TRANS-STRUCTURES

Fluid Architecture and Liquid Engineering
Response-able innovative structures

TRANS-STRUCTURES

When bricks are drops…

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Introduction

Adaptability within a dynamic environment, that utilizes smart materials and response-able structures, enables designers to be inspired by sustainability without limitations. This book's aim is to explore the potential of these dynamic structures through detailed case studies and an introduction to the philosophy behind their design.

The book explains laboratory tests and introduces prototypes parallel to the design methodology to present the full spectrum of the research process, in which constraints of realization and design thinking evolved simultaneously.

Build case studies follow the design introductions of: two experimental houses designed by Kengo Kuma Architects, the Water House pavilion by Allwater, thermo-bimetal and new breathable building skins of Bloom project by DOSU Studio Architecture, BIQ bio-responsive façade of Splitterwerk, and finally an experimental water house built in Tokyo. The examples are related in their capacity for response-ability, but the utilized materials and solutions vary from air to steel to water and from cutting-edge technologies to biological materials.

The research on response-able structures and the Water House model started 7 years ago in the University of Tokyo's Department of Architecture, in the laboratory of Prof. Kazuhiko Namba. Trans-structure is the next stage of this research process, with research being conducted in Prof. Kengo Kuma laboratory.

Kengo Kuma Lab at the University of Tokyo's Department of Architecture (UTDA) is responsible for architectural research and production of high-level cultural events, focusing on projects that join tradition and innovation. UTDA belongs to an elite group of world-renowned architectural schools including the Harvard Design School, London AA, Columbia University, and the Beijing Tsinghua School of Architecture.

Synopsis

Trans-structures are building elements with the response-ability to change according to external conditions in order to maintain stability in terms of structure and/or energy. In this type of building, any effect (structural or thermal load) would generate an immediate affect (a response of the structure). Energy and weight would be counteracted and on a total scale, change would not occur. Such buildings are always in transition from one state to another, unlike conventional structures.

This approach is basically the opposite of conventional design methods in engineering when a worst-case scenario is applied to the designed structure. The benefits of trans-structure are not only energy-saving and better thermal comfort, but also create a more innovative and cost-effective building as well. This approach to stability represents a completely new paradigm for sustainability, based on the assumption that strong structures are not truly stable, because real stability comes with response-ability.

This book is compromised of two main parts: theoretical essays and an introduction of constructed prototypes. The former lays down the framework of trans-structure and is also accompanied by photos and diagrams of the laboratory tests. The constructed prototypes are each discussed in one or two interviews with a key designer of the project and then discussed with a further analysis of the design.

Theoretical essays are written by Matyas Gutai (JSPS Postdoctoral Researcher at The University of Tokyo, designer of Water House pavilion and inventor of patented Allwater panel technology). The interviews include project architects and engineers from the Kengo Kuma Architects and professors from universities in Japan, USA and Europe.

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I/1. Transition: Running without moving

Whether it comes to energy or structure, stability is fundamental for architecture. Buildings are expected to keep unchanging state both physically and environmentally.

Stability has been achieved by strength in the past, simply because it was the best strategy that available technology could offer. This was true for embedded energy need of structures (more material) and also for environmental energy demand of constant and comfortable microclimate (more insulation). The long history of this strategy founded the misconception, that strong is stable.

Real stability however, comes with response-ability, when any “effect” (structural or thermal load) can be counteracted with an immediate “affect”, a response of the structure. Energy and weight could be counteracted and on a total scale, change would not occur.

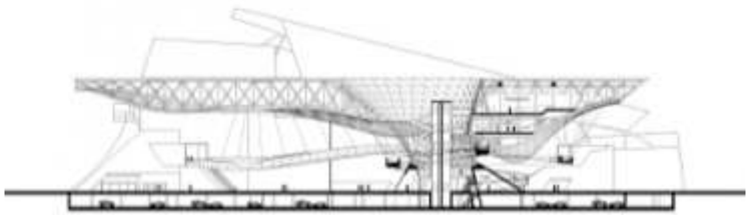
When it comes to energy, conventional structures work more like a spaceship: close environment out to achieve stability. Trans-structure is the opposite: by accepting the changes of environment it is in constant transition to achieve unchanged state, like ‘nomads move for greenery and the surfers for waves and summer’.

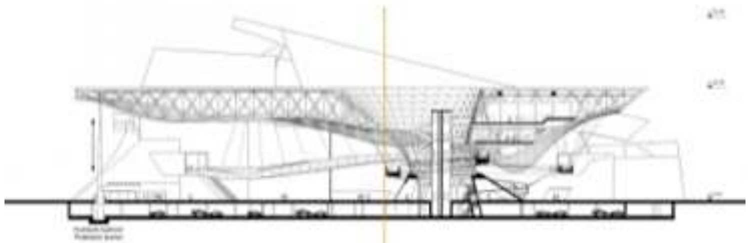
A structure like that would not have a static state, neither in sense of energy nor of matter: it would be heavy some cases and light in others depending on the actual structural demands; also it would be warm or cold according to the requirements of the microclimate. On the scale of the whole structure, its own weight and contained energy could be dispersed in different way each time, defined by actual conditions and demands. Such structure is never a stable one, to be able to assure real stability. This way the structure is always in transition from one state to the other, which is the most important essence of a trans-structure.

Trans-structure with its perpetual change can assure the state of “dynamic stability”, which is not only essential for self-sustainability, but also can transform the limits of sustainability into inspiration for architectural design. This dynamic structural state however requires us to redefine the basic principles in engineering, because our current technologies rely on static systems only.

