The Motile Fluid House (MFH) -
An Infra-free 2030 Design Scheme

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Abstract

Current housing technology divides our 'homes' between *a passive protective shelter* that isolates the occupant from the environment while providing limited visibility, mobility and tactility, and *a centralized infrastructure system* that provides all of the user's needs that are normally satisfied by interacting with the terrestrial environment. Proposals on future housing architectures deal mostly with interactive interior solutions using sensors and monitoring technologies, but the house still remains an idle protective enclosure seeking isolation rather than becoming an active part that mediates interactions with the environment.

MFH concept proposes an autonomous alternative architecture for the future; modeled after normal terrestrial interactions with the environment in which the house actively intercedes life support processes to reduce the need for centralized infrastructure. It deals with innovative material, energy and system integration and control technologies; increasing both the interactivity of the building skin with the user and the environment. The house no longer exists in a single state, but resides in a motile fluid state changing and adapting to the comforts of it's user and the state of it's surroundings. MFH components flow as a cohesive structure blurring the reality of inside and outside, and redefining the way the user interacts with everyday objects and spaces. Efforts have focused on proposing and investigating potential and critical concepts for their application to the housing industry. Continuing advances in material sciences and technologies addressed in this paper are expected to mature by 2030.

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1. Introduction

The primary object of MFH concept here is to determine the extent to which the concept can be applied to all aspects of future housing design to reduce or eliminate the need for externally supplied expendable materials and equipment and to increase the freedom and effectiveness. In present housing, the structure serves only as a protective barrier between the user and environment isolating the inhabitant from environmental conditions. This effectively prevents all of the normal mechanisms by which we reject metabolic waste products to our environment and regulate our comfort, forcing to use of an centralized infrastructure to provide these services and supply the energy necessary. The MFH concept reserves this paradigm by applying emerging materials, chemical technologies, biomimetic and miniaturization techniques allowing the habitat to control the transport of energy and materials. This can permit the user to interact with the environment in a manner closer and drastically reduce the need for centralized infrastructure.

2. What is Infra-Free?

Infrastructure consists of interconnected elements that provide the framework for supporting the entire system we inhabit. They provide basic facilities, services and installations needed for the daily functioning of our communities. Today, we primarily rely on *centralized infrastructure* to organize and manage our complex systems of flow, movement, and exchange forging an obvious reliance on its constant supply.

Infra-Free (Infrastructure-free) is the concept of not having to rely on centralized infrastructure. It also embodies a new way of thinking about existing objects and technologies to enable us to be more *self-reliant*. With the current paradigm shift toward information-based technology, digital production and mobility there is an opportunity to expand towards an **infra-free architecture**. Research conducted through the IF project seeks to integrate smart, technologically and biologically inspired, or other unconventional approaches to lead to aggressive improvements in the efficiency, versatility and safety of future architecture. The foundation of this multi-disciplinary project is research on smart materials and construction systems associated with micro-electronics, environment protection, sensing and real-time adaptation to system changes as shown in Figure 1.

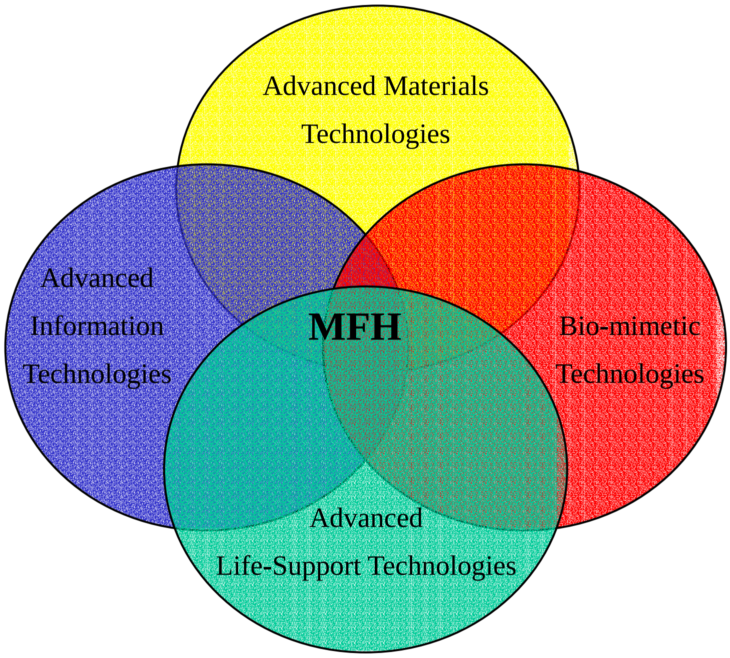

Figure 1: MFH concept is centered in the convergence of emerging technologies

2.1 The MFH Concept

The MFH concept is rooted in a technology revolution driven by the synergy between emerging information technology, materials technology and biomimetic design concepts and approaches as following:

- Engineered and bio-mimetic materials; inspired by and emulate biological materials.
- Energy conversion and transport materials; capable to convert energy between light, heat and electricity.
- Integrated advanced life support systems to minimize or completely avoid the reliance on centralized infrastructure,
- Mechanically active materials to enhance protective and mobility performance,
- Chemically active materials; reducing required hardware and materials for life support,
- Energy harvesting to capture incident solar and other energy sources, and usable portions of metabolic waste heat and storage techniques.
- Energy storage systems; contemporary energy flow, distribution and storage concepts.

Success of MFH project will depend on the future development of multiple advanced materials and technologies that are beginning to emerge, illustrated in a preliminary roadmap shown in Figure 2.

Figure 2: MFH2030 Concept Evolution Roadmap

	2010			2020		2030
Concept Evolution	**No-Expendables**	**Integrated Heat Pump**	**Self-Fitting Shelter**	**Integrated Life-support**	**Energy Generation**	**Infra-Free Systems**
Enabling Technologies	Smart Polymer MEMS Wearable Electronics	Polymeric Thermo-electrics Micro-turbines/ Micro-channel	High Force Active Polymer Advanced Join Designs	Chemical Transport Smart Polymers- Selective Membranes	Polymer Photo- & Thermo-Electrics Advanced Energy Storage	Biomimetic Technologies Artificial Photosynthesis
Research Needs and Directions	Active Polymer Space Environment Tolerance High-Performance IR Electrochromics Fabric- MEMS Integration Large Scale Wearables Integration	Advanced Energy Concepts Flexible, Light-weight, Thermoelectric heat pump Efficient Integrated Micro-Fluid Systems	Electro-Active Polymer Molecular Design Advanced Structural Design and Modeling Controlled Anisotropic Materials	Chemically Enhanced Transport Membranes Transport Control Mechanisms Integration with Active Polymers	High Efficiency Photo Conversion Broad Spectrum Photo-Energy Capture High-efficiency Thermal Energy Conversion	Extended Life Metastable States Enhanced Charge Transfer Low-Energy Cost Reactions

The development and characterization of specific implementation concepts is central to our study of the MFH concept. Its application to housing industry is multi-faceted involving the incorporation of many candidate technologies to numerous life support, protection and mobility needs; increasing the number of possible combinations as described in Table 1. These are not an exhaustive set, but are intended to present a reasonable survey of the possibilities that can be foreseen in this approach.

Step	Technology Basis	Perceived Benefits	Comments
1	Wall-integrated heat pump	Make use of waste heat, increase operating environment	Applies emerging thermoelectric materials or micro-machines. Thermal energy harvesting limits battery size.
2	Step1 + wall membrane transport of waste gases and humidity	Eliminate air-revitalization systems	Design of integrated life-support systems of space stations offer system design solutions.
3	Step2 + active shelter fit materials in walls	Improved fit and mobility	Requires increased material active stress capability. Reduced wall surface area increases membrane performance demand.
4	Step1 + active shelter wall materials for mechanical pressure design	Enhanced mobility. Enhance safety for small tears and punctures. Better heat rejection performance.	Limits wall life support options by eliminating vent loop contact with most wall surface area.
5	Step3 + Photo-voltaic energy harvesting	Reduced battery size, reduced system impact on energy systems	Sensitive to different environments, but excess energy available for most units.
6	Step5 + water recovery system	Elimination of sewer. Energy recovery from solid waste	Energy control and transport challenge. Sensitive to environment.
7	Step 4 and 5 + integrated electrochemical and biomimetic recovery	Reduced mass and volume for storage. Reduced logistics and more mobility. Independence from centralized infra.	Mass transport between wall layers an issue. Uncertain energy balance feasibility. Sensitive to environment.

Table 1: Possibilities of combination reflecting the range of demands on constituent technologies and resulting system capabilities.

