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Sensors In Buildings: Aadding Another Layer Of Expression In Architecture

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ADDING ANOTHER LAYER OF EXPRESSION IN ARCHITECTURE

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Master of Architecture Degree, 2012
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Abstract

Biological organisms, from microbes, to plants, to humans, survive in part because these bodies respond and react to changes within and outside their bodies. In order to function, these living things use sensors to read the environment and sense changes, and relay information back and forth. Sensors should no longer have one simple functional role but should be a node in an entire cybernetic network. By using sensors in a building, we can make systems more efficient, without losing effectiveness of their functions, allowing energy to be saved within an action and reaction feedback network, but more interestingly sensors can be used so that buildings can emerge with greater opportunity for expression and therefore user experiences.

Acknowledgements

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Introduction

Designers are currently limited to their use of traditional design tools such as colour and light to convey their intentions in the expressive qualities of their artifacts. Sensors allow them to design the matrix in order to convey those expressions more clearly to users. The utilization of sensors in buildings allows a new type of architecture to emerge, one that results in buildings that are poetic, which stimulate human senses, and use these sensors to involve themselves in those experiences.

The word "sensor" derives from the word sense, which means to perceive the presence or properties of things. A sensor is a device that detects or responds to a physical or chemical stimulus. Even though most of our experiences with sensors are with electronic devices, this technical aspect is not defined and therefore sensors can also be passive and use natural property reactions as a mode of communicating what is being sensed and actuate that response in different ways.

Definition of the word:

Organism

Pronunciation: /ˈɔːg(ə)nɪz(ə)m/

noun

1. *an individual animal, plant, or single-celled life form*
2. *the material structure of an organism*
3. *a system or organization consisting of interdependent parts, compared to a living being*

I have started this report with the definition of organism to clarify its use as a metaphor when speaking about the potential of sensors in architecture in my work. I put the definition of the word here so that it is clear that the relationship between sensors and organism in my proposal is referring to the third meaning of the word which is; “a system or organization consisting of interdependent parts, compared to a living being”. The only relationship between sensors and living organisms in my work is as examples of sensors in biology and their benefits.

Biology

Sensors are an integral part of all living systems. Our human bodily systems require sensors to function properly, and without them systems would fail, creating life threatening situations. The same condition exists for other eco systems and other biological entities, such as plants and animals.

For example, locusts have natural visual sensory-processing systems. These animals have potentials), prompt the locusts to take evasive action, and the entire process, from motion detection to reaction, takes about 45 milliseconds which allows constant movement and therefore constant collision prevention (Creative Commons Attribution, 2010). Another example of survival dependant on sensors is the snow buttercup plant (Ranunculus Adoneus), also known as the alpine buttercup. These plants use sensors to track the sun rather than tracking light. This process, called heliotropism (the daily movement of organs to follow the sun) is different than what most other plants have, which is the use of phototropism (turning towards a fixed light source). This sensor allows this and other arctic or alpine plant species to survive by maximizing their exposure to the sunlight, allowing them to take full advantage of the short sun cycles in these harsher climates (Galen, 2011).

Figure 2.1 - Locust

Figure 2.2 - Swarm of locusts

These life forms use and need sensors for their daily survival, and as humans we have the same requirement. As mentioned,

Figure 2.3 - Snow Buttercups

our internal body systems function because of sensors which relay information and physiological data through our nervous system. Our bodies operates because of the brain and its relaying of information with other bodily systems in reaction to external and internal sensors. The nervous system which acts as the mode of communication between these sensors and detectors, sends this data to our brain and relays reactions back in response to different readings and stimuli. As an example, when a cold breeze flows over our skin, sensors detect this temperature change and this data is sent to our brain which takes action of attempting to regain temperature and prevent more loss, by raising the hairs on our arms, or reducing the flow of blood to our skin. If the temperature is cold enough, the brain might also send signals for our muscles to begin contracting, known as shivering (Chiras, 2012). These responses and reactions have already been captured and imitated through thousands of different application methods. The typical thermostat used in most buildings is similar to that sensor on our skin, which relays information to the mechanical systems to take action in an attempt to balance the temperature change in buildings.

The majority of these inspirations have come from observation, meaning external influences, rather than studying entities as a whole, as a complete unity of internal and external elements and systems, which rely on each other to sense and asses responses.

Leonardo da Vinci's drawing of the Vitruvian Man, based on the works of Vitruvius, illustrated the correlations of ideal human proportions with geometry. This focus on the external should also reflect the internal systems which support those external forms. There are a number of internal human systems which all use sensors in cohesion with the external system of elements, and this unity of systems is one that is lacking in the majority of today's mechanical solutions.

Like our human systems, sensors need to work together harmoniously. A human body sleeping has very little visible movement, but in the invisible realm of operation, our nerves are firing electro-chemical reactions, blood moves through our veins, and air passes through our lungs. This system of parts working invisibly is what sensors do in a building traditionally. This thesis begins to explore the expressive potential of electro-mechanical sensors.