Busan Cinema Center designed by COOP Himmelblau is a good example to show the potential of this thinking. The spectacular 80 meter long cantilevered roof could not have been built based on conventional engineering: the structure was simply not strong enough to resist the typhoon winds. To overcome this difficulty, additional columns have been added to the structure, which only rise for limited period of the year. This unique solution was based upon the recognition, that a simple shift from a rigid and closed structural design to an open one has the potential to provide new possibilities in architecture.

The same goes for trans-structures, with the difference that responses have to be generated immediately to maintain balance. The manner of change is however also important: smart structures “Act” (state of change) while responsive environments “React” (state of change with normally minimizing the environmental “Effect”), but only trans-structure is capable to generate an exact “Answer” (state of change as perfect countermeasure, annulling the original “Effect”). The “Effect” however seldom changes one property only, therefore the possible “Answer” can vary as well, especially, because these properties are connected and depend on each other all the time. Trans-structure design therefore naturally cannot follow the conventional design methods, because in addition to capacity of change, the model also has to include the effect of Interrelation.





I/2. Interrelation: Dynamic stability of energy and matter

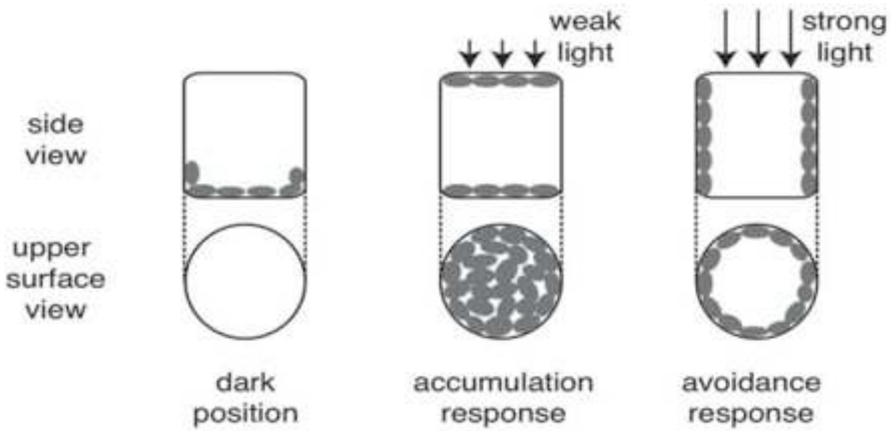
Dynamic states for trans-structure are fundamental, but simply the possibility of change is not sufficient. Smart materials or responsive structures can change also (“act” and “react”) but trans-structure gives a “response” to balance and eliminate the external effect.

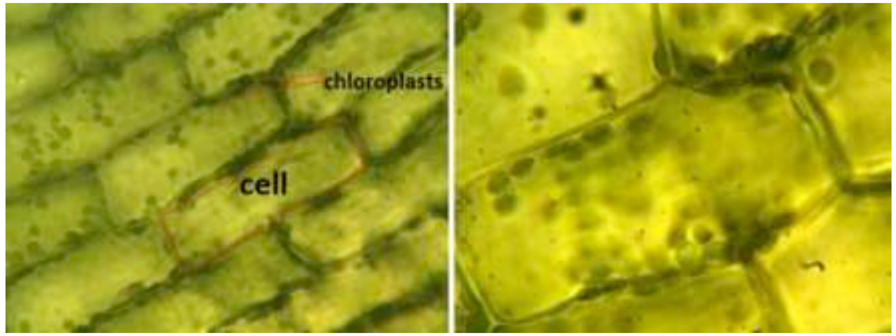
The strategy of change to counteract an external effect is not typical for built environment, but more common in nature. Chloroplast movement is a good example: depending on the sunlight intensity, the pattern changes constantly, to maintain ideal conditions for photosynthesis. In case of a building however, several factors have to be considered.

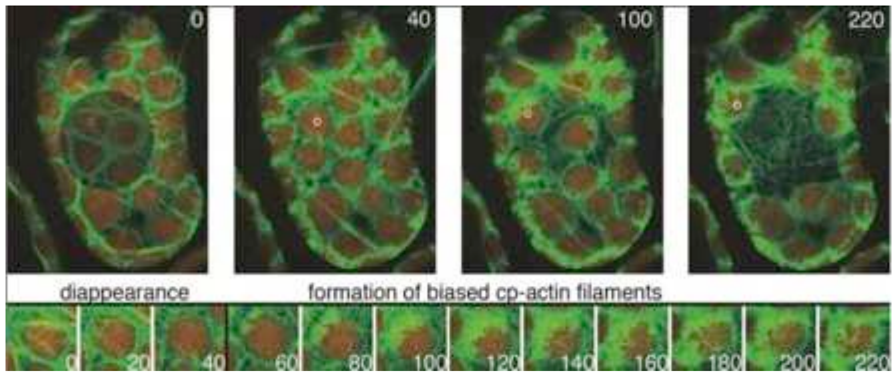
Environmental or structural changes may occur rapidly and also concentrated in some cases; while they can be slower and affect the whole building in others. Trans-structure can work effectively, if the system defined can generate rapid responses even for small changes in the environment. When it comes to thermal comfort for example, even change of 2-3 degree Celsius can make a difference.