These combinations provide the starting point for more detailed definition of functional schematics, design approaches and technology development. The points of departure for the development of top-level concepts exist. From these, possibilities intend to present a reasonable survey of applications reflecting the range of demands or constituent technologies and resulting system capabilities.

4. Emerging Technologies in future housing industry

With new technologies constantly being invented in universities and companies across the globe, the transformation in our computing, medicine, communication and energy infrastructure will affect our lives and work in revolutionary ways- whatever next year or next decade. Mechanical systems, which are combined with electric components and software that can identify and correct flaws in real time to ensure the overall system functions as intended, already exist in aircraft and photocopiers. The falling prices of both microprocessors and sensors make them ready for prime time in the housing industry. These ideas have already been introduced to housing industry through many projects, usually as interactive interior arrangements using sensors and monitoring technologies.

One field, which remains here untouched, are new materials and devices which will be created incorporating innovations inspired by nature to answer critical needs in construction industry.

By mimicking nature's designs and incorporating synthetic or natural components as well as self assembly-based fabrication techniques, it will lead us to intelligent materials and machines that will change medicine world and manufacturing as well as construction industry and housing. These ideas can be grouped in three categories:

- Super-smart
- Super-light

4.1 Super-smart

Multi-disciplinary teams from different research fields design materials, which can be customized with sensitivities to signals such as heat, light, impact, pulses of electric currents and motion. While chemists research the realm of the super-small with the mission to develop enzyme-like tools to construct super-smart self-assembling materials, tissue engineers are building polymer scaffolds that support the growth of human organs and tissues. Recent material research succeeded to develop polymers with embedded capsules full of 'healing liquid' that, upon rupture, self-corrects cracks in plastics and fiberglass. Self-healing and self-tightening structures could have a great impact anywhere synthetic polymer is used, from microchips to the wings on a full-size aircraft, and in near future, change the complete building process in construction industry.

4.2 Super-light

Aerospace engineers and architects, respectively, benefit enormously from the efficiency and versatility of porous gels and flexible films. In the realm of the super-lights, less is always more. A material's lightness is important to consider when designing such things as mobile structures, portable appliances, and fuel-efficient vehicles. With handheld electronic devices and electric cars, super-light lithium batteries are used in place of heavy lead-acid batteries; lightweight materials are especially critical for electric vehicles, since the point with these is to conserve energy. Carbon-fiber materials such as nylon and Kevlar, both light and strong, are commonly used for sporting equipment associated with speed, like car racing and cycling, and in the aerospace industry, where aerogel does most of its work today. Aerogel is as much as 99% air and is typically made out of silica, but it can be made out of a wide variety of materials, including carbon and polymers. Although it is the lightest solid on Earth, aerogel is primarily used aboard spacecraft as a collection device for interstellar and cometary dust. Its pores and particles are smaller than the wavelength of light and it has low thermal and sound conductivity and high insulation properties. A block of aerogel weighing only 2g can support a brick weighing 2.5kg.

As the current science can move atoms manipulating matter at atomic scales, the question would be if mimicking biological, not mechanical, systems will lead us to an innovative pallet of materials. As computer chips become smaller, their tiny electrical connections are getting smaller too; enabling entire new materials and manufacturing methods to replace current technologies in current industries. These are the basic principles to develop a contemporary "house of future".

5. MFH System Concept Definition

To achieve all key concepts mentioned in previous chapter, an over-arching examination of the merging technologies as central of MFH concept is listed below:

- Integrated micro heat pumps to expand operating environment capabilities,
- Integrated 'chameleon' building skin,
- Integrated technology of mechanically active materials to enhance protective and mobility performance; chemically assisted transport and energy harvesting,
- Overall system integration and control.

5.1 Integration of Heat Pump

As mentioned in Table 1, the first step in MFH research is to integrate a heat pump system to make maximum use of thermoelectrics; a cascaded integrated thermoelectric module, interconnected by thermal stunts to achieve heat pumping as shown in Figure 3.

