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Interactive Integration of Robotic Architecture and Non-Standard Fabrication

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The architectural relevance of robotics

Architecture is the process and product of design, planning and construction. The aim of both processes and products of architecture is to adapt the environment according to human needs. Detached, remote and slow design processes have to rely on hypotheses. In order to meet actual human needs, architects have to develop their skills for adaptation. They have to work on their capability to let real-world conditions of change and multiplicity into their praxis and products. Therefore, architects have to learn how to design adaptive architecture, optimized for efficiency and affordances, for immediacy and massive participation. If architecture is to be seriously optimized for adaptation, robotic architecture becomes a necessity.

In a recent article on robotic architecture, Miles Kemps states that ‘Our current static environments are predetermined, and grossly under-performing in the potentials they can offer their users.’[1] The importance of creative immediacy in architecture however was already addressed in the 1960s. In 1972 Charles Jencks stated in ***Adhocism*** that ‘[...] needs and purposes are normally frustrated by the great time and energy expended in their realization. A purpose immediately fulfilled is the ideal of adhocism; it cuts through the usual delays caused by specialization, bureaucracy and hierarchical organization’, followed by a critique of the architectural products of his time: ‘Shaping the local environment towards desired ends is a key to mental health; the present environment, blank and unresponsive, is a key to idiocy and brainwashing.’[2]

Jenck’s adhocist ideal was revisited in 2008 by Usman Haque: ‘We propose here a new model for the production of cities, where design and planning are abandoned in favour of beginning immediately with building and construction. This new adhocism requires us to disregard any temptation to sketch, to plan, or to model and above all to discard any desire to ‘brainstorm’. All these activities can be performed on the actual materials we wish to build with, while the thought-processes directly engage with or become the lived-in artefact, articulated at a 1:1 scale.’[3]

Back in 1969, Andrew Rabeneck noticed in his article ‘Cybermation’: ‘Imagine that we can improve the built environment through developments in performance design and industrialized building, but that people’s need for change accelerates faster than our ability to satisfy it. Our predictive ability remains inadequate. What then are the requirements for a built environment, which can meet changing needs? We suggest:

1. Buildings ought to allow change over time.
2. Buildings ought to satisfy their occupants, both functionally and fashionably
3. Any chosen form ought to be available, given the constraints of current technology [...]’[4]

Looking beyond the constraints of their contemporary technology, Charles Jencks envisioned digital communication could enable consumers to get direct access to all produced building materials, Gordon Pask investigated the relevance of cybernetics in architecture[5], and Andrew Rabeneck proposed to apply computation and digitally controlled fabrication so that architectural production and products could catch up with the speed of changing human needs. The technologies at the core of these visions of the 1960s have by now become ubiquitous, yet we still have to implement their envisioned applications.

Robots as creators

Since architecture is both process and product of the creation of buildings, due to their versatility architectural robots can be both creators as well as creatures. >>

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Figure 1: Hyperbody's protoSPACE

They can be either adaptive parts of buildings or actors in the process of building.

In creation of architecture, robots can be employed to CNC (computer numerically controlled) fabricate building components. In construction robotic arms as known from the automotive industry are employed in the assembly of buildings. In these activities the robot differs from the conventional machine in that a robot will execute unique manipulations without loss of efficiency. Efficiency is even gained as through its embodiment the robot measures its spatial context. The output of its construction activities will be made to measure according to the situation at hand.