In addition to speed and sensibility, the perpetual changing process has to be monitored and controlled during operation. This also necessary, because the same actual condition can trigger different responses from the structure, while likely only one of them is ideal, which has to be selected: an increase of indoor temperature for example can be counteracted with cooling, or more thermal mass and even with more transparency (if outdoor temperature is lower).

Furthermore, trans-structure has to practically cover the area of the maintained balance space as well of course. This may seem obvious, but is also results an important dilemma, because this also means that rapid response and sensibility has to be assured for a larger scale structure.





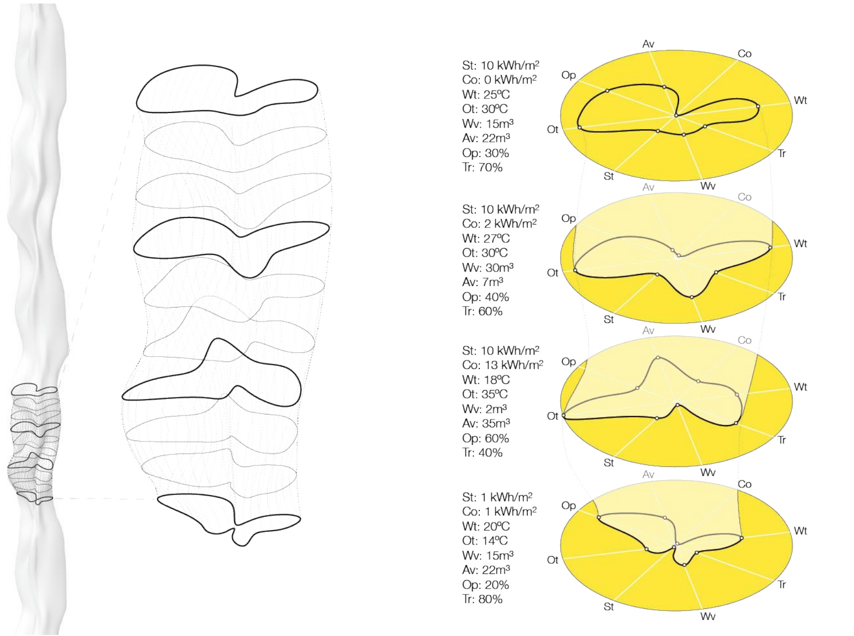


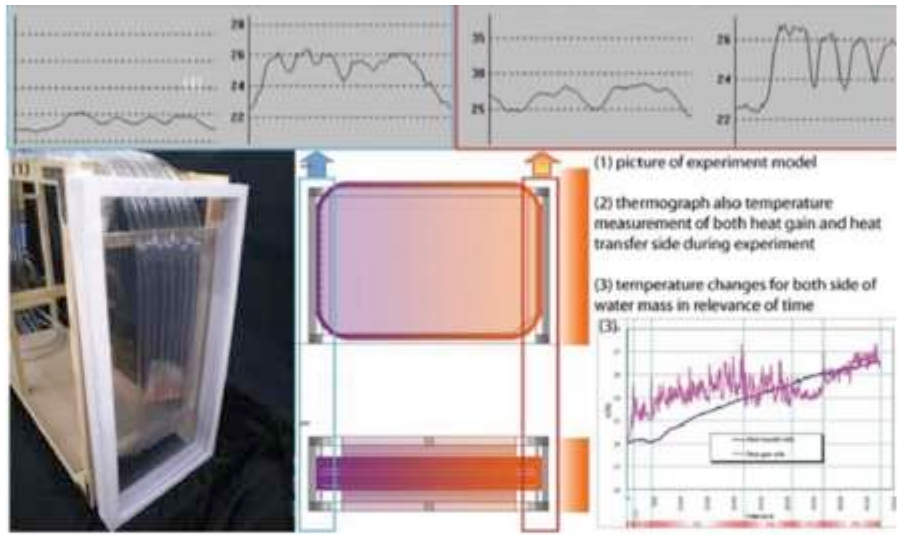
To investigate the possibility, whether such structure can be built without complex monitoring and environmental technology, a test model was built in The University of Tokyo Department of Architecture. The final tests were conducted in the Budapest University of Technology Faculty of Architecture.

Thermodynamic model for the desired balance was planet Earth. Conventional structures are built as union of Mass and Insulation, and in case of energy, they work as our Moon. Earth however, achieves balance with one additional material, to assure Distribution also. Trans-structure design followed the same method: Mass was provided by plastic and wood, Insulation by air, and water was filled in for Distribution. Water throughout the structure was connected, to form one large fluid volume. The goal of the test was to prove, that such simple unit can work as a trans-structure: maintain balance without outer control, just based on the responses of the structure.

One vertical side of the model was exposed to constant radiant heat during the test, and facing walls were monitored for temperature changes. The system performed as anticipated: the exposed area started to warm up, but soon experienced drops in temperature, as the other side toke and stored the heat surplus.

The conducted test is not only important, because it proved that the thermodynamic model of trans-structures could be realized. Union of the different materials in the structure redefines design thinking completely, not only because time enters as an important reference, but also because this way trans-structures introduce materials in completely new context. The constant change not only redistributes energy and matter all the time, but also may change its role in the actual balance: a heater volume can become storer later for example. This eliminates the basic stable state and function of building constituents, and leads us to the question of Multifunction.