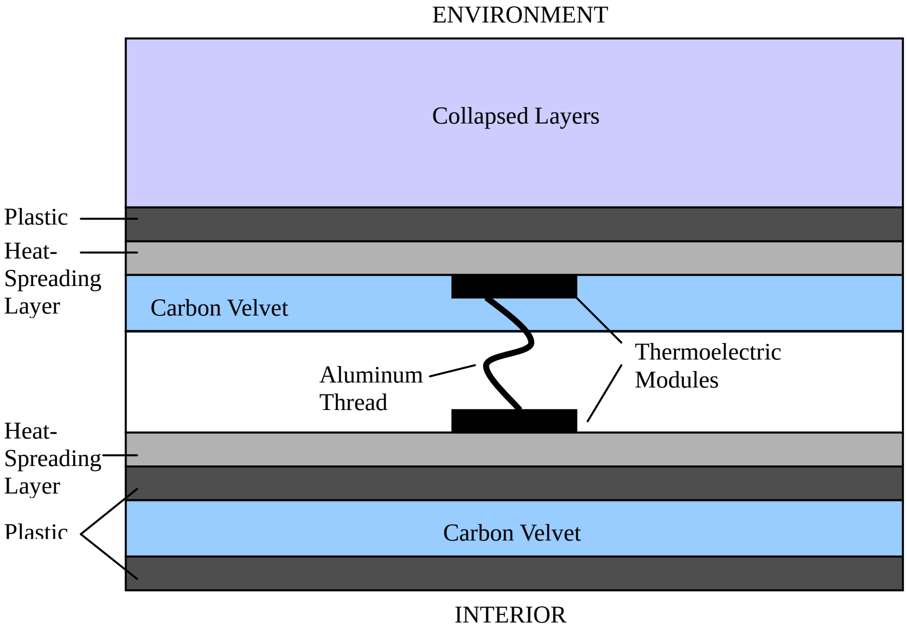

Figure 3: Integration of heat pump inside the building wall

The actual wall composes of six layers of plastic with membranes, polymer actuators and carbon velvet in between them. Two layers of heat spreaders were added, along with an aluminum thread to help move the heat from thermoelectrics out of the building skin.

5.2 Definition of 'chameleon' building skin

The building skin is the most important factor in this research as maximum efficiency and mobility is desired. In order to achieve a 'universal' design, the building is thought to 'ADAPT' itself to any kind of environment with minimum configuration changes similar to a 'chameleon' as depicted in Figure 4. Figure 5 shows a simple architectural concept of how a house interacts with environment through the change of seasons.

Figure 4: A chameleon's interacts with surrounding environment increases his survival chances

Figure5: Interaction between house and nature can be achieved through simple solutions.

MFH building skin consists of actuation mechanism polymer-based called electro-active polymers (EAP), which is due to an ion-exchange process between the conducting polymer and an electrolytic medium shown in Figure 6.

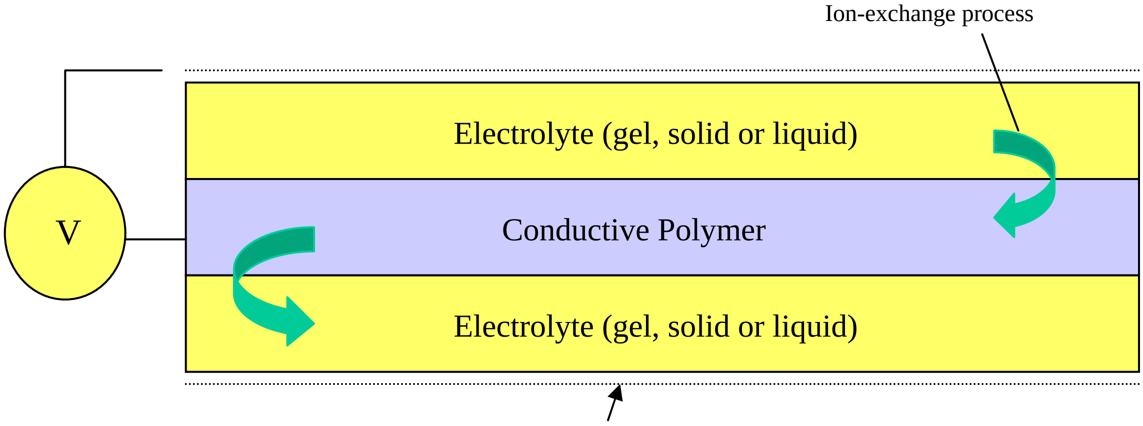

Figure 6: Functioning scheme of the proposed EAP building skin

The electrolyte can be a liquid, gel or solid. The actuator relies on ions from the electrolyte moving in and out of the polymer, which causes the swelling of building skin. The building skin is transformable and can be shaped upon application of an electric potential. In order to assure protection but at the same time also interaction with the environment, a textile-based EAP-building skin proposal is shown in Figure 7.