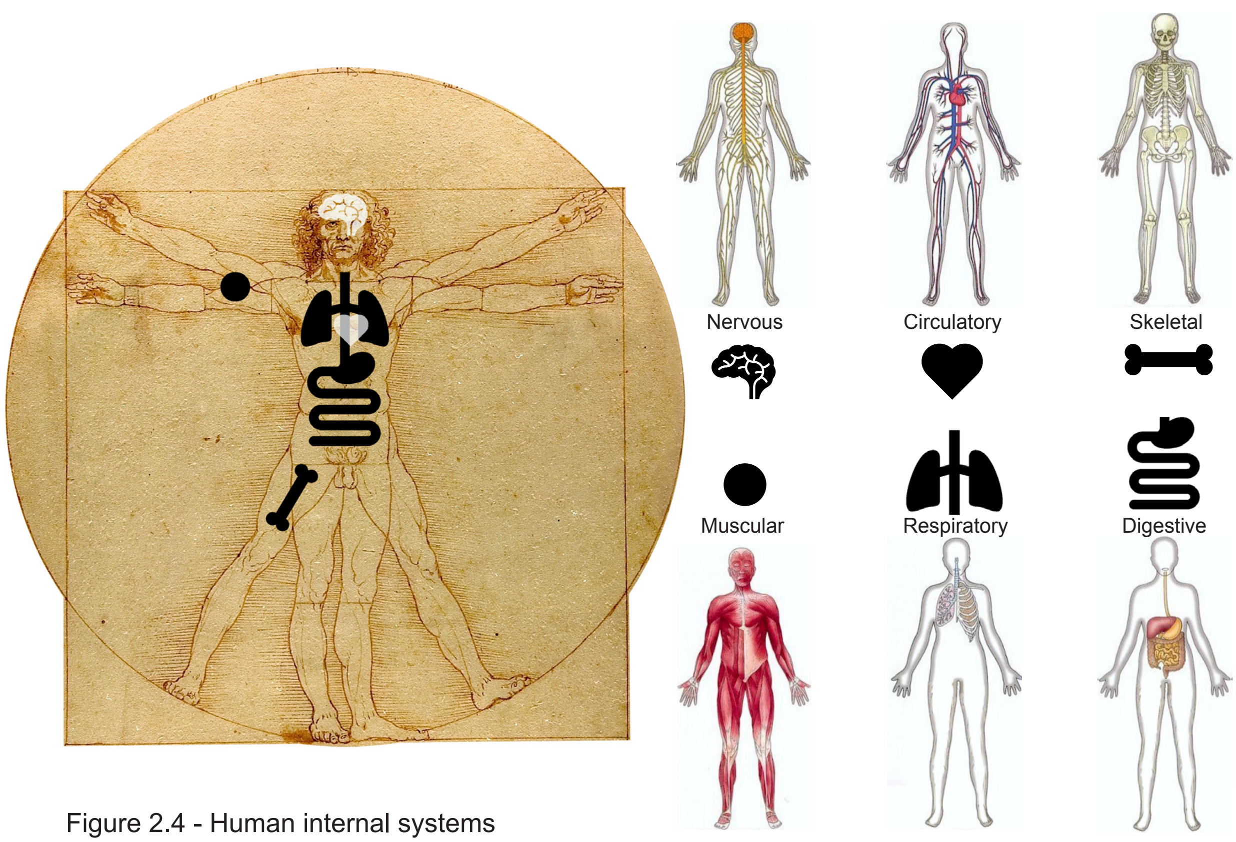


Figure 2.4 - Human internal systems

Biomimicry

The efficiency, effectiveness and beauty that designers strive for is a reflection of what nature has already accomplished. By studying ecosystems, organic life and other natural elements, the solutions to many design problems have been solved. One of the earliest examples of biomimicry and design solution is with the first attempts at human flight, in which humans looked at birds and tried to mimic them. Leonardo da Vinci would be the first to document this design thinking process, which was then furthered and realized by the Wright brothers who studied pigeons to perfect their design and successfully man their flying machine. By looking at nature, studying it and understanding how it works as an organism, we find design solutions that have been tested and proven for 3.8 billion years (Benyus, 2011). We also grow a larger appreciation and respect for our world and planet as we study nature and biology and incorporate aspects of them into our lives. We heighten our understanding of these entities through knowledge which creates more respect for the complexities that ecosystems and organisms have.

At Sogang University in Korea, a team of researchers have developed a humidity sensor which is inspired by the exoskeleton of the Hercules beetle, which changes colours naturally when exposed to different humidity levels. Within minutes, these beetles change their colour from black to a greenish yellow and back again. Even though, after sensing humidity, the resulting action of the beetle is displayed externally, the research team at Sogang studied the internal components of the organism to fully resolve the mechanism of this change. Their research has created a film type humidity sensor, which without the need of electricity, changes colours from blue-green (at 25% humidity) to red (at 98% humidity) (Kim, Moon, Lee, & Jungyul, 2010). (See Figure 2).

This type of sensor is what is categorized and described as a "passive sensor", which means that it functions without the use of any external energy. Another example of a passive sensor is a typical thermometer which uses the natural properties of mercury or alcohol to display a temperature reading. The material (mercury) is the sensor and its

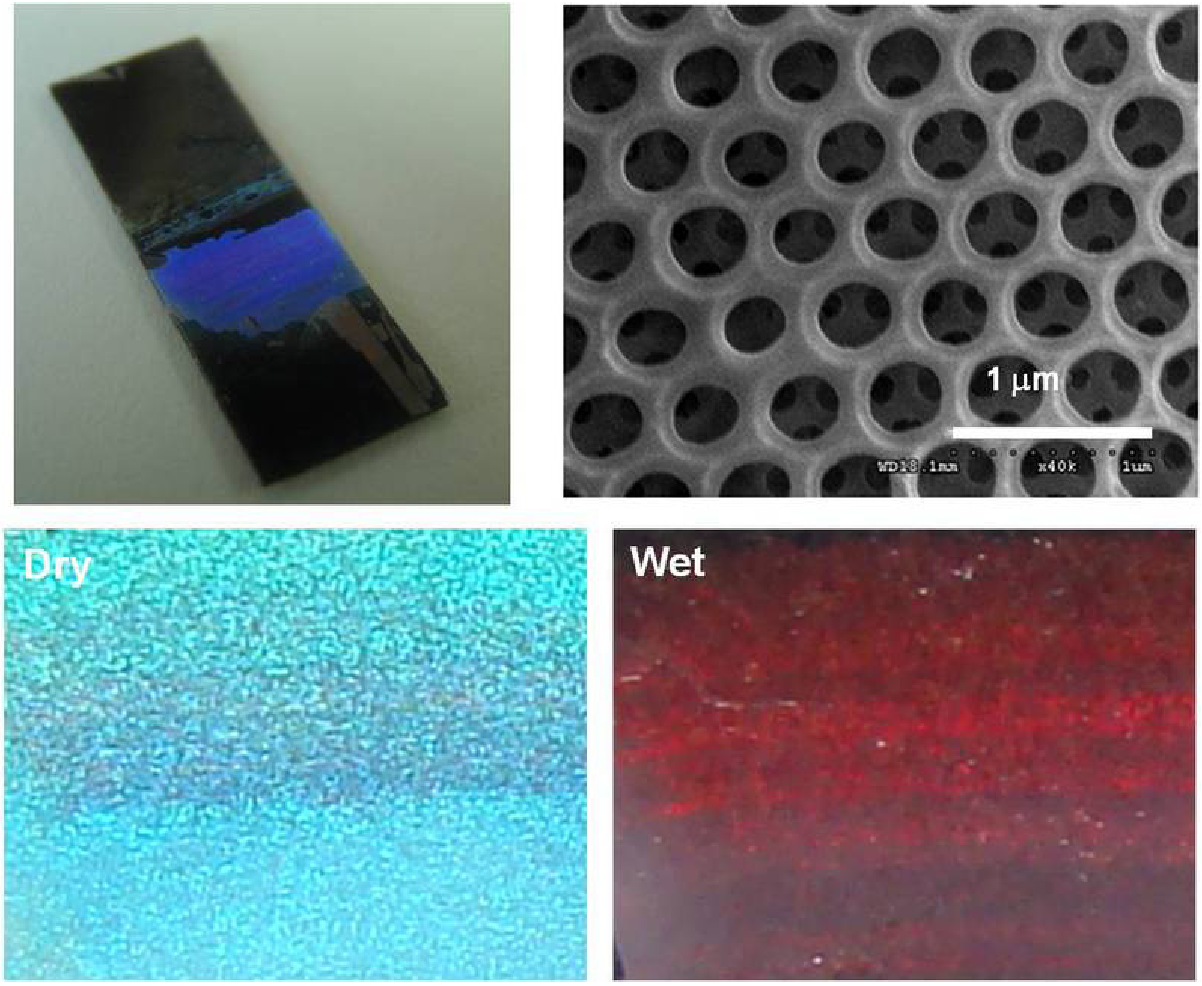


Figure 3.1 - Sogang University humidity sensor

inert properties of change (expanding and contracting) is the actuator. These passive materials are used in buildings as part of passive energy design principles.

Passive responses to design are a critical step in our progression to a world less dependent on non-renewable sources of energy. By implementing passive design strategies in our lives and elements of our lifestyles, we reduce our dependence on energy, and by reducing our energy usage, we can meet the remaining need with renewable forms of it. Nature is filled with passive strategies and we can learn from them.