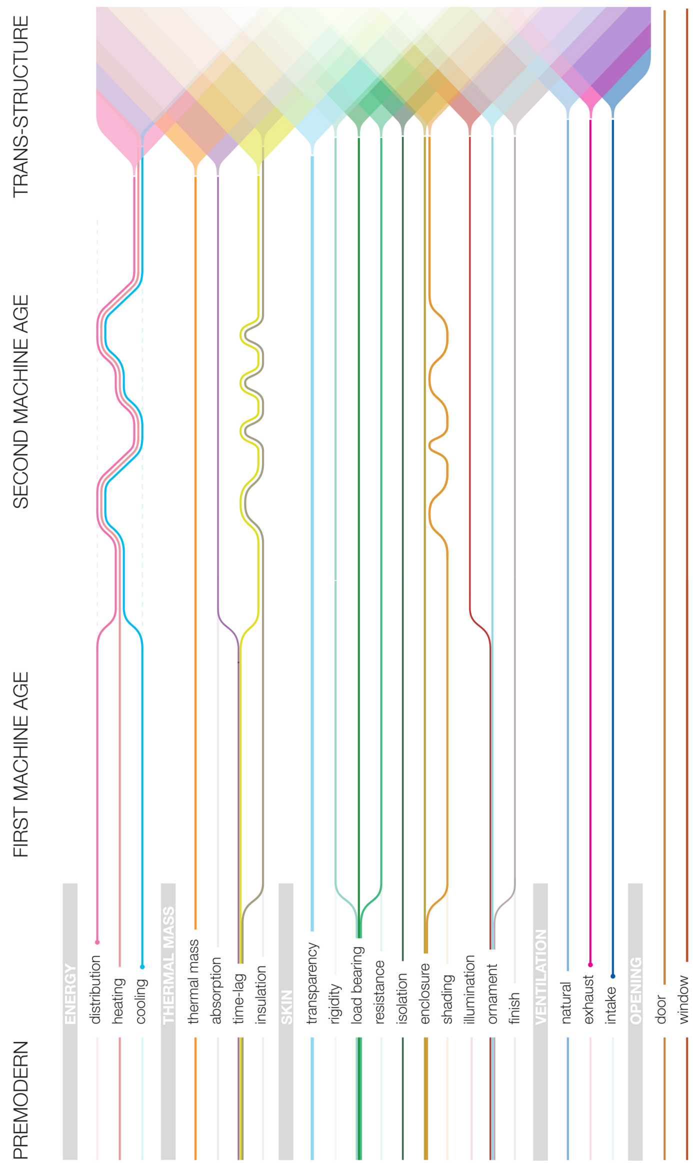


I/3. Multifunction – One piece Tetris

Despite all technical development, building elements are still mono-functional today: for each new task or demand always a new element is added. This method has been used also for sustainability: energy efficiency is often only achieved with new attached elements, while material use is often neglected or considered to be minor issue compared to energy consumption.

Perpetual state of change requires different solution than simple assembly of mono-functional constituents: a wall in trans-structure is not only a boundary or support, but also a heater or cooler when necessary, and also can act as a heat collector for example. This is because Multifunction is not simply a byproduct of trans-structure, but also a necessity: rapid response is an important factor for balance and stability, which union of mono-functional elements cannot assure properly, because only changeable structure can produce responses instantly on scale of the whole building. Furthermore, the cooperation of mono-functional elements would also require high-tech monitoring, and compromises are inevitable. In case of a changeable structural core, this ideally happens naturally, and the assembly is like playing Tetris with only one unit.

Multifunction is not only important because its energy efficiency. It can affect and change fundamentally different aspects of building, and above all, it has the potential to provide new solutions for architecture: conventional elements (like shading) can be united with the structural core or simply eliminated, also leading rules of design (like orientation and solid-transparent proportion of facades) become obsolete and completely reinterpreted: north and south facades or glass house and insulated box becomes equal in sense of energy and thermal comfort.