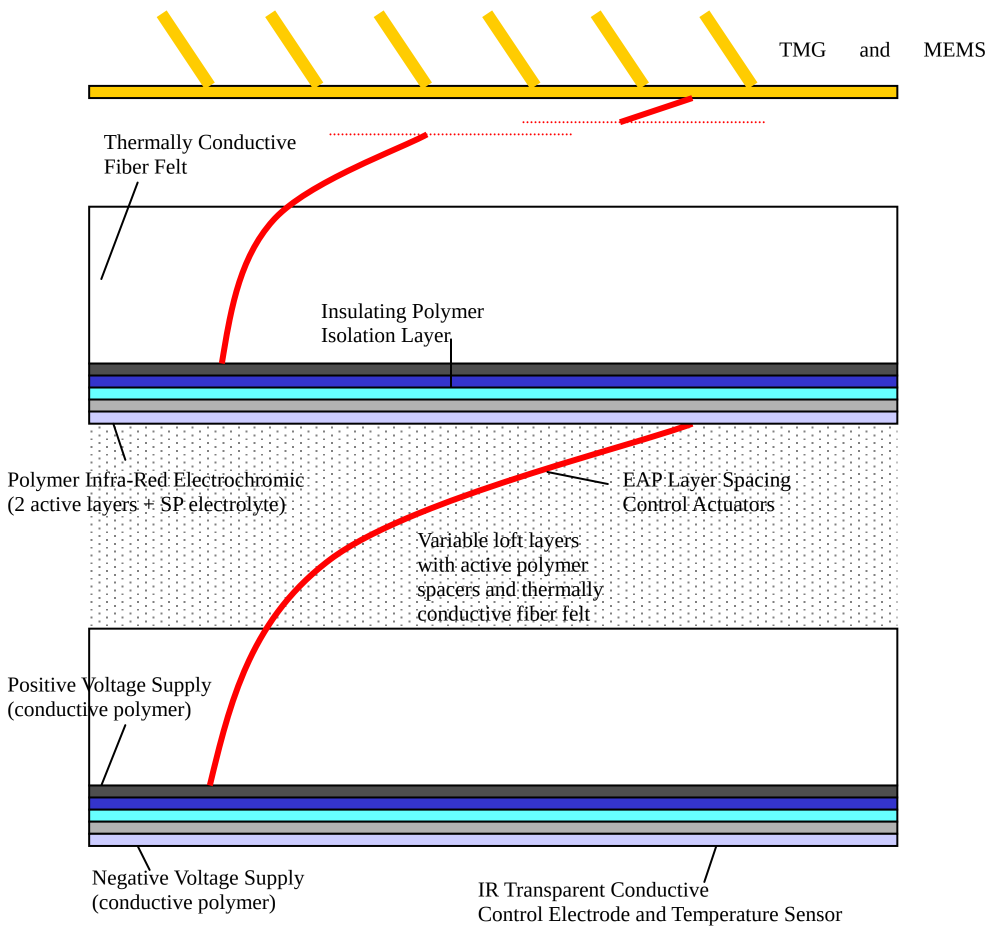

Figure 7: Effective thermal control using emerging technologies

5.3 Technology Integration

As technologies play a great role in achieving MFH concept; a detailed list of emerging technologies, their advantages and disadvantages, and application into MFH concept is listed in Table 2.