The robot as creator enables designers to realize their design directly from their digital building plan and directly situated in the environment. It offers a constructive immediacy, similar to the experience painter David Hockney has of painting with the iPhone application brushes: 'It's always there in my pocket, there's no thrashing about, scrambling for the right colour. One can set to work immediately, there's this wonderful impromptu quality, this freshness, to the activity; and when it's over, best of all, there's no mess, no clean up. You just turn off the machine. Or, even better, you hit Send, and your little cohort of friends around the world gets to experience a similar immediacy. There's something, finally, very intimate about the whole process.'[6] While David Hockney's creative experience takes place on a screen; its principles of immediacy can be transferred to robotic building. The robotic creator allows the designer to immediately connect to constructive action even over large spatial distances. And as robots can build precisely measured according to the context there will be less waste generated on the construction site. And finally, there is value in the unprecedented closeness to the act of creation which robotic building allows for designers, builders and users. Walter Benjamin stated in the 1930s that in the age of mechanical reproduction, as a consequence of their mass-reproduction, works of art lose their 'aura'[7]. To illustrate the loss of value with an example of our time: a piece of music as digital file will be copied without effort and uncontrollably; immediate interaction with actual live performers however is invaluable. When any piece of information can be digitized and copied, and when even material objects can be digitized and copied by robotic creators, material objects - both original and copy - lose intrinsic value. If the (re)production of any artefact, be it informational or material, becomes almost effortless, immediate vicinity to the act of creation gains in value. Robotic creation is a technical means to introduce this immediate vicinity to the act of creation into architecture wherever conventional human means fall short.

Robots as creatures

Next to their role in creation, robots are creatures themselves, created beings. If as such they become active and integrated parts of buildings they offer embodied forms of interaction in which people and things not only talk to each other, but also are capable of manipulation through their embodiments. Kinetic robotic structures and the possibility of (self-) reconfiguration of a structure composed of robotic modules extend the repertoire of architectural adaption.

‘Robotic Architecture’ though may be a contradictory term. While ‘robot’ suggests a spatially and functionally autonomous entity, architecture relies on the holistic relationship – pars pro toto – between parts and the entire building design. If the parts of a building are to be robotic, the autonomy of its robotic part has to be maintained, without threatening the integrity of the whole building. In recent case projects in modular spatial robotics, robotic modules are connected to form larger structures that behave according to the combined capabilities and behaviour of the incorporated robotic components. Examples for such projects are the Self-Replication Module by Cornell Computational Synthesis Lab[8], M-Tran 1, 2 and 3 by Distributed System Design Research Group at AIST[9], Claytronics by the Claytronics Team at Carnegie Mellon[10] and Metamorph by Miles Kemp[11]. For actual architectural purposes however individual robotic modules will have to adapt to new purposes beyond the reach of just one type. These projects are developed as generalist systems in which just one atomic type of robotic component is used. After all, it is hard to make a functional building just with bricks, and very limiting to have to rely on bricks of just one shape and dimension. In this point robotic architecture projects do not answer to one problem which robotics in architecture can solve – the fabrication of unique components is as needed in a specific context.

Robotic habitats

‘Habitats for the digitally pervasive world’, as proposed by May and Kristensen[12], are localities that offer their inhabitants support in the form of opportunities, services that allow inhabitants to interact and to achieve their various goals. According to May and Kristensen, as digital technologies are spread throughout our environment, designers should reframe their concepts. They should move from thinking in terms of space to thinking in terms of habitat, from concepts of buildings as machine towards buildings as systems in evolution. Durability is no longer guaranteed by stability and solidity and can only be achieved as robustness and longevity. Performance is no longer given by fulfilment of function, but by support of rich interaction. Instead of simplicity and clarity, the new minimalism follows principles of adjustment to context, situated-ness, and heterogeneity. Where once there were mere spaces laid out on the ‘tabula rasa’ empty sheet of grid paper, architects now intervene in environmental tissue to create localities where life and growth takes place. Architectural robotics fit into this picture of changing, growing habitats. However, they have to be designed to support human needs without prescribing functionalist user roles. And if they are to be durable, in order to persuade us to engage with them, they will have to help us in the realization of our goals.

Case study: protoCOLOGY

In Hyperbody’s 2009/10 MSc2 studio Immediate Architecture, the hybridization of Interactive and Non-Standard Architecture was taken to a higher level. The

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assignment was a response to the real world observation of intended and actual use of protoSPACE (Figure 1), Hyperbody's real-time collaborative design environment. In protoSPACE 3.0, lack of an intermediate layer between interactive building envelope and work places lead to employment of regular furniture, which resulted in the suboptimal use of the interactive environment. Therefore the project assignment was to create an architectural system for the support of design sessions in protoSPACE.