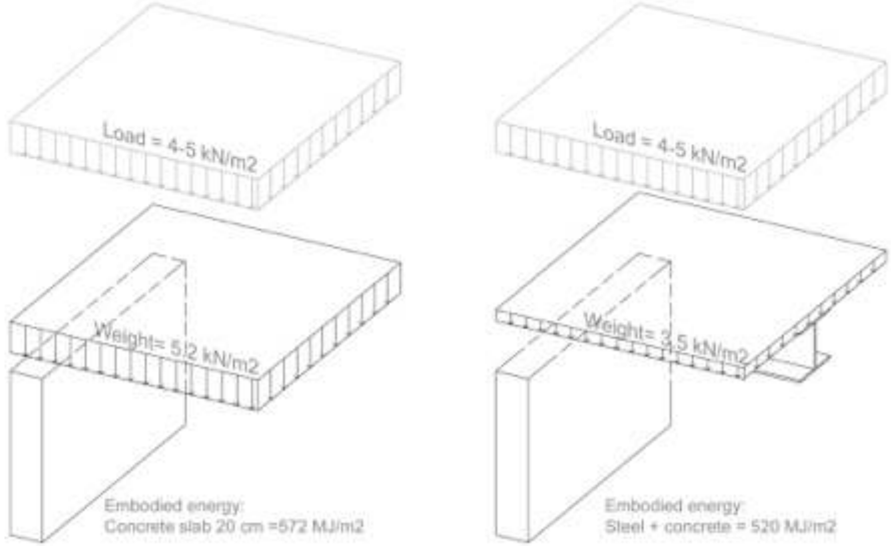


I/4. Dual Loop: Hybrid and Fusion

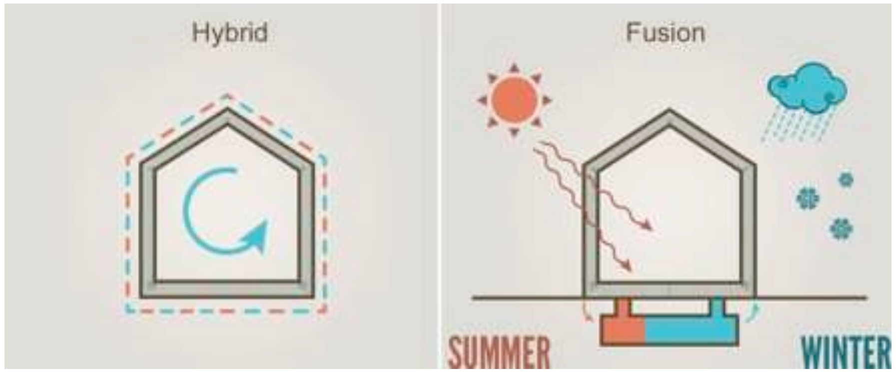
The choice between Light or Heavy construction is inevitable for each building. Both have benefits and drawbacks, but the decision is already a compromise itself. Additionally, when it comes to embedded energy both have limited efficiency, despite many would think of light construction more sustainable. Thinking of weight only, it is valid to ask ourselves, why we build concrete slabs with weight of 5-6 kN/m2, when their sole purpose is to carry only 4 kN/m2. But we also should not forget, that embedded energy of steel and aluminum is 18 and 144 times more (in MJ/kg) then that of concrete.

Both dilemmas however are valid only for conventional structures, since the main characteristics are set in the beginning and remain constant after construction. Trans-structure's constituents however belong to two separate groups: core and medium. The reason for this distinction is simple: solid core is always responsible for the stable properties (like geometry and volume) while the medium is utilized to assure the capacity of change: modify the mass from light to heavy or switch it from storer into a consumer or the opposite. Practically the built examples show 2 main ways to achieve this.

<u>Hybrid:</u> The first method is to embed the medium into the new structure. This way the structure's weight changes during construction because the medium only enters the solid mass in the last stage, which unites the advantages of both building methods: light during construction and heavy while in operation. Hybrids can be connected to external storage in addition to conventional energy source. This case the captured heat can be stored to profit from the from the heat surplus. A house practically becomes a heat trap and stores the heat gains instead to close them out. Allwater pavilion, an experimental house works exactly this way.



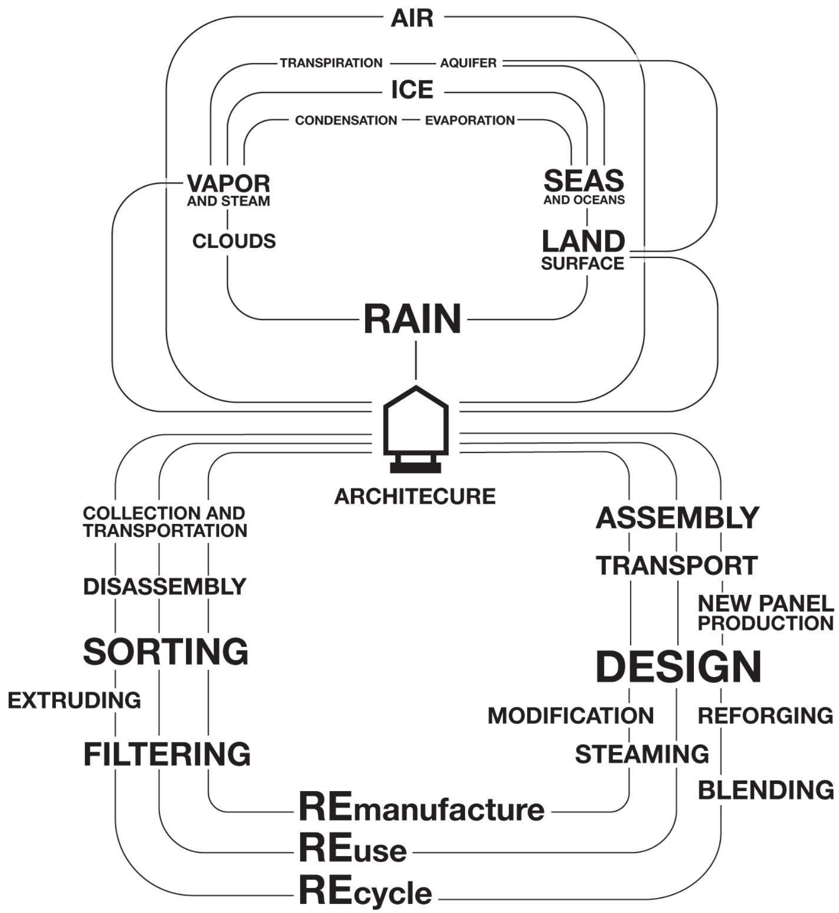
Weight may be different for steel or concrete construction, embodied energy does not change proportionally.
Trans-structure's medium is made by natural materials (air or water) which lowers embodied energy considerably.



