The One Day House

**Intelligent Systems for Adaptive Buildings**

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As the global population continues to climb and environmental conditions become further unpredictable, the creation of a more robust, intelligent, adaptable yet affordable housing system will become an evermore-significant issue. Existing housing typologies find themselves lagging behind other industries such as aerospace and even automotive, lacking advanced fabrication infrastructures as well as embedded intelligent technologies that could allow for: Global interconnectivity and or manipulation, automatic software/hardware updating and physical/computational adaptability. The use of advanced tools for manufacturing resembling industrial robotics, 3D printing and as well as intelligent fabrication systems currently remains nearly non-existent. Constructed using outdated design methodologies, materials and construction techniques, the current dwelling functions merely as an enclosure for life rather then an integrated system for information, comfort and commerce. This paper questions the current typology of "house" through the rethinking of not only form and material, but by reimagining the dwelling as a whole. Rather then observing the dwelling as a static form for infrastructural permanence, this paper redefines the home as a globalized commodity, which is both physically and technologically connected and adaptable.

**Keywords:** Responsive housing, Adaptive skin, Robotic fabrication, Mass customization, Computational design

**INTRODUCTION**

In today's rapidly evolving digital/computationally-based society, the tools and interfaces we interact with on a daily basis are becoming more and more adaptive and intelligent. From ever-more autonomous automobiles with the ability to read their surroundings and adapt their external form based on varying driving/weather conditions (Bangle, 2008) to mobile devices with the ability to model our environment in 3D or finish our sentences, a growing level of computational "awareness" has begun to appear within our everyday tools and environments. This awareness allows for the further development of more user centric and efficient environments, where...
it is no longer necessary for the user to be in complete manual control. Yet this level of intelligence still remains all but absent within the spaces and interfaces people invest their greatest quantities of time and assets, the detached dwelling.

Current building typologies remain static and globally disconnected, unable to adapt to their inhabitants changing needs as well as their surrounding environments in real-time. Recently, a growing number of architects and designers have been delving more into the realm of “smart” and “adaptable” building technologies. Spaces with the ability to sense temperature, occupation and internal/external lighting conditions and can then learn to adapt through usage patterns are becoming more commonplace (Wit 2014). Through these integrated systems, buildings are beginning to gain the ability to not only sense and adapt to their surroundings, but also communicate autonomously with their inhabitants through inter-connected mobile devices.

Although certain systems or artifacts within these buildings have become more “intelligent”, the fact remains that these new systems were built upon an existing framework consisting of archaic building materials, construction methodologies, enclosure systems and infrastructure that are both outdated and impervious to change.

Rather than attempting to make existing building materials, construction methods and integrated systems smarter, this paper questions our current methodologies of designing the built environment, and proposes a novel system fueled by the integration of advanced composite materials, robotic on-site fabrication for mass customization, environmentally adaptive/robotic “soft” light-weight ETFE skin systems and adaptive/intelligent data collection/dissemination systems that allow for continuous monitoring and upgrading of building systems. This move away from standardized materials, common construction methodologies and preconceptions currently linked with the idea of “home” allows for more emergent/adaptive technologies to evolve simultaneously with the formal design and programming of the building itself, rather then applied to an existing system afterwards.

Recent projects such as the University of Stuttgart’s ICD Hygro Skin: Meteorosensite Pavilion (Menges 2013) as well as their recent robotically fabricated composite pavilions (University of Stuttgart 2012-2014), the Yeosu Expo 2012 Thematic Pavilion (soma 2012) and ONL’s 2003 NSA Exhibition in Pompidou (Oosterhuis 2003) begin to question not only our current formal logic but also our preconceptions on ridged envelope systems and material choices. These innovative projects not only push our current design preconceptions but also introduce questions on the long-term continuous occupation and material durability.

Through a series of small-scale prototypes and robotically fabricated tests (figure 1), this paper takes its first steps towards furthering these advanced materials, methods and robotic fabrication systems further into the everyday architectural realm, with hopes that future research will lead to the production of a series of novel, full-scale, high-quality dwelling prototypes.

Throughout this ongoing process, a sequence of four design strategies been utilized and pushed for the realization of the "One Day House" prototype: 1) Form finding through minimal surface tensile modeling 2) Composite robotic fabrication and modularization 3) Adaptive/robotic ETFE enclosure systems and finally 4) Intelligent control/monitoring systems. Following
are the processes and results shaping this evolving research.