In regards to building design and architecture, termites create massive mounds which utilize passive strategies for their survival. The sculpted mounds of hardened mud can reach up to 9 meters tall in extreme cases (Korb, 2003), and are considered as one of the most sophisticated and impressive of animal homes. In northern Australia, "magnetic termites" build massive mounds with broad flanks and narrow edges oriented North-South. The reason for this directional placement is not in fact a magnetic response, but climatic. Termites don't like the cold and can easily overheat, and therefore by building their mounds with this orientation, they prevent both cases. Going underground might be a logical solution for them because the temperature below is much more controlled, but because in this specific region it is known to flood, they therefore must live above ground in their mounds. Unlike these Australian termites, West Africa is where Nigerian termites create their "cathedral mounds". Unlike the magnetic termite mounds, these mounds above ground are hollow and empty. These insects do not need to worry about flooding, therefore they live deep underground, so why do they build these massive hollow mounds above ground? Termites store dead wood and grow fungus in their mounds as their food supply. This fungus does not grow anywhere else in the world but inside these mounds, and can only survive and grow if the air is at a constant temperature of 31 degrees

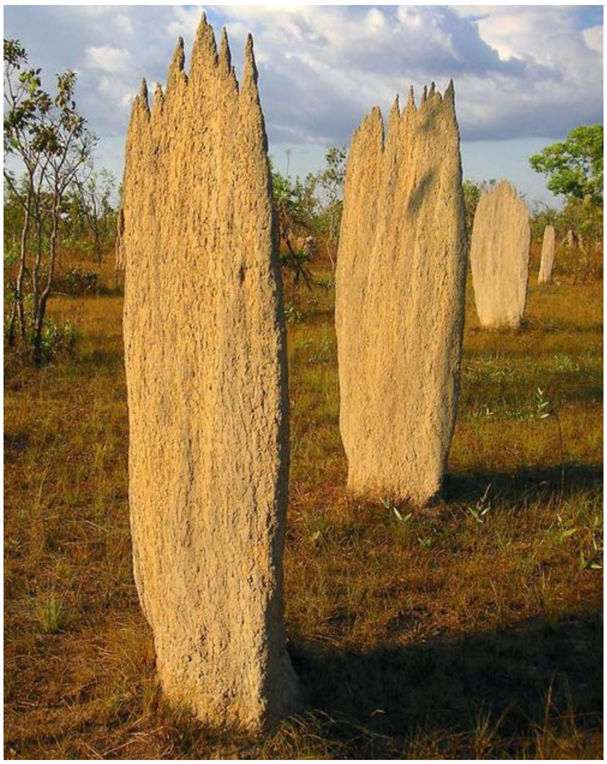


Figure 3.2 - Magnetic termite mounds, Australia

Figure 3.3 - African termite “cathedral” mound

Celsius. With a population of over a million and a half insects in each colony, the heat of the termites and their production of food would overheat the environment and create stale air which would make both living in and producing food impossible. To allow all this to function, they have created a very sophisticated system of natural ventilation and thermal control. The mounds seen above ground are chimneys that allow stale and hot air to rise up and out of the nest. At 6 feet below the surface, there is a cellar where the ceiling is a series of webbed rings which support the colony above and allows moisture to evaporate off the webbed rings, cooling the entire space. The warm fresh outdoor air is drawn in and sent up in the chimneys as the cool air drops the temperature inside the hill. Each chimney and ventilation shaft puncturing the nest is then opened and closed continuously as the termites control the interior climate to maintain the necessary temperature for living and food production. These design strategies have allowed termites to survive and live comfortably in their environment by implementing passive elements.

Biomimicry and nature based design is becoming a very powerful and respected field of design. By using the termites, and other organisms, as an example and their utilization of their passive design elements, we can implement such passive strategies in our buildings reducing our dependence on energy. The current shift from non-renewable sources of energy to renewable sources of energy, would be much easier if we reduce our overall energy consumption. Passive design strategies help us reach that goal in buildings. If we consider buildings as organisms, then in the larger eco system perspective, buildings and other entities approach a system that consists of interdependent parts, of which sensors play a vital role of communication between those parts like the human systems.

Passive

Reducing scale and living a more simple life can help with reducing our energy dependence. If we have a smaller living space, we don't need to heat and cool large volumes of space that we do not occupy, as in typical "McMansions". Another simple method of reducing energy consumption is using passive design techniques in building design. These simple strategies look at basic design gestures, such as form and site positioning, to prevent the need for extra energy use. Like the magnetic termites of northern Australia, passive design strategies tell us to position buildings north-south in hot climates to reduce the amount of exterior wall areas exposed to the sun, thus preventing added needs for cooling. Also like the termites, passive design uses natural ventilation to cool spaces; either with simple, and most commonly, cross ventilation or evaporation pools. This trend of both reverting to nature and also using passive measures to design are emerging quickly as first design steps in any building construction proposal. The Passivhaus Institute established in 1996 by Dr. Wolfgang Feist, sets guidelines and parameters of what needs to be done and checked to accomplish a Passivhaus awarded building. Passive design strategies are an increasing trend which are the result of looking for new essential methods which move away from inefficient building designs and systems.

The building process, from design to construction to occupancy, is a staged process with overlapping elements. There are aspects of the process that are decided early on that have major influences on the future of the building itself and its users. Some of these choices made are hard to change later on and therefore must be planned and designed with more attention given to them. For this reason, it is important to design, and choose materials and design strategies, that help different goals, such as energy use reduction and energy loss prevention. The design elements that are by the Passivhaus Institute are examples of such strategies that meet these energy guideline requirements. Why would a building sacrifice simple design techniques in order to unnecessarily battle future energy problems? In the Northern hemisphere, we are, on a yearly basis, more worried about heat loss rather than heat gain, and therefore insulation and orientation become key design standards in building design.

A north-south orientation works well for buildings in hot climates, such as Australia where the termites have built appropriately, but in the north, east-west orientation is required to maximize solar gain. Rare intense peak summer temperatures can be easily prevented with exterior solar sun shades and natural ventilation, which will be implemented in this design project, as another passive design strategy. The majority of the year, temperatures are within comfort zones and usually slightly lower, therefore, by orienting the building east-west, and maximizing the south wall exposure to the sun for natural heat gain, energy is collected passively which reduces the need to artificially heat the interior space. Any heat gain is also captured and held in by using insulation and better constructed wall assemblies with higher insulating values. The more passive strategies that are used, (such as natural day lighting, natural ventilation, proper solar orientation, etc.), the more successful a building will be in lowering its energy load and therefore saving energy.

One of the roles of sensors used in buildings is to reduce the amount of energy loss and maximize energy production in an effective and efficient manner. Therefore, if implementing a system of sensors, and other associated technologies, increases the energy use rather than decrease it, it is a failed application. These efforts should not counter affect their purpose. For example, calculations must be made for a static photovoltaic panel versus active panel that tracks the sun throughout the day. If the amount of energy collected from the rotating PV panel is not greater than the stand still panel, then why have it track the sun? In this calculation, embodied energy in the mechanical system, as well as maintenance efforts and costs must be taken into account when coming to a conclusion. Most individual sensors today are cost effective and use very little energy to operate therefore their influence on the total energy load is minimal compared to other elements. Their use as guidance control and feedback responses is vital in these systems maintaining their level of effective operation.