An applied, integrated system

This system should allow adaptation of protoSPACE to match diverse team design situations and spatial settings. Students were instructed to develop a reconfigurable assembly of interactive components. Following concise assignments they developed interactive scenarios and made designs for environments based on specific interactive interventions. Concurrently to the architectural design of the environment, they were instructed to develop the protoCOLOGY system for its production, maintenance and behavioural control.

protoCOLOGY is an attempt to maintain the autonomy of robotic components, without sacrificing freedom of architectural expression. It is developed to enhance capabilities of users and designers to improve the performance of their built environment with minimal effort, anytime, immediately. protoCOLOGY is a real-time system encompassing all phases of the architectural process – use, design, construction including fabrication – as strategy to integrate robotics and architecture.

protoCOLOGY is aimed at a dialogue between architectural system and users, whereas three different modes of physical interaction are addressed:
1. Interaction with an assembly of robotic components as-is,
2. Reconfiguration, i.e. the possibility for users to manually re-assemble a set of components in a different configuration, thereby changing structure, shape and interactive performance,
3. On-demand rapid fabrication of additional components of non-standard shape and performance.

The last mode, on-demand non-standard fabrication, is necessary for any modular robotic system to answer to architectural design. It allows design of form and structure beyond the limited degrees of freedom system with a limited vocabulary of quickly available component types. Also, it will have to be employed whenever an additional component of specific shape or function is needed for a design update. For this strategy to unfold its full potential, the fabrication process should ideally take place as fast as existing components can be repositioned, it should not be just rapid but immediate.

System development

Design sessions are complex processes in which unpredictable social behaviour

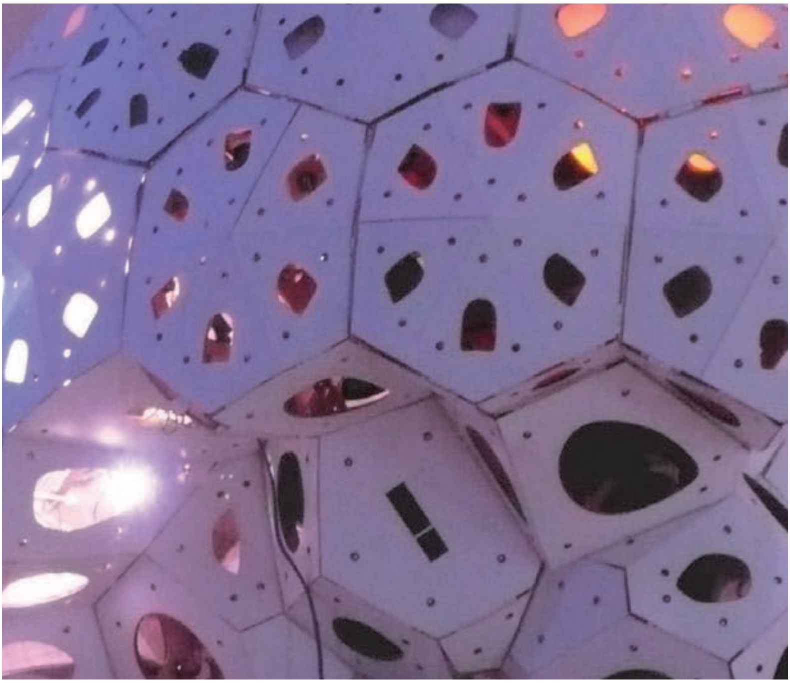

Figure 2: protoCOLOGY assembly
Figure 3: Reconfiguring the protoCOLOGY assembly

and design proposals may arise. In such dynamic activities an interactive adaptive environment could positively influence teamwork. With this idea in mind, the students analysed their collaborative design processes. Real-world design sessions were video documented and reviewed for key moments in which the design team collaboration could have profited from an interactive intervention. From this analysis a series of interaction intervention proposals emerged, which were evaluated for feasibility and commonalities. In the end, a basic set of interactive components was found, which could be combined in order to give supportive interactive intervention in several situations.