**Context**

Following the March 11th 2011 Earthquake and Tsunami in Northern Japan, an international initiative was started to reimagine the potential of the detached dwelling. Initially envisioned as a means of rethinking with emergency housing, the potentials of the "One Day House" initiative have spread beyond, with the hopes of redefining the detached dwelling as a whole. By re-examining of spatial needs through the integration of adaptable/efficient spaces, the "One Day House" collapses the overall area requirements of the dwelling. Ranging in footprints of between 600 -1500 sqft. allows for the easy integration of composite structural systems fabricated through on-site robotic fabrication. The following describes early studies in structural form finding, robotic fabrication and small-scale prototyping used throughout the ongoing research in the "One Day House" initiative.

**INFORMED FORM**

Architectural form can be generated through many means, though many of today's methodologies are outdated and do not afford buildings the highest levels of formal variation, material efficiency and adaptability necessary for today's rising environmental and technological demands. Dependence on standardized materials and dimensions currently force the buildings form into inefficient shapes and configurations in an attempt to minimize waste and upfront costs. These attempts though fail in the long run as these forms lack both environmental adaptability and longevity.

Subtractive and stick-frame construction methods although quick and requiring less skilled labor, require many layers of inefficient ridged material between the interior and exterior skins, while creating minimal surfaces with any potential for adaptability. This process also leaves inhabitants with huge amounts of waste both during construction, as well as at end of life. Although some of this waste can be repurposed as hybridized composites, a large majority ends in landfills.

In addition, additive construction methodologies tend to also use high-energy materials such as steel reinforced concrete. In repetitive situations reusable formwork can limit waste, but our desire for the creation of unique built solutions requires that extensive custom formworks be manufactured creating vast amounts of un-recycled waste. Also, the movement of time-sensitive/high-energy heavy-weight materials over extensive distances in conjunction with additional materials required to compensate for low tensile strength also leaves this methodology to be less desired.

Rather then relying on and working with these outdated form-finding methodologies, this project investigates using techniques such as computational tensile-membrane modeling and inflated-surface modeling while utilizing evolving internal and external environmental conditions as constraints to determine an optimal, yet slightly flexible structural form.

In conjunction with robotic formless composite winding of materials such as pre-impregnated carbon fiber tow, and clad in an adaptable pneumatic ETFE pillows system to create an extremely flexible, high quality, low-waste and structurally robust enclosure system, this project aims to facilitate a novel lightweight structural system for adaptive housing.

The "One Day House" currently investigates form through several evolving inputs: 1) Monocoque vs. Modular Structures 2) Formed and Formless Composite Winding 3) Continual Environmental Adaptation and 4) Re-configurable Programmatic Spaces.

**Form-finding through MPanel & Kangaroo**

Building form was generated through the utilization of the Rhino 3D plug-in's Meilar MPanel (a tensile modeling software) and Kangaroo (a physics engine created by Daniel Piker). As the enclosure system was to be designed and potentially fabricated as a singular continuous skin in smaller instances of composite winding, a system was developed for the easy trans-
translation from digital model into a physical wound prototype.

Initially, a basic outline for the dwelling was defined from a simple primitive form. As this system is parametric, the outline and base form could be manipulated or altered based on varying conditions at any point. Thereafter, building site orientation, external environmental constraints (sun, wind, etc.) and internal programmatic forces were exerted on the original formal outline as a series of dynamic vectors. These forces in turn distorted the base form creating a revised initial programmatic and formal diagram.

Following the initial formal creation, a formless winding framework is derived through the extraction of the open-end form geometries. These extracted splines become the end structure of an aluminum jig that the composite tow will be wound between. These curves also act as the bounding geometry for tensile form finding within the MPanel environment. Within MPanel, this end geometry is then configured as edges within a “fixed edge” tensile membrane structure. These ends are then interconnected through a network of equally sub-divided meshes representing the un-relaxed tensile forces. (A refined mesh geometry is important here, allowing for the highest level of accuracy in future composite winding.) Intersecting edges within the form are defined as structural ridges. These ridges represent catenary cables around which the composite material will be wound. The cable also acts as a temporary structure connecting the two frames together during the baking process. Material properties are then programmed in MPanel and the meshes are relaxed creating a more robustly defined structural form.