Even with most electronic sensors being very low in energy consumption, their combination with detectors and actuators might increase the overall energy usage. By using passive sensors, this concern of sensor activity energy costs is resolved. There

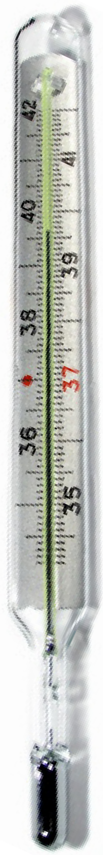


Figure 4.1 - Mercury thermometer

are a number of sensors that exist that do not need or use external energy to operate. The traditional thermometer used mercury (which was later replaced with red dyed alcohol) which rose and fell to indicate the temperature. This simple device functioned as an indicator without any energy use other than the changes in temperature which affect its natural properties. By using the ideologies of passive design and using it with biomimicry research, there is the potential for other "natural" sensors such as the humidity sensor discussed earlier, developed by researchers at Sogang University in Korea (Kim, Moon, Lee, & Jungyul, 2010). If a sensor operates with electronic means or natural means, this method of communication also affects the experience of the users. We are currently surrounded by electronic devices and how we experience these devices is just that, a reading from a device. But by incorporating natural sensors into buildings, the interaction between user and actuator is a much softer and personal one.

Some elements of a building require electronic sensors for safety and effective reasons, such as smoke detectors, but the energy use of these sensors should still remain as little as possible. The application of the 4 R's (reduce, reuse, recycle, remove) have an impact on the building design as well as user experiences. As the overarching concept, the 4 Rs can be expressed in energy terms. A well designed building reduces energy use, reuses energy so one device can do multiple tasks, recycles energy so nothing is lost, and removes the use of energy where possible. Reduction is simple to understand and is quite literal. Reuse of energy is an example where the energy used to perform one task is also used to do another. Since energy is consumed and cannot physically be re-used, devices that can share the same energy loads will qualify it for energy reuse. Recycling is demonstrated with a buildings water flow and water management strategies with rain harvesting and water cleaning and recycling. Finally, removing energy is a representation of changing the attitude of the building users to lower their usage. Timers which shut systems down when the building is vacant, or indicators which remind users of energy conservation are used in this manner.

As we move towards designing, building, and living with the planet's finite resources in mind, looking at new and reinvented building materials are steps to finding a solution to our excessive energy habits, but the building itself must be addressed as well. Interior components must be made more efficient without loss of performance. Artificial lighting is one of the first advancements in this area. Buildings have transformed from using incandescent lighting to florescent and are now making greater steps into the utilization of LEDs (light-emitting diode) in lighting fixtures. No matter how little energy LEDs use, we should not allow a new technology to persuade our judgements on energy use. If they save energy, it does not mean we can now leave all the lights on in our homes. The best form of energy saving is not using energy at all. By maximizing natural daylight, using LED fixtures with dimmers and having automatic shut off triggers incorporated into the lighting system with daylight, motion, and proximity sensors, as well as an intelligent interface that adapts and learns from inputs such as user schedules, we begin to create a system that can learn, react and perform, meeting the user's needs without sacrificing energy and performance.

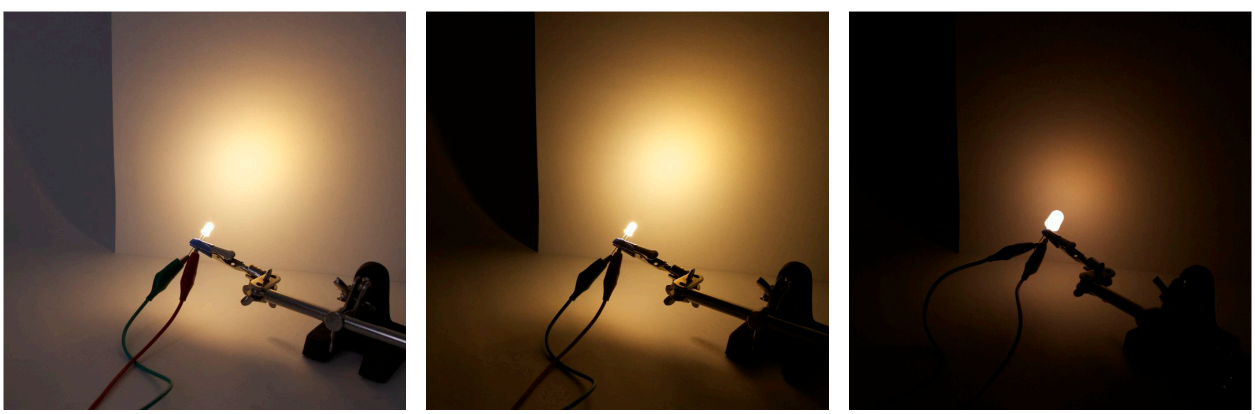


Figure 4.2 - LED’s used in this project are programed for different atmospheric expressions

Local

Designing with the concept of time and lifecycle in mind, the outcome of the things produced are much different than if we ignored time. By understanding that buildings degrade over time, we can use building materials that have low embodied energy. The reduction of embodied energy in materials, building and design consideration limits our use of the remaining finite resources of our planet. One element of reducing the embodied energy of materials is using local materials.

The importance of local materials are acknowledged in the Leadership in Energy and Environmental Design (LEED) point rating system. Points are awarded for local material use and local transport of the materials. The concept of locality is currently being placed on locally grown foods to better our diets. This benefits our food intake quality as well as the environmental aspect which revolves around the high energy costs of growing and shipping foods internationally. The use of locally grown foods creates a micro economic system, where the local farmers produce for their neighbours. This "village" mentality allows community growth to take place, both economically and socially. In a similar way, using local materials creates a connection with our environment which once again develops and grows our respect for our planet and what it offers.

The greater our connection with our planet, the greater our understanding of its finite resources and therefore the better we will be at controlling our consumption of them. The connection that we establish is one that is echoed in our interactions with nature. The use of local materials allows a user to see a direct relationship with their habitat and life, and that of their environment. On the West Coast of Canada, wood is a largely used resource and building material. The mild climatic conditions allow for wood walls and cladding to be used in construction without the need of excessive insulation values and worry of extreme cold fronts. The use of wood in construction is also a representation of the vast amount wood available from the large coastal rainforests which cover the landscapes. Creating another connection with the environment, the use of wood allows a visual cohesion to exist with buildings and their surroundings. Many consider the use of wood as being a poor material choice because of its high potential to rot in comparison to other materials, but that is another aspect of the life of a building and is explored further through design in this project.

Typically the use of local materials is highly beneficial and common, because they posses inherent properties that can be associated with the local weather conditions. In hot desert climates, mud bricks and rammed adobe walls are used because, the low amount of water fall allows that material to survive without being destroyed by the weather. Likewise, in northern climates, peaked roofs made with high insulating properties are used in buildings to shed large amounts of snow. Improper use of materials and building techniques can cause serious problems to the structure as well as user health. An example of the misunderstanding and misuse of building technique and material use occurred in Vancouver, BC in the 1990's.