Independently from the design studio timeline, technological development took place in parallel strands of iterative improvement of all constituents of the system. From the very start of the semester students were asked to continuously produce components, to improve the fabrication process and the material aspects of the components, and to expand component performances for interaction and reconfiguration. With this fabrication and development setup, students iteratively explored alternatives for materials, connections, and interactive performances. A real-time behavioural design model was gradually integrated into the fabrication stream. The goal of the technological process was integral optimization of the component system for interaction, for reconfiguration, and even for on-demand fabrication as strategies for immediate architectural adaptation.

Out of the different time-scales of adaptation arises temporal complexity. Building life cycle, component life cycles, and continuous adaptation in use necessitate means to trace the life cycle for each individual component. This life-cycle trace functionality would help to sustain functionality of a protoCOLOGY assembly, and even when applied to conventional non-intelligent components it would improve sustainable building maintenance.

These considerations regarding rapid on-demand fabrication and component lifecycle tracking, lead to the development of the assembly as digital material hybrid. Hybridization takes place by linking digital model and material components at each stage of a component's lifecycle:

1. Real-time virtual model generates visualizations for assembly, geometries for fabrication geometry and offers a control interface for interaction.
2. Streaming fabrication pipeline enables rapid on-demand manufacturing of components.
3. Database tracks component data and lifecycle, and
4. Intelligent building components are actively communicating with model and database.

Digital structure and material structure of the system are connected bi-directionally and remain connected throughout design, construction and interactive reconfigurable use. Design and construction become integral part of interactive use and adaptation.

Component geometry

A prime consideration in the development of the system was to achieve balance between easy reconfiguration and component differentiation, a balance that affects both shape and interactive performance of the environment. A system, which allows only one component form and type, for example cubes, would maximize reconfiguration possibilities between components since any component could be combined with any other component following the standardized cubic symmetries. In such a super standardized system freedom for architectural expression and meaningful combination of interactive components however are limited. Besides, one standardized component type will hardly suffice to address all needs that arise in the construction of an entire building. When she relies on standardized components, the architect has to include different types of components for differentiated performances - for example, special types for floors, walls, doors, and windows. And then still, a good portion of the standardized components has to be trimmed to fit within the building geometry. Therefore the chosen strategy was to develop a system that by default is irregular. In order to compensate for the loss of recombination possibilities in a set of irregular components, a technique for rapid on-demand fabrication of components is integrated into protoCOLOGY.

The digital model of a protoCOLOGY structure has to generate robust fabrication geometry, without sacrificing the range of possible shapes. It has to be useable as real-time interaction control, as fabrication modeller and it has to be capable of tracking the structure of the assembly as it is reconfigured. These diverse functional requirements were met with a 'flat' modelling method, in which three-dimensional components were derived from points of a point-cloud. In the model, based on Delaunay Triangulations and Voronoi Diagrams, all of space is subdivided into parts and each part can be either empty space or a component. In this topological model, each point owns a part of space. The location of the point and its neighbourhood is used for construction of a geometrical model of the point's part of space. This modular yet topologically flexible model of space was expected to be adequate to the speed of interaction and to the continuous permutation and open-ended extension of a collection of components.

A new component in this system (Figures 2, 3) does not have to be constructed, since it is already defined as a chunk of space. It only has to be defined by changing the boundaries between this chunk of space and its neighbours.

In the developed protoCOLOGY system, the component pattern without external or design influence is that of Weaire-Phelan cells. This pattern fills a given volume with foam with the least material. In this sense, the basic Weaire-Phelan pattern is as generic to foam-like space filling system as a sphere is to a soap bubble or a cube is to salt crystals. The modeller expects space to be filled with this pattern up to infinity, unless it is diversified by design interventions.