Fusion: Another method is the union of the structure with surroundings. Stone plants (Lithops) in South Africa follow this method, when use the soil to store more heat that they could alone. In case of such solution, solid shell and medium can both be lightweight, because the main mass of the building is provided by the storage connected to the medium. A good example for that Memu-Meadows designed by Kengo Kuma and Associates. The experimental housing reinterprets the traditional way of heating called Chise: the central fireplace burns constantly and in case of heat surplus, the structure stores the heat in the ground below the house. Later, when temperature drops, the heat returns to the interior to maintain stable temperature. To assure ideal microclimate, air flows in the whole perimeter surface as medium, and heating in floor also warms the air layer in the walls, which is connected to another heat storage zone in the top.

Trans-structure unites the advantages of Heavy and Light construction and also decreases embedded energy. Duality of core and medium is ideal for recycle, because the materials are kept separated at all time. The medium can be part of natural material circulation: water or are is only "lent" from the environment, while core can be recycled. Material circulation for trans-structure is a dual loop, in which the two materials are united for sake of the building only and returned to industrial or natural circulation later on.

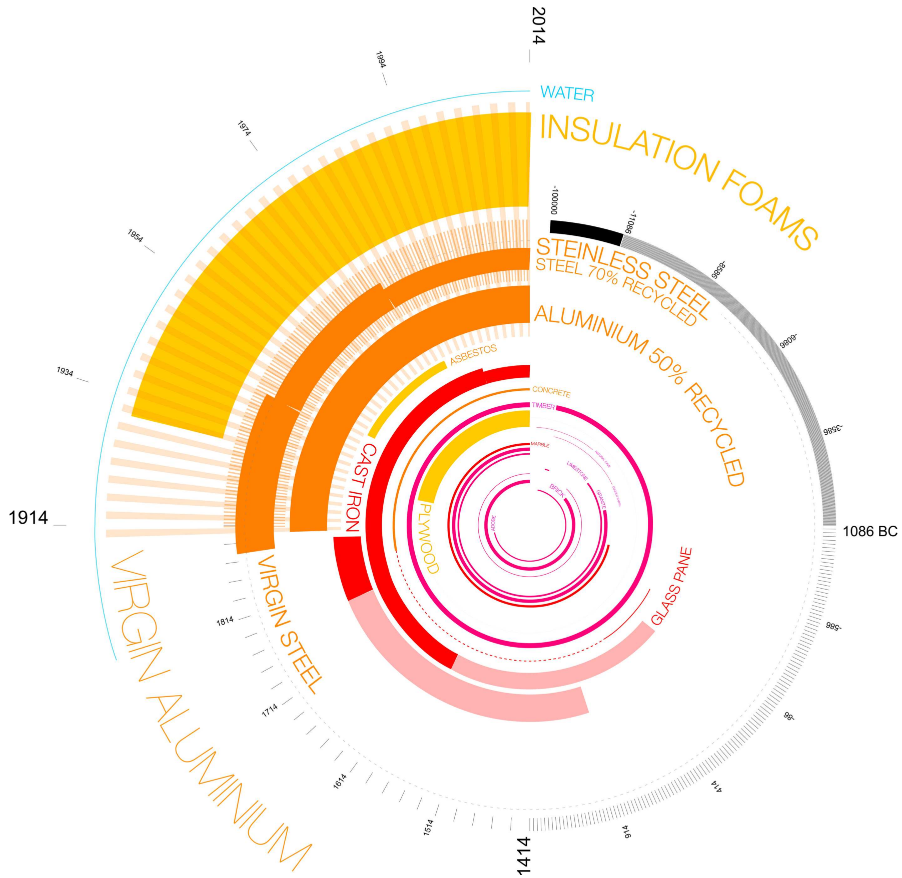
The duality of material use brings another important benefit. Since the structure is separated into two constituents, the structural requirements can be split between them. Conventional structures have only one material to be responsible for all the demands: heat storage, load bearing, fire-resistance, acoustics etc. In case of trans-structure each task can be given to one of the constituents therefore ideal materials for different tasks can be selected.



I/5. Energy: Consumption and Matter

Operational energy demand and embedded energy of building materials are not only essential for sustainable architecture but are also related to each other. Operational energy has been minimized typically by utilizing more material in the past (i.e. more insulation), although these new building materials had higher embedded energy demand compared to structures in the past. Passivhaus method invented in Germany is a perfect example of this approach, when focus is on almost perfect isolation of indoors from environment to minimize operational energy needs. Active house designs seem to be opposite of that at first glance, since environmental appliances (like solar panel) reduce energy consumption. Regardless all differences between the two methods, when it comes to total energy impact, both face the same dilemma: since embedded and operational energy are inversely proportional, energy savings are limited because in order to lower the former we have to increase the latter. But again, the problem is with the model and not with the structure.

Trans-structures are union of solid core and medium. The former is recyclable product of building industry and the latter is always natural material, which is only lent from nature for the sake of the building. Unlike building technologies, the structures of nature present us a design logic, where 'material is expensive and form is cheap'. The distribution of building envelope's functions between two different constituents takes a step from conventional technologies into this direction. The solid parts this way can be designed for recycle, while the medium provides mass for the building envelope at a very modest energy costs, since the materials are not only available already on the site, but also can be released back to nature later.



II. Memu Meadows
II/1. Interview: Takumi Saikawa (Kengo Kuma Architects)
II/2. Archaic to contemporary: Memu-Meadows house

This experimental house in the harsh climate of North-Japan is a unique fusion of local vernacular architecture knowledge with contemporary design and latest building technologies. The cooperation of Kengo Kuma and Associates with the Institute of Industrial Design at the University of Tokyo made a new building type possible, which takes advantage of the Chise model of ainu architecture, and combines it with new building materials and structural system. The result is a reinterpretation of the archaic, which has not only effect on thermal comfort but also drives design and creates extraordinary atmosphere.

