrik Schumacher. Project Associate: Cristiano Ceccato. Project Director: Satoshi Ohashi. Project Architect: Yoshi Uchiyama. Project Manager: Raymond Lau. Project Team: Stephan Wurster, Michael Hill, Samer Chamoun, Eugene Leung, Rita Lee, Lillie Liu, Rolando Rodriguez-Leal, Wen Tao, Tom Wuenschmann, Seung-ho Yeo, Shuojiong Zhang, Michael Grau, Shu Hashimoto, Shao-Wei Huang, Chikara Inamura, Lydia Kim, Yasuko Kobayashi, Wang Lin, Yereem Park, Christoph Klemmt, Dorian Bybee, Kyla Farrell, John Klein. Local design institute:

BIAD (Beijing Institute of Architecture and Design), Beijing. Facade engineer: KT Kighton Ltd., Shanghai. Timeframe: 2008–12. Programme: Mixed-Use Commercial & Retail Complex, Shell & Core Fit-Out. GFA: 360,000m2 + 150,000m2 Below Grade. Site Area: 50,000m2. Height: 67 metres = 16 Floors Above Grade.

MEDIA-ICT

City: Barcelona. Country: Spain. Completed: January 2010 (started 2005). Office: Cloud 9 (Barcelona, Spain; est. 1997)

Architect: Enric Ruiz Geli. Collaborators: Josep María Forteza (Building advising), Agustí Obiol (Structural engineering), David Tusset (Engineering), Hector Yuste (Project management), Joan Buj Cotes (Construction), Carlos Siscart González (Construction), Ben Morris (Construction), Lluis Renom (Construction), Edouard Cabay (Architect), Javier Pérez Contonente (Architect), Francesco Ducato (Architect), Felix Fassbinder (Architect), Nora Graw (Architect), Konrad Hofmann (Architect), Victor Llanos (Architect), Max Zinnecker (Architect), Marta Arranz (Collaborator [office]), Ruben Alonso (Collaborator [office]), Luis Borunda (Collaborator [office]), Marta Banach (Collaborator [office]), Daniel Corsi (Collaborator [office]), Cristina Guadalupe (Collaborator [office]), Albert Lopez (Collaborator [office]), Mireia Luzarraga (Collaborator [office]), Patricio Levy (Collaborator [office]), Alex Muiño (Collaborator [office]), Beatriz Minguez (Collaborator [office]), Veronica Mansilla (Collaborator [office]), Federico Ortiz (Collaborator [office]), Mireia Pallarès (Collaborator [office]), Marisol Verges (Collaborator [office]), Hale YoungBlood (Collaborator [office]), Pep Bou (Art), André Macedo (Design). Client (Public): Consorci de la Zona Franca and 22@. Programme: Office.

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WAVED WOODEN WALL

Kilden Performing Arts Center, Kristiansand, Norway. Architect: ALA Arkitekter AS, Helsinki, Finland. General Contractor: AF Gruppen AS, Oslo, Norway. Timber Facade Contractor: Trebyggeriet SA, Hornnes, Norway. FaCade Cladding, CNC-Fabrication: Risør Trebåtbyggeri AS, Risør, Norway. Facade Structure, CNC-Fabrication: Blumer-Lehmann AG, Gossau, Switzerland. Façade Engineering: SJB Kempter-Fitze, Eschenbach, Switzerland. Consulting, Digital Planning: designtoproduction GmbH, Erlenbach/ Zurich, Switzerland.

LOUVRE ABU DHABI 1:33 LIGHT-TEST PROTOTYPE

Construction of the 1:33 prototype has been a cooperation between: 1:One | Computational Geometry (programming), George Ackermann GmbH (manufacturing & assembly) and Honkahe Interior+Furniture (modelmaking and consulting).

PHOTO CREDITS

RESEARCH PAVILION ICD/ITKE

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UNIKABETON PROTOTYPE

All images © Per Dombernowsky and Asbjørn Søndergaard 2010.

FREE-FORM METAL INFLATION & THE PERSISTENT MODEL

Anders Ingvartsen: 1, 3; Anders Holden Deleuran, CITA: 5.

MATTER & MAKING

PERISCOPE FOAM TOWER

Matter Design, 2010: 1, 2, 4, 5, 6, 7; FABLab University of Michigan Taubman College of Architecture and Urban Planning, 2010: 3.

BENT

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MATERIAL ANIMATION A NEW INTERFACE TO CUSTOM FABRICATION

Greg Epps, 2010: 1; Nick Puckett, 2010: 3.

INVESTIGATIONS IN DESIGN & FABRICATION AT HYPERBODY

Jelle Feringa, 2010: 1, 6, 7, 8, 9, 10; MarkDavid Hosale, 2010: 2; MarkDavid Hosale/ Marco Verde, 2010: 3; Jan Jacobs, 2009: 4; Marco Verde, 2010: 5.

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THE RICHMOND SPEED SKATING OVAL ROOF

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RADIOLARIA PAVILION

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WAVED WOODEN WALL

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