The problematic, severely damaging, and extremely unhealthy case study is known as the Leaky Condo Crisis. This crisis is the result of a number of things; new product introduction, lack of installation knowledge, poor detailing, poor building maintenance

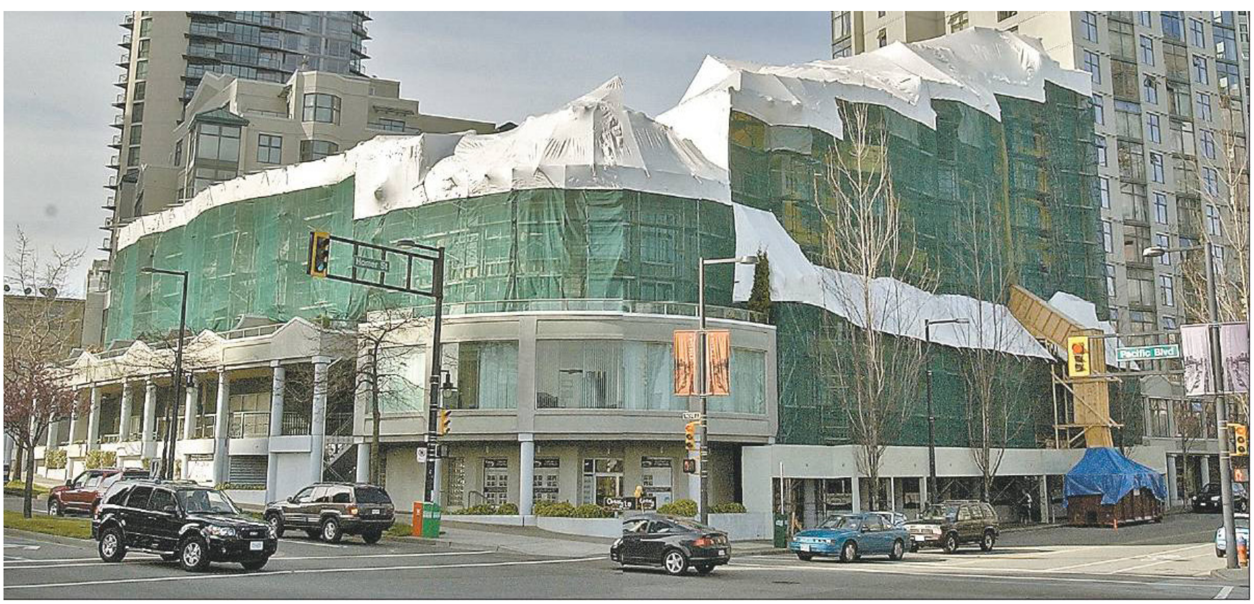


Figure 5.1 - A “Leaky Condo” building in downtown Vancouver, BC

up keeps, improper inspections, and so on. From an architectural point of view, one of the main causes was a copy-cat mind set which resulted in an architectural design trend. Designers began to detail and design their building in the likes of Californian homes and condos; low and sometimes no overhangs, improper flashing and tight seal stucco finishes. The idea to finish buildings with this aesthetic obscured the basic understanding that climatic conditions would eventually intervene. Vancouver's very moist, rainy, and saturated climate took over the weak design detailing in these buildings and caused large public health problems resulting from these condos developing extreme amounts of mould growth in their walls, and in some cases fungus in the form of mushrooms growing on carpets. The height of the crisis was in the 1990's but even today more complexes are being discovered with moisture ingress and mould growth. A report done for the provincial government of British Columbia in 2008 reported that an estimated 24,000 units would still need repair until the year 2012, nearly 20 years after this costly trend stopped (The Vancouver Sun, 2008). The only positive outcome from the Leaky Condo Crisis was the new knowledge that emerged and resulted in the development of new rain screen technologies and methods which were studied and are now greatly used in all similar climatic regions, such as Ireland and Germany.

Figure 5.2 - Detroit home transformed due to unmaintained weathering and abandonment

Weathering can be a cause of great problems if left alone and not respected. In Detroit, after a short period of abandonment, many buildings are being taken over by nature and due to weather, they begin to transform. This transformation in many eyes and opinions is considered to be called destruction, but in reality it is a representation of growth. Similar to all organisms that exist on this planet, buildings also age, and like biological entities whose cells begin to deteriorate, building skins and structural bones become brittle and weaken, which cause failure (see Figure 3). Over time, the natural environment engages with building surfaces and begins a breakdown process. If this process is left uninterrupted, materials, systems and entire buildings fail (Mostafavi & Leatherbarrow, 1993). To prevent this failure from occurring, buildings undergo maintenance, and if the maintenance of a building cannot keep up with the pace of natural building age and change, a renovation occurs. It is vital to understand that buildings age and are not permanent artifacts. As architects and designers, if we understand lifecycles of buildings, designs can be made to embrace this inevitable change due to weathering and time, rather than fear it and try and ignore it. We must understand that weathering affects all aspects of a building, from the exterior, to the interior. All materials have a lifecycle and assemblies have shorter ones because once one of the materials fail, then the assembly fails. The combination of different materials, components and elements make a building. Like an organism, buildings are a combination of parts that work together, move and change to live the length of their lives. As they are placed on a site, buildings have the opportunity of being integrated with the environment and contribute to and become part of the landscape, rather than being a foreign object sitting on it.

If the building is considered as an organism, then with its site and surroundings they become an ecosystem changing over time as they age and grow together. This connection with landscape is similar to the connection users experience in a building with sensors. The structural sensors which relay information, or the diurnal sensors used for water collection and usage monitoring, all give the users the experience of time and lifecycle with the building. As an example, using wood rods instead of rain chains hanging outside as rainwater leaders will eventually warp and rot as the seasons pass and this representation of life and time is an element that the users engage with as they need to go and replace the rods with new ones.

Technology

As technologies emerge, they affect our lifestyles and affect architecture. These emergences reform the way users interact with these advanced things as well as each other creating new experiences for the users. For example, the introduction of the microwave oven has made food preparation less time-consuming, allowing more free time for other activities. The simple procedure of warming up leftovers involved the use of a stove in the past, but microwaves have shortened the time spent heating meals and allowed more time out of the kitchen to enjoy meals with company. This subtle change which has created free time, has refocused dwelling and moved people away from one space and increased the use of other spaces; such as moving away from the kitchen and increased more use of social areas such as conventional dining and living spaces. These changes have now adjusted the architectural purpose of those spaces and the way a user interacts with them therefore changing modern culture. Currently the kitchen is no longer considered a working area but is more celebrated as a social space. With the use of sensors, architects and designers can initiate and promote these spatial experiences by highlighting expressions of these spaces. To further that example, kitchens are now open and more connected with social spaces such as the dining and living areas rather than being concealed and hidden.

Processes which eliminate mundane tasks or reduce the time to accomplish small jobs, is something that many sensors and their implementation into detectors have made our lives less busy and more freed, allowing more time to be spent on more meaningful activities.

We currently use sensors in many aspects of our lives and allow them to manage certain tasks; such as our temperature control and our security systems and have them integrated into the many household appliances we use, such as the aforementioned microwave ovens, as well as the laundry machines. Some sensors are more visible than others, in the forms of actuators and detectors, but they are all tacked on or attached devices that do not contribute architecturally. Sensors should no longer have one simple functional role, but should be a node in an entire network. Increasing the deployment of sensors in buildings and extending their functional domain allows their potential to emerge. By multiplying the number of sensors we use, and introducing them into other aspects of our living, we can allow them to control mundane tasks, allowing us to enjoy the company and space that we share with fellow users (friends and family). This proposal of sensor control is meant to allow user customization of space and reduce the amount of time we spend adjusting and re-adjusting certain elements in order to create our personally desired condition. As an example, let us look at temperature control.