The traditional house of Chise utilizes the thermal mass of the ground below the building, the central fireplace is also sunken below the floor to increase the storage effect. Memu Meadows takes a further step on this path: in addition to the central fireplace and soil storage, the walls and roof became even lighter, and all perimeter surfaces are united by an air layer embedded in the structure. The air layer becomes the medium of the trans-structure: carries heat from one location to another when necessary, distributes the heat coming from the ground, and finally, also stores heat in the increased air layer of the roof structure. This innovative solution is also combined with a translucent insulation, so the house remains strongly connected to its surroundings in sense of both energy and natural light. The house and the interior opens up when the sunlight enters in the morning through the translucent skin, and gradually turns into itself by the end of the day. In this manner the house reconnects us with nature and aims new lifestyle and architecture the same time.

III. Water-branch house

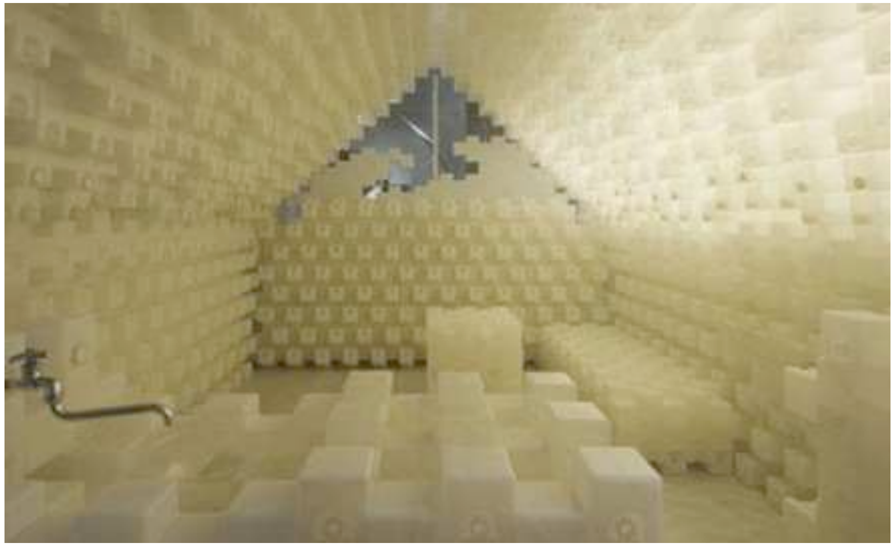
III/1. Interview: Tomoko Sasaki (Kengo Kuma Architects)

III/2. Stream construction: Water-branch house

The idea of building a house by plastic bricks filled with water was designed by Kengo Kuma Architects originally for temporary housing. The plastic brick assured easy assembly and reuse, the water provided an accessible thermal mass and insulation for ideal indoor comfort.

The idea was later developed in the office to Water-branch and exhibited in MOMA New York. Finally, a temporary house was built in Gallery MA Tokyo, for 'Kengo Kuma: Studies in Organic' exhibition. The plastic-water bricks not only provided the structure of the house, but also heating/cooling and insulation for the space. The bricks were connected to each other, and formed a stream, which flows from floor through the wall until the roof of the building. Connected to geothermal heating and cooling, available almost any location in Japan, the structure formed an ideal fusion of lightweight structural core and water medium, with limited capacity of trans-structure: responses to environmental condition by utilization of external energy sources. External effects were counteracted by the considerable thermal mass capacity first and in case that proved to be insufficient, geothermal energy covered the additional demand.

This solution was not only important for the energy concept of the project: the final goal was to define a self-sufficient housing system, which is capable to aim for a different lifestyle in Japanese archipelago, which is traditionally dependent of Tokyo and its centralized services. This way Water-branch not only defined a trans-structure system by the union of water and plastic shell, but also was capable to profit from the potential of new structural system to define new lifestyle and spatial atmosphere.



IV. HygroSkin
IV/1. Interview: Prof. Achim Menges (Univ. of Stuttgart)
IV/2. Embedded responsiveness: HygroSkin Pavilion

HygroSKin and the research work of Prof. Achim Menges is an excellent example how a challenge can be turned into advantage instead of working against it. The inspiration for the project comes from biology: the hygroscopic behavior of was the model to develop a response-able perimeter skin for buildings.

Conifer cones change shape depending on moisture and this property was used to develop a building skin, which can control ventilation and shading in interior space. With decreasing sunlight and humidity, thin wooden layers of the skin open up, and when later the air returns to normal, the surface also closes gradually. The solution has various advantages at the same time: changes occur gradually without additional control, monitoring or energy demand, because the external effects modify the skin directly, which also makes the responses proportional to the changes in the environment. After several prototypes and a temporary construction, the research on HygroSkin recently built the first pavilion in Stuttgart and now develops change-able construction elements and systems for projects on a larger scale.

HygroSkin project represents a trans-structure, which not only embraces change, but also takes advantage of it. The trans-structure crated by responsive perimeter skin is an effective tool for desired stability, and it is also source of inspiration and an element that redefines architectural space from static and homogenous experience into a dynamic spatial atmosphere. This section includes a description on the ongoing research projects and also an interview with Professor Achim Menges, the leader of the research.