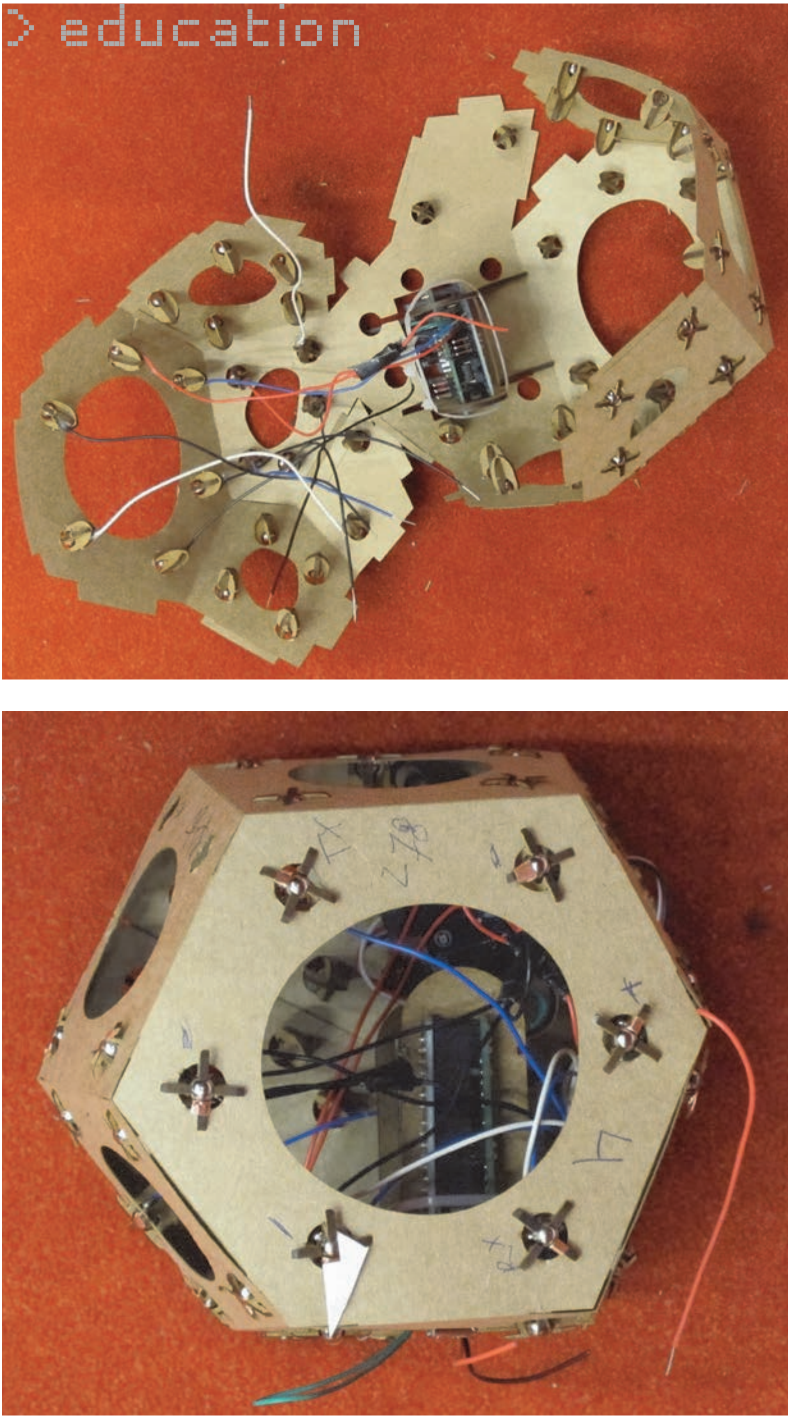

Figure 4: Component

The digital model was implemented in the development environment Virtools. The model allows users to create and change assemblies using both already generated components found in the StreamLog database and components, which are to be fabricated and have yet to be defined.