A thermometer is a simple device that displays temperature. It has changed over the years, but it is mainly remembered and thought of as a thin glass tube containing a liquid that rises and drops with changes in temperature. The liquid inside is the real and passive sensor, and combined with a measurement scale, together, it becomes a detector. Once again, due to advancements in technology, in more recent times, the thermometer has now become digital, and more accurate with its sensing and displaying abilities. In a building setting, the thermometer has taken the role and responsibility of maintaining desired indoor temperature by controlling the mechanical systems. Mechanical systems, as they are, respond to criteria

Figure 6.1 - Typical sensor, detector and activator devices we find in North American homes

input by users through these thermostats. In most buildings, a typical single thermostat is responsible for an entire "zone" and can be placed tens of meters from the diffusers and users. The problem that arises is that there is not enough data and information intake from the sensor to make appropriate judgements of the space. These sensors were installed to remove the need for users to manually adjust heaters and coolers, but if in a typical home, there is only one thermostat per floor, then the temperature cannot be represented properly by the system, which results in improper and energy wasting decision making. Either it's too cold or too warm and no one is ever happy, which causes users to constantly be readjusting the thermostat in attempts to finding the required thermal comfort level.

A solution to this problem is to increase sensors and temperature readings throughout the building and have the mechanical systems increase or decrease heat in certain areas, rather than entire zones, allowing the resulting environment to be more accurate to the request of the users input criteria. Having sensors work alone and independent of each other can also cause confusion within the system. If we look at our bodies again, the sensors on our skin are not independent from our muscular system. Meaning that if our hand is placed over a candle, our bodies don't only sense heat, but it registers pain, and our muscles contract to move our hand away. The importance of such integration is now becoming a guideline for new innovations.

An example of an integrated sensor system is the newest thermostat called "Nest", developed by Nest Labs. This device claims that after one week of manual adjustments, it learns your daily needs, and adjusts building temperatures according to your schedule. It is constantly learning as soon as you change the temperature and is connected with an internet connection to read weather patterns and therefore will predict changes in temperature required to maintain indoor comfort. It is also built with a proximity sensor to only light up when you are close to it, to save energy from unnecessary display screens, as well as having built-in activity sensors to sense when the room is empty to set itself to "auto-away" which shuts the mechanical systems off. It can also be adjusted remotely by computer or Smartphone giving another layer of customization and accuracy to the sensor reading and output (Nest Labs, 2012). The integration of these sensors in one device represent the same type of integration and functional cooperation and feedback that all sensors within this project have in order to function to their fullest potential. Nest Labs created this innovative thermostat because 90% of programmable thermostats are rarely, or never, programmed, therefore rendering them inefficient (Nest Labs, 2012). And with 50% of residential energy bills being controlled by thermostats (2007 Buildings Energy Data Book, Table 4.2.1), the potential was great for energy savings. The true innovation in this device comes from the integration of advanced technology which has allowed sensors to become smaller, more effective and more powerful in their processing ability. The combination of these elements, integrated into one device represents the creative possibility that sensors posses.

Figure 6.2 - Nest thermostat integrates different sensors and actuators into one

Technology is always advancing. Incorporating high levels of electronic technology has become the focus of many industries, such as automotive and communication industries and sensors, detectors and actuators are in the middle of most of these advancements. Communication devices have transformed from telegraphs to personal global computers. Conventional mail is almost forgotten, as the move to digital has jumped the industry forward. The introduction of e-books, and e-learning has changed the way we look at reading and education. In medicine, examples of transformation are paper records being digitized, treatments simulated electronically, and surgeries are conducted over the internet. All the stages of medicine and other professional industries have advanced with technology, but in architecture the utilization of this higher level of technology has primarily remained in the design process stage through software use and not as much in the resulting products, the buildings. The use of drafting tables has been replaced with computers, and project studies done with physical models are now being done with highly tuned and intelligent digital simulation. Even with physical models that are still created, laser cutters, CNC machines (computer numerical control machines) and 3d printers are regularly utilized. These technologies, and others, have also moved forward from the design stages and into the construction and building stages, as architectural discussions advance regarding mass customization, pre fabrication, and digital fabrication. The result of all this technology use in the design phase, as well as now more increasingly into the construction phase, is still a designed building that is relatively the same as it was tens of years ago. If we compare communication devices, personal computers, and even automobiles, that are on the consumer market now to those of the past, they would be more advanced and evolved, but buildings have relatively stayed dormant in this progression. By implementing and using sensors in buildings, this gap begins to be closed as a small step towards advancing building operations to the level of current technological standards that are available.

The major use of technology has remained in architectural installation type work, and in many cases, this digital trend is being used as an aesthetic for visual entertainment. Near Tachikawa station, in Tokyo, N Building, a commercial project designed by Terada Design with Qosmo Incorporated, has a facade that is a giant QR Code (a two-dimension bar code (Wikipedia, 2011)). Pedestrians can use their mobile devices to scan the code, and depending on the holiday season, will be treated to different graphics, but will also be able to read real time tweets that are being sent from users inside the building. (The tweeters inside are tracked with GPS locators and their public tweets are forwarded to the building database for real time display through the buildings QR code application service). Using QR codes and mobile devices for entertainment and interaction is a very quickly growing trend which some predict will be the future norm of human socialization (Tokui, 2010).

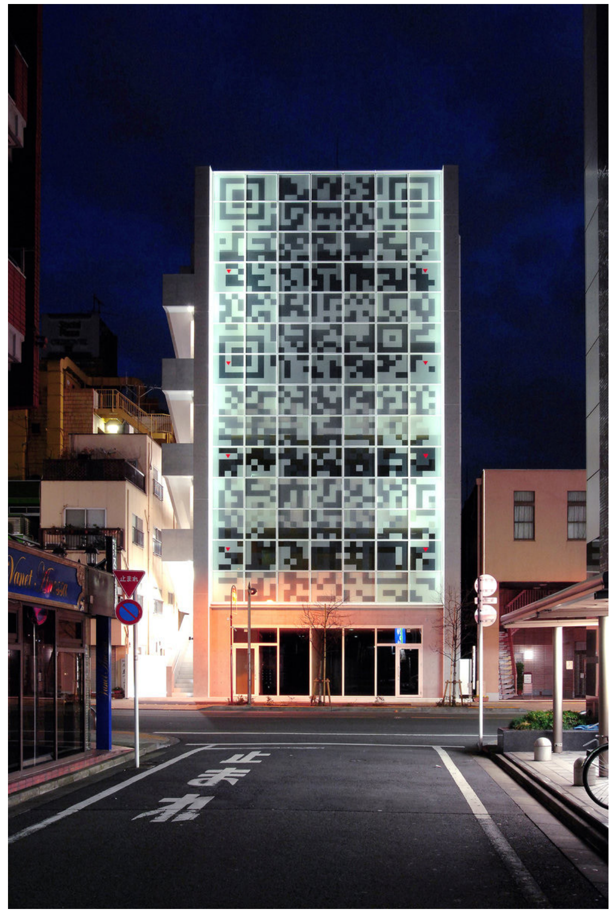


Figure 6.3 - N Building, Tokyo, Japan

The use of mobile devices is becoming more dominant in our lives. The more advanced they become as a technological tool, the more we depend on them. It is almost impossible to think of a life in the developed world where we are not connected to the internet and the introduction of social media has fortified that feeling of necessity to be logged in at all times. This "microchip living" is just another step of technology growth and is slowly making its way into buildings as well. In the past few years, many media corporations and companies now offer "complete" home services. This complete package now not only includes the standard home phone, and cable television, but also internet services, wireless mobility, and home monitoring. Home monitoring, as the market it, is a new system that links all the previously mentioned services under one package and one system. It also adds home security with a number of "smart sensors" which they define as being motion detectors, door sensors, cameras, smoke and fire sensors, carbon monoxide sensors and water leak sensors. These sensors, in addition to wireless control over lighting, small appliances, thermostats and home entertainment, are all linked into one database of control which can be accessed remotely from a website, or viewed on a Smartphone.