V. BIQ house, Hamburg

VI/1. Interview: Jan Wurm (ARUP Germany)

VI/2. Responsive instinct: Algae powered bioreactor façade

The research to create the first bio-responsive façade started in 2009 with the collaboration of the Austrian architect office Splitterwerk and the engineers of ARUP Germany. The important innovation in field of building materials opened new possibilities for energy production on building facades: the structure made by algae embedded in translucent water-plastic perimeter panels both profits from the caught heat energy and from the created biomass, which is constantly harvested from the panels to produce further electric power.

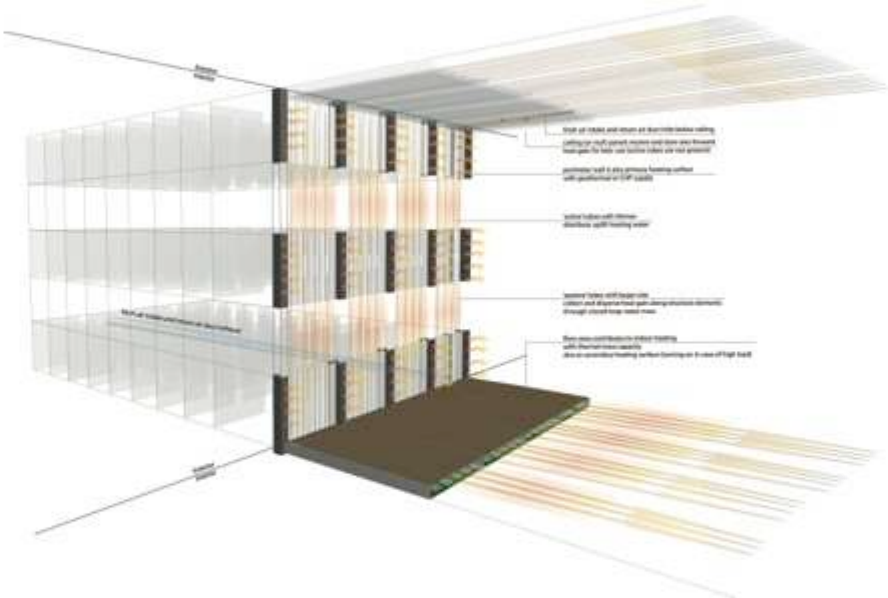
BIQ was the first pilot project to attach about 200 m2 on a residential building in Hamburg, Germany. The algae content in the panels changes all the time depending based on external conditions, therefore it represents the first example, which case the state of perpetual change is achieved by biological process instead of properties of simple matter. Although the bioreactor façade of BIQ project is united with a conventional perimeter structure this case, it still works as a trans-structure, but in the opposite way then the other examples shown here: instead of manipulating with the interior to assure stability, the external effects are taken at the perimeter already; to maintain stability indoors. The properties of the façade elements (insulation or absorption capacity) depend on the algae population, which increases or drops depending on environmental conditions. This however not only affects biomass production, but also solar absorption for example, which inherently increases heat energy production and insulation capacity at the same time. In this manner, unlike the other examples, trans-structure not contains the stable indoor area, but simple wrapped around it for the same effect.

VI. Water House pavilion
Planet Earth as building model: Water House pavilion

Water House pavilion is an experimental construction, which aims new strategy for sustainable building, based on the thermodynamic model of planet Earth, where air, soil and water are united to provide insulation, mass and distribution. Water is filled in all parts of the structure; in both opaque (steel) and transparent (glass) panel units. The water volume is connected: wall, floor and ceiling works together all time for ideal microclimate, where air and all surface temperatures are perfectly maintained indoors. Furthermore, the building also works as a battery: the structure stores heat of summer for later use during winter.

This solution keeps energy consumption at a minimal level, and also presents a built trans-structure example, which case the capacity of heating/cooling + distribution is also extended with the property of long-term energy storage. Water enters in the last stage of construction to unite the advantages of Light and Heavy construction methods. Furthermore, energy distribution and operational control is based on the natural properties of the water as much as possible, to eliminate the need for high-tech energy control and monitoring: heat is collected in the lower area of the building and creates a constant flow moving upwards, where it is finally taken to the external storage. In winter the same process occurs in the other way around.

The design was based on 7 years of research and laboratory tests. Description of the building includes the introduction of the tests and the results, the anticipated building model and the final results of building monitoring after completion.



VII. Tea-water pavilion

Bricks are drops: Tea-water pavilion

Tea-water pavilion is the third stage of 7 years of research on Water House thermodynamic model, which started originally in The University of Tokyo. After the theoretical model, the first water structure experimental house was built in Hungary as the second stage of the project; and currently Tea-water pavilion is designed in The University of Tokyo. The structure is to be built until the end of 2014 in the university campus. After completion, the small pavilion will be offered for the people who lost their homes by the Fukushima earthquake and currently living in modest temporary conditions. The small building will be there for 2 years and constantly monitored during that time.

The function of the small structure is a Tea pavilion, which can be later shared by the people in Tohoku area. The size of the building is is 4.5 tatami mats, which is the area of a traditional chashitsu or Japanese teahouse.

Designed as a trans-structure, thermal comfort is achieved by the perpetual state of change in the building: solar heat gain is absorbed by the opaque areas and stored for later use, which not only assures comfortable microclimate during summer, but also makes the gained heat the primary energy source for winter heating. To achieve this, the model of trans-structure is pushed towards its limits: although the climate would normally require, the small experimental house is designed without any insulation, to assure balance and stability solely based on response-ability.