Interaction design

Based on video analysis and real life experiences, several interaction scenarios were developed. These scenarios consisted of an explicit design for the shape of the assembly, and the distribution and function of interactive components within this shape. All proposed scenarios were evaluated against three criteria; the spatial qualities of the design, how it supports team communication and how it connects the physical environment to digital design space. The balance between these criteria shifted per proposal. For example, proposal The Cloud would descend from the ceiling and allow users to pull down vortexes of intelligent components, which would suck up and distribute design data, while the cloud would visually express data streams and conflicts. Movable Rock (Figure 6) on the other hand focused more on constructive and spatial aspects. It looks like a cave, into which users can dig intimate places, surrounded by roots and crystals.

For different types of components, diverse interaction modalities were proposed relating to all human senses. Sensor components could register sound and even speech patterns, brightness, proximity and movement of users (Figures 5, 6), touch, whether they are connected to each other and whether they have been shaken or turned. In prototypes, all of these sensing modalities were implemented except for speech pattern recognition. Proposed modalities for output components were light, sound, movement, vibration, wind and even olfactory. For these output modalities technical plans were made, however during the semester only light and sound were realized in prototypes.

protoCOLOGY components (Figure 4) connect magnetically. They are therefore, attached and removed from an assembly without the use of any tools or fixtures. As soon as they are attached through the magnets they receive power from their neighbours in the assembly and start to communicate with their neighbours, immediately contributing to the interactive performance of the assembly. Users can put together and modify a component structure with ease, and with a simple set of components many diverse configurations can be achieved. Replacement of defunct or out-dated components becomes trivial.

When combined in clusters, components of different kinds form functional units, which can perform interactive interventions. Proposed interventions were to welcome arriving team members, to let users model data by reconfiguration and visualize results, to provide ambient display extension for presentations, to give visible feedback on speech patterns occurring in discussions and lectures, and to serve as controller either by recognition of user position and gestures or as hand-held controller.

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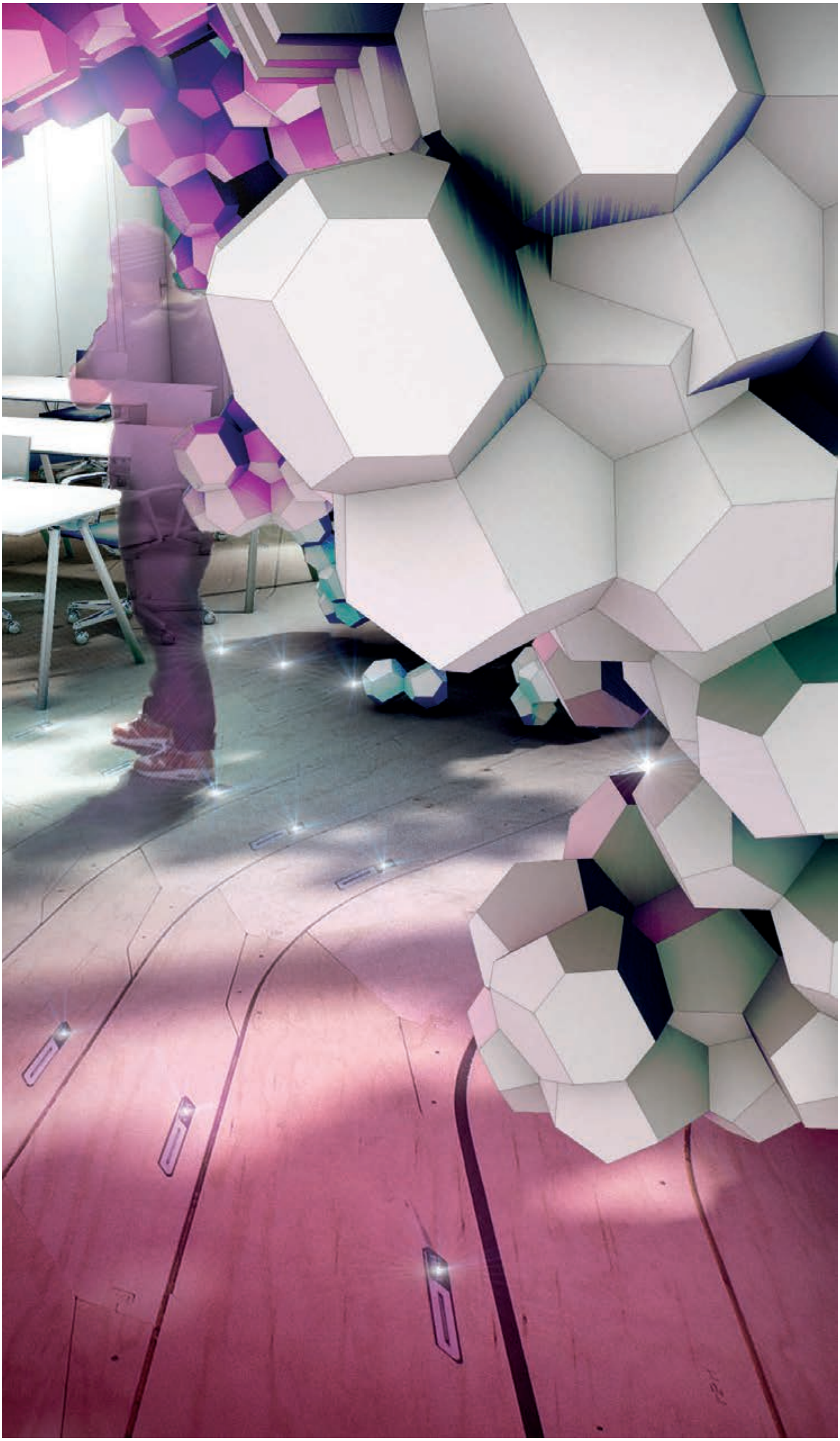
Figure 5: protoCOLOGY scenario developed by B.A. Nguyen Phuoc