The connection with mobile devices that these companies have made as a marketing tool, is a reflection of the understanding of our cultural need to be connected. By increasing the use of sensors into other areas of the home, the result is other connections being made between user and building. The interactions that occur with a sensory building are more rich than a normative one because the building can react to users and other stimuli creating a sense of personal connection to an otherwise simple artifact. This interaction and connection is an extension of the expressive qualities that sensors in a building bring.

Cars

The automotive industry has embraced the use of sensors, and it is very hard to think of a vehicle without them. They were always a major component of an automobile notification system, with symbols lighting up on our dashboards when something was wrong, and their use in speedometers, fuel levels and internal engine processes, are invaluable to making driving a possibility. These sensors that started out as gauges and measurement tools, have now emerged as the leading technology in cars today. In Formula 1 cars, there are over 300 sensors including some on the driver which communicate with the pit crew via live telemetry (MacManus, 2010). The live and constant stream of information that is collected, sent and processed by the crew, allows micro adjustments to be made in order to reach the full potential of this engineered super machine. But sensors are not used only at that extreme level of high performance.

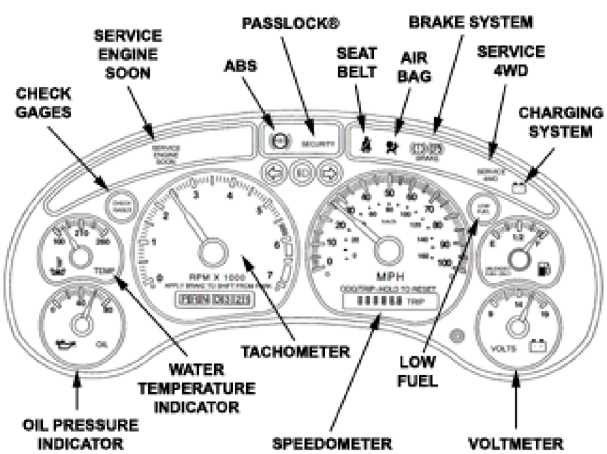


Figure 7.1 - Example of a car dashboard

Cars are filled with sensors which allow them to perform better, to be more efficient, and make driving safer and easier for their users. Sensors are used in all new cars as major safety controls. They notify and remind us to wear our seatbelt with the use of pressure sensors in the seats; they deploy airbags in a tenth of a second once a collision is sensed, and for comfort purposes, they automatically start the windshield wipers as soon as water is sensed on the glass, and allow smart cruise control to exist with the use of proximity sensors to sense approaching vehicle from ahead, and slow the vehicle down automatically and then resume speed once a safe distance is regained.

The recent jump to mass production and sales of hybrid vehicles would not be possible without the use of highly tuned sensors. The Toyota Prius, for example, contains more technology and sensors than any other market vehicle today. The hybrid engines require sensors to detect, predict and respond to changes in acceleration, speed, torque, fuel reserves, etc, all simultaneously in order for it to constantly determine when the engine needs to switch seamlessly between the electric motor to the combustion engine and vice versa. It also has an up to the second interface and processor which displays on the dashboard to the driver and passengers all the readings regarding engine performance, energy consumption, etc. In vehicles, this high level and high number of sensor use results in the automatic decision making system which makes cruise control and hybridity possible.

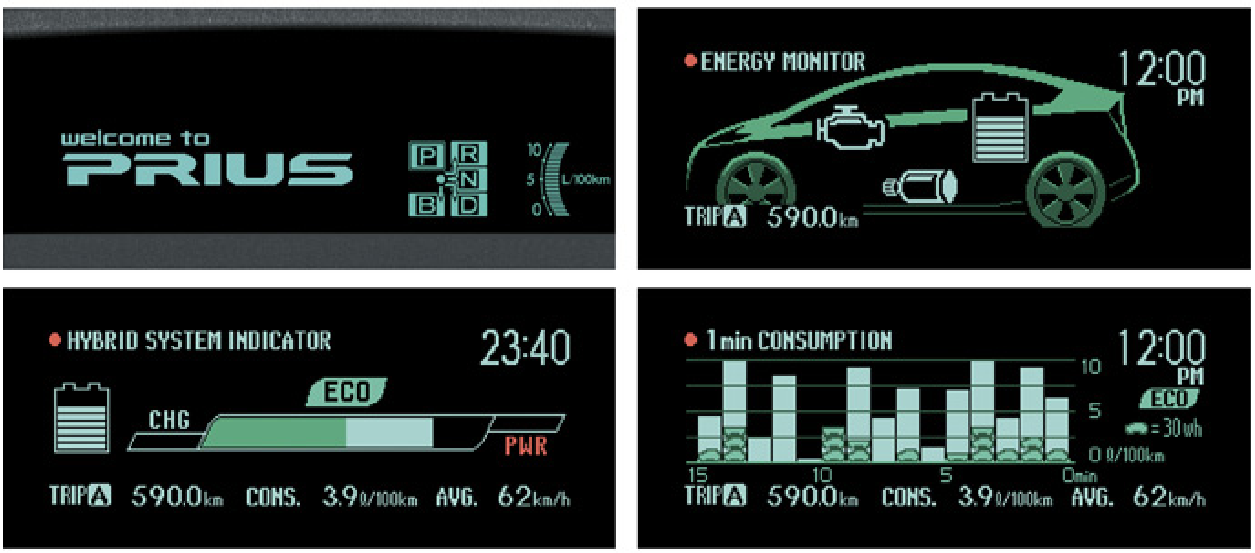


Figure 7.2 - Prius dashboard information display

The use of sensors in cars has created a new type of hybrid vehicle to emerge and also has changed the way users interact with them. In most cars, the driver controls the vehicle and uses the gauges and sensor readings for comfort reasons and safety reasons, to warn him or her if something is wrong; either mechanically wrong or socially wrong (like speeding). In newer vehicles that have more sensors, the role that these sensors play still keeps the high levels of safety and comfort but also expresses to the user the processes that are occurring which are normally hidden. The expressive nature that these sensors provide brings a new experience to users of these unique vehicles, similar to those interacting with a building with sensors.