Technology	Advantages	Disadvantages	MFH Application
Engineered and Bio-mimetic materials			
Functional Polymers	Inexpensive Light-weight Binding & adhesive strength High-conductive	Technology focused as structural material, with limited attention to optical properties.	Incorporating ability to provide specific or active mass transport or which catalyze and participate
Nano-composites	Nanometer size Enormous strength Significant effects on performance characteristics	Nanometer size deformations affect strength. No manufacturing experience	Optimization in size and mechanical strength, heat transfer, electrical characteristics
Active-Shape Change Materials (Electroactive Polymers(EAP))			
Electronic EAPs (Dielectric EAP, electrostrictive graft polymers, electrostrictive paper, electro-viscoelastic polymers, liquid crystal elastometers, ferroelectric polymers)	Long Life in room conditions Rapid Response Can hold strain under DC actuation Induces relatively large actuation forces	Required high voltage (~150mV/m) Requires compromise between strain and stress No low temperature application	Shape control of large and lightweight structures, unique bio-mimetic devices, remote technologies, communication technology
Ionic EAPs (Carbon nanotubes, conductive polymers, electrorheological fluids, ioner polymer gels, ionic polymer metallic composite)	Large bending displacements Mostly bending actuation Low voltage	Do not hold strain under DC voltage Slow response (10-800ms) Low actuation force Difficult to produce consistent material Hydrolysis occurs if >1.23V	Application as actuators for pneumatic or mobility applications, variable form and adaptation capability to the environment
Energy Conversion and transport materials			
Thermoelectrics	No moving parts Can be made smaller and lighter No expandables	High production cost Poor efficiency	Maintenance-free system deployment, local thermal control
Polymer Thermoelectrics	Small thermal conductivity Low density Flexibility	Materials must be doped but doping decreases Seebeck coefficient, which has low merits	Deployment of thin and flexible thermoelectrical composites

Thin-Film Thermoelectrics	Scavenging waste heat Tiny layers increase integration possibilities	High operating temperature Overall end thermal conductivity low	High energy recovery, application on/inside building skin
Photovoltaics	Electricity from sunlight Aesthetics	32% maximum (low) efficiency High-cost	All kind of applications available
Polymer Photovoltaics (example: titanium dioxide cells)	Low-cost and low-temperature manufacturing Absorbs any kind of wavelength	6% maximum efficiency Thought as military application only	Wearable electronics, lightweight, compact, integration on building skin
Thin-Film Photovoltaics	Thin-film technology has big future	Still 12%-19% efficiency More funds necessary	Miniaturization, selectively transmissive coating
Electrochromics	Emissivity control without compromising weight and mobility	Requires more research in manufacture and insulation	Control the amount of heat and light passing through openings
Chemically Active Materials			
Selective Membranes	Continuous duty service, no regeneration	Mechanical properties needs more research	CO2 removal and water transfer using external skin
Artificial Photosynthesis	Energy and oxygen recovery from natural processes	Technology replicating the ability of natural photosynthesis	Closed energy-rotation circle with minimum infra requirement
Energy Storage Systems			
Primary Lithium Batteries	Great specific energy and power density	Special care and control while charging	Distributed power system development
Micro Gas Turbine	Energy from combustion gas Macro-scale used in aerospace	Nano-size application never experienced	Energy from waste gas, compact size application in housing
Fuel Cell Technology	High efficiency Reliable	Specific safety requirements	Providing necessary power for homes
Extended Surface Electrolytic Capacitor Technology	Electro statically stored charge. High capacity, unlimited life, easy replacement, simple	Lower energy storage density and variations in terminal voltage	Surge requirements where charge discharge cycles can be relatively short

Table2: List of emerging technologies for housing industry

Results of this technology development, will continue to support the ultimate viability of the concept, but also revealed areas where the present state of knowledge leaves substantial risk that some of the envisioned capabilities will not be successfully implemented within the target time frame until 2030. However, as mentioned in Table1, different steps of applications offer the capability for a building to gain more independence from centralized infrastructure, mobility and transformation, and most important, the integrated building skin forming not only comfortable living environments but also using the complete surface of structure as part of life-support system.

5.4 Overall System Integration and Control

Integration technologies are central elements in MFH concept, which requires active sensing and control devices distributed over the surface of the building skin. Study concepts entailing heat pumping and energy recovery functions increase the integration challenge by introducing new technologies and materials. In this sense, critical technologies will require multiple path implementation and traditional methods of buses, cabling and connectors will have poor reliability for MFH concept.

3 areas of requirements addressed in integration and control technology innovation are:

- *Infra-Free (Integration Architecture)*: Consideration of the interactions of MFH with user and environment leads to the conclusion that its design must include independent zones for many system functions. Much of the control of each zone should be driven by local variables that can be sensed and used directly. Distributed control architecture with limited reliance on centralized infrastructure could help in using the building skin more effectively while increasing mobility.
- *Environmental Considerations (Alternative Power)*: As environmental protection becomes more important in our century, future energy systems need applicable platforms, where power may be available from distributed energy harvesting systems in complex and largely unpredictable temporal and spatial patterns. System design choices in terms of distributing energy storage, location and type of energy will have a substantial impact on the specific demand placed on these technologies. Power control can be enabled with assisted mobility, mechanical-counter pressure systems, thermoelectric cooling, energy harvesting and the building as the storage system itself.
- *Sensing (Clever-Building)*: Sensing is required to provide the control of building systems; this includes the interaction of building skin with environment and the user. Monitoring technologies to understand user’s needs are achievable by applying sensors inside the building. An integrated architecture could not only serve the user, but also the building itself to respond to environmental conditions, enable data communications and coordinating control devices throughout the system.