The finalized MPanel form is then parametrically linked into Kangaroo where internal and external forces can again redefine the building's form to an infinite numbers of variations. The continuous mesh is then offset inward creating a secondary mesh for structural depth. The offset has the ability to be asymmetrical depending on structural loading and winding densities. For monocaque typologies, splines can now be wound around the two meshes creating an interconnected 3D structural network to be extracted as the robotic winding data within KUKA PRC.

**Monocaque vs. Modular**

Two structural design methodologies were investigated for the "One Day House" both utilizing the above-described form finding methodologies. In situations where interior floor area is minimized and clear fabrication space is available, a singular monocaque system would be utilized. This system allows for a more simplified fabrication process through the utilization of a rotating platform and one or two robotic arms. Although this method minimizes material and time, it also faces several challenges. Firstly, as the current composites must be baked in a low temperature oven to cure this methodology requires the fabrication of a large-scale portable oven. This can be easily achieved though a modular insulated system but requires three times the spaces for fabrication, oven, and foundation.

The monocaque methodology also makes it more difficult for the initial form to be manipulated, as the structure is one contained element. In time if the occupants wish to add on to or manipulate the houses basic form, their number of options will be minimized. A potential option for manipulation of this system could be addition through aggregation of additional large-scale monocaque modules that can be attached in either direction to allow for later additions.

In instances where the overall building form may be to large or complex to be fabricated in a single continuous module, the initial minimal surface geometries would be subdivided, thickened and wound as individual bolt-on structural modules. This system would allow for the creation of elements currently ranging between eighteen and sixty inches based on the current end effector prototype that could be easily condensed for baking, transportation and assembled on site. This modular system could also allow for a high level of post completion customization both spatially as well as with the façade.
system as individual modules have the ability to be individually replaced and interchanged without disturbing the overall structural integrity.

Just as with the monocaque system, there are inevitably downsides. First is an increase in complexity. Where the monocaque system condenses structure into a single module, the modular system could consist of around one hundred unique modules depending on the structural patterning. With the addition of panels also comes an increase in material. As individual elements must now connect to several adjacent modules, each unit must now contain robust structurally wound walls creating connection points. Finally module accuracy and ease of on-site aggregation will be of utmost importance, as imperfections will compound throughout construction.

**Modularization**

With the current end effector prototype (to be described below), there is huge potential for variation within the modularization of the form. Current modular systems are modeled off of a hexagonal patterning with a varying diameter of between eighteen and sixty inches. The current prototype also has the ability to adjust in length in 1/8” increments of length creating extra flexibility (figure 2). For additional variation in form or winding patterns, arms can be completely removed creating new modular typologies or elongated asymmetrically. Also, as symmetry between the inner and outer surfaces may not be structurally or visually desirable, each arm also has the ability to rotate 45 degrees on either direction outside of vertical. This allows for interlocking between adjacent panels.

Module connections are currently designed as flexible rubber hinges which allow for a minimal amount of flexibility between the modules. The connection system will be developed further in later research, and as the individual module system becomes more robust.

**Robo-Winder V.6.0**

Opposed to the previously discussed Monocaque based structural winding; ROBO-WINDER (figure 3) was designed specifically to investigate a system of smaller lightweight high-strength composite modular building blocks. With the "One Day House's" potential to be designed, fabricated and assembled on-site with minimal manpower and material waste, ROBO-WINDER aims to physically and visually re-imagine what housing could look like in the near future.

Through the utilization formless composite winding, the dwellings form has the ability to remain flexible (form, joints and skin), as the building is no longer constrained by the ridged connections and cross sections of standardized materials such as wood, steel.
and glass. Complex doubly curved surfaces can be computationally optimized and broken down into unique, easily fabricated and workable geometries in Rhino 3D’s plug-in Grasshopper. These surfaces are then reconfigured based on the end-effector working tolerances. After each module has been individually calculated, a winding simulation is created within Daniel Piker's Kangaroo Physics with the output being a single continuously wound spline. The spline data is then oriented in KUKA PRC where robot code is simulated and is exported as robot code for winding the pre-impregnated carbon fiber tow around the end effector. Following composite winding, each module is densely stacked and baked on-site within a low temperature oven. Through the design, fabrication and testing of a series of prototypical end-effectors, ROBO-WINDER initiated the examination for the potential of both thin shell aggregated modules as well as densely woven 3D modules.