The possibility of kinetic structures was considered. To equip the already intelligent components with servomotors would have been a trivial action. Yet, in the chosen geometry and fast reconfiguration environment, the development of meaningful structural movement requires more development time than was available, for two main reasons.

The first reason is the possibility of manual reconfiguration, which was found to be more direct and interactive while introduction of axes of movement needed for mechatronic actuation was found to be limiting at this early stage of development. Kinetics however is a logical extension of the capabilities of the protoCOLOGY system and should be added in future reincarnations of the project.

The second reason is the chosen geometry, which is space-filling and expects irregularity. Only directed, planned interventions would generate symmetries along which kinetic movement can take place. Besides, protoCOLOGY ‘s geometric approach is to cut up three-dimensional space into parts. A, actually space-filling structure is more affected by kinetic behaviour than e.g. a one-dimensional beam which can be bent or a two-dimensional surface which can be easily folded. While one- and two-dimensional structures are naturally part of the chosen three-dimensional approach and any one- or two-dimensional solution could be applied to respective elements of the chosen structure, to the developers of protoCOLOGY implementation of kinetic movement would have only made sense if it addresses the volumetric nature of the component logic.

Conclusion

protoCOLOGY is an explorative research project on hybrid modalities of human-building interaction. In a protoCOLOGY environment, mechatronic interaction is placed beside tactile reconfiguration and allocated rapid fabrication of interactive components. Goal of the project is to establish an architectural environment, in which all three building interaction modalities are equally approachable, effortless, fast and cheap. With the protoCOLOGY system realized over a semester, a new component could be modelled in real-time and fabricated in about half an hour at a cost of €15 for structural and €40 for interactive component prototypes. While fabrication time and cost could definitely be improved, protoCOLOGY components already exhibit an impressive range of build by use performances. While the choice of adaptations and its modality are up to the user’s input, the protoCOLOGY system guarantees that desired interventions are sustainably and seamlessly executed. The protoCOLOGY system is generated and adapted in interactive use, showcasing the potential of robotic architecture. Robotic building interaction encompasses design, fabrication and construction as the constituents of the environment offer the affordances to be built and adapted by use.

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Figure 6: Interaction by gesture in protoCOLOGY