5.5 Further Research

Current scenario integrates various technologies introduced in this paper into one system architecture shown in Figure 8.

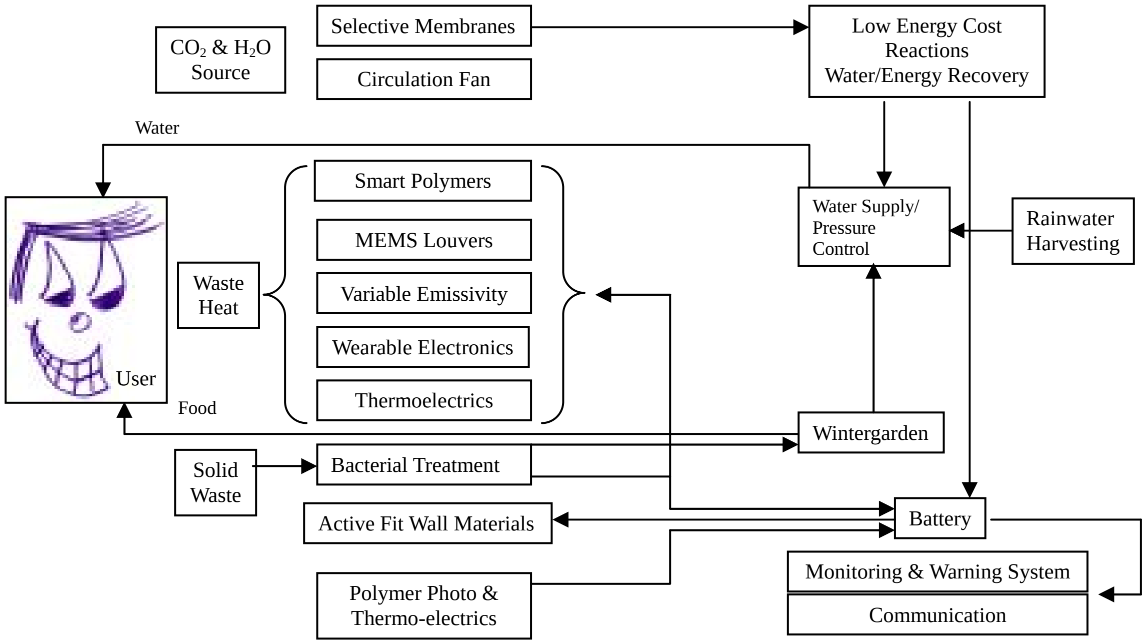

Figure 8: MFH System Integration- Basic concept in order to develop various scenarios

Further research will focus on developing various scenarios considering different technology integration architectures, their system analyzes and comparison like mass and energy balance, storage, mass transport, potential impacts and system robustness.

6. Conclusion

Throughout the history of humanity, there has been no big change in how homes were designed and built, except improving the structural quality and interior comfort. Most future house proposals focus on improvements in interior solutions, proposing a wide-network of sensors and monitoring technologies for more comfort and communication. But the house still remains as a protective shelter and such future technologies limit the user's mobility; the house becomes more protective in a sense of not only physical but also physiological aspects.

This paper addresses the issue that the 'future house' is not only the integration of innovative communication and sensor technologies for comfortable interiors, but also, adapting emerging technologies to form an interactive building skin as part of an independent and mobile system integration architecture. Many of the required capabilities of material sciences, biology, chemistry and electronics introduced in this paper are explored in university, industry or government research laboratories. Although some of them are still speculative at the present time, some other technologies are widely applied in computer and IT industry. Consequently, a research effort to ascertain and understand the current status and future prospects of required technology development efforts has been a main part of MFH research activity.

Acknowledgements

This research has been kindly supported by the Japanese Ministry of Education, Culture, Technology and Sports and Mizuho Foundation.