**Initial Prototyping.** Initial prototyping for winding was accomplished through a simple modular based system which allowed for individual users to create large varieties of symmetrical or asymmetrical structural modules for the construction of the project. Although the current end effector utilizes six adjustable arms, each arm has the ability to be removed or split to allow for higher levels of variation. Initial prototypes were fabricated of laser cut cardboard or acrylic and focused on creating a simple system for building skin modularization into three-dimensionally thickened units to be later wound in carbon fiber winding (figure 4). As initial testing focused on varying winding methodologies and end-effectors typologies, structural rigidity and module connectors initially suffered and were developed further in later prototypes.

Each prototype was designed with ease of assembly and robotic actuation in mind. End effectors were created to be simply laser-cut or water-jet cut, and bolted together within minutes on-site. Each prototype also allowed for vast amounts of programmed variation. Through a series of simply defined numerical sliders, users were able to adjust the length of each arm, the arms angle of attack as well as the density of the wind. Each element of the end effector could also be easily replaced with other iterations or simply robotically actuated by the integration of a system of pneumatics. This embedded flexibility allowed for the creation of modules ranging from basic composite wrapping all the way to complex three dimensionally wound composite structural modules with vast levels of variation.

**Further Development.** Initial prototypes and testing allowed for a robust understanding of robotic composite winding and complex form generation through robotic end-effectors and computational design. Although these tests showed the possibilities of aggregated composite modules, they initially lacked the necessary structure to create larger-scale projects with longer life spans.

The current phase of development investigates the formal logic of the individual module, while creating a more robust three-dimensional carbon fiber network for structural applications (figure 5). Through further material explorations, advanced panelization, winding methodologies and structural tests, ROBO-WINDER aims to create a novel system for the rapid fabrication of the "One Day Houses" composite structural system.

**ENCLOSURE SYSTEM**

Just as with the dwellings structure and infrastructure, it is important to rethink the dwellings skin. Cur-
rent skin systems are extremely complex requiring multiples layers and barriers. These barriers if not installed correctly can also lead to long term, imperceptible problems that can appear without notice. Rather than using these out of date systems, the "One Day House" proposes a small-scale variation of the ETFE pillow systems such as those found on buildings like as the Water Cube in Beijing (figure 6).

Rather then working with a static system, this project proposes an adaptive system that modifies air pressure within individual pillows to accompany necessary insulation values and lighting controls (through printed offset fritting). Where as typical buildings insulation remains static even in conditions where the sunward side of the house retains the same value as the shaded side, this system would have the ability and intelligence to adapt values for the optimal interior conditions and energy harvesting.

As the structure has a controlled structural depth, the façade system would consist of both interior and exterior pillow systems with a controlled air space in-between. As individual pillows are related to singular modules, damaged or aged pockets could easily be replaced within a minutes. If lighting conditions or insulation values are not appropriate to the inhabitant, they could also be easily adapted by varied inflation, fritting or material density.

Computational modeling for the ETFE pillows was accomplished through a combination of MPanel and Kangaroo physics. Initial constraints such as material thickness, tension, air pressure and so on are entered into the MPanel software where individual pockets are rendered. These static panels then parametrically inserted into Kangaroo and linked to LadyBug+HoneyBee which collects environmental data from a given area then allowing for the manipulation of inflation pressure within the individual pillows. These new minimum and maximum values are then once again verified in MPanel for material stresses and tolerances. The output of this is the current adaptable pneumatic skin prototype currently under further development.

CONCLUSION
Although the "One Day House" is still in the early stages of development, current research has shown the potential and necessity for the integration of advanced materials, fabrication methods and robotics into the design and fabrication of future housing solutions. Through the utilization of these new materials and methods, the potential for the creation of
a new typology of intelligent dwelling that is both more formally diverse and environmentally reactive has become increasingly feasible.

Rather than focusing on the formulation of a formal language from the onset, this project utilizes environmental constraints (internal and external), fabrication methodologies (such as formless composite winding) and adaptable lightweight skins to shape the buildings form.

This new pedagogical framework for building also questions the current production of artifacts where the design process ends upon the completion of construction, and asks whether both the design process and the building itself could continue to adapt and evolve throughout the lifespan of the building.

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