Swarm

Sensors have changed personal computers, cars and phones and therefore have changed our experiences using them. With sensors and actuators in buildings, we can also change user experiences. The utilization of a mass numbers of sensor types and quantity, like in a vehicle, allows a network to emerge which no longer senses individual elements, but now senses entire contexts. These detailed sensor networks allow for better and more accurate readings which result in better responses. Existing technologies developed for "smart dust" and "swarm" uses are ideal for this application. Nano sensors are now being created and used in the biomedical industries, which are able to sense cellular changes and deformities allowing physicians and scientists to specify the exact time and location a cancer forms (Carrara, 2011). Some scientists believe that in the near future we will be able to inject nano sensors into our blood stream which can gather and relay full readings on our internal systems. Other scientists at Tel Aviv University's Faculty of Engineering, have taken the nano sensors to a higher level. By using small carbon nano tubes, about one-billionth of a meter in length, these researchers are able to sense the movement of atoms (Tel Aviv University, 2012). If misunderstood, one would assume that only noise would be sensed from the movement of atoms due to the fact that all atoms are in constant motion. What this advancement in sensor technology represents is the amount of possibilities and detailed data that can be collected from these sensors and detectors.

While these advancements are inspiring and very interesting, for the purposes of this thesis project, the use of nano sensors will be disregarded due to the difficulty to demonstrate feasibility and practical use in an architectural application as it is being proposed. In order to sense context, swarm systems of sensors will be able to achieve the required results. As discussed, using a large number of sensors placed throughout a space, allows more detailed and more accurate readings to be taken from the sensors which in turn can assess the needs more precisely, which results in better and correct judgments and in the mechanical and electrical systems. For a large number of sensors to be used in all aspects of the building environment, they will still be required to be small in size in order to remain as an invisible realm of operation as possible. Small sensors have already been developed for swarm use by many governments and agencies as new frontiers for border control and security surveillance. These sensors are equipped with proximity detectors and use radio frequencies to communicate with one another into one giant surveillance grid. Many of these sensors are being designed to be dropped by planes and can be reprogrammed to sense a number of stimuli. Another example is using them in mining and potentially hazardous environments to humans, where the sensors are dropped from safe heights (for the pilots), can sense and relay information on the ground about any chemical or radiation levels that would be harmful for human intervention (BW, 2009). By dropping thousands and millions of sensors from airplanes, the cost would be enormous, but similar to many other areas of technology, as advancements progress, more precise instruments are being created at lower manufacturing costs. These small sensors now cost tens of cents. In 2005 researchers at University of California, Berkeley, developed "Spec" (see Figure 8.1), a programmable indoor sensor with a twelve meter sensing range and combines communication, computation, and sensing into one device. Equipped with radio frequency capability, this sensor is one of the steps towards "Smart Dust" technologies, and it only costs 30 cents to manufacture (Steel, 2005). A few years later in 2009, Tel Aviv University researchers presented "Smart Dew" (see Figure 8.2) which has a fifty meter sensory range and costs only 25 cents to manufacture. This device also has a radio frequency transmitter and is designed for all environments and is fully programmable to sense different stimuli such as proximity, sounds, magnetism (vehicle detection), vibrations, temperature changes, light, carbon monoxide emissions, etc (Tel Aviv University, 2009). In addition to finding and using small precise sensors that are low in cost for utilization in a smart dust or swarm use scenario, the battery life of these sensors is also important.

If sensors are being integrated into all the layers of a building then access to replace the hundreds of sensors will be limited and the large number of sensors proposed would make it a laborious task. Fortunately, this energy issue is also being resolved by researchers and scientists. Most of these sensors have battery lives that can last up to 10 years (Bigelow, 2004), but this is all dependant on their size and processing

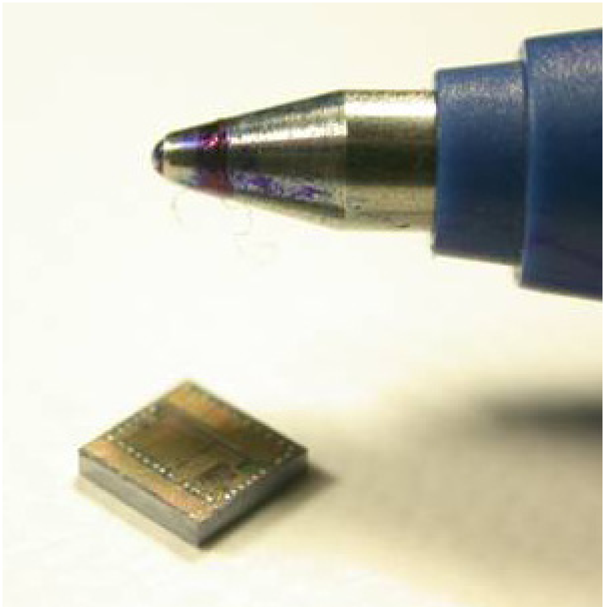


Figure 8.1 - “Spec”

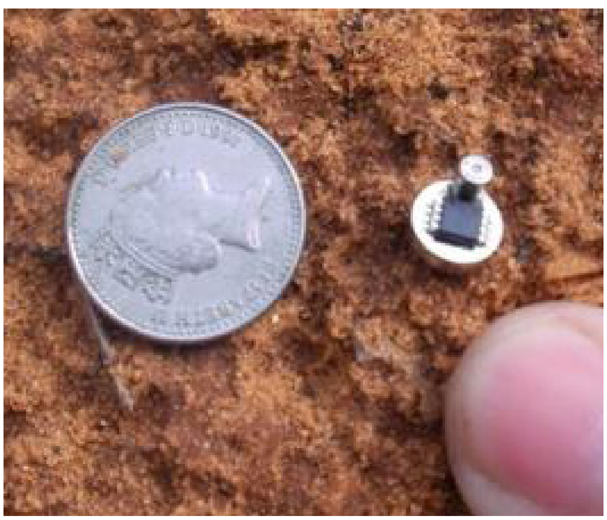


Figure 8.2 - “Smart Dew”

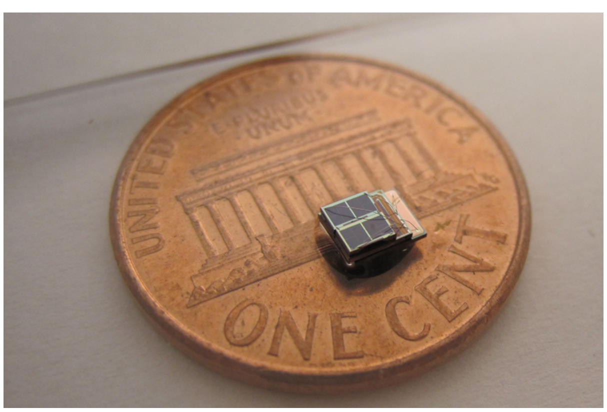


Figure 8.3 - 9 cubic mm solar panel

power use. Some sensors today can be created with solar panels as small as the sensor itself which would satisfy the small amount of power the sensor would require to function and charge the installed battery reserves. At the University of Michigan, a nine cubic millimeter solar power system has been developed for sensor integration and potential commercial use in biomedical implants (see Figure 8.3). Since most sensors spend their time in a sleep mode, and only self awake to make readings every minute (or whatever is specified in the programming), they require very little energy. A sensors total average power consumption is less than a nanowatt (one billionth of a watt), and therefore small solar panels, such as this suffice the energy needs of a sensor (Moore, 2010). For sensors that do not have access to the sun other forms of energy production can be implemented. According to Berkeley electrical engineering professor Kristofer S.J. Pister, similar to a self-winding wristwatch, sensors placed in wall cavities can be powered by small vibrations, or even barometric pressures, and that in the near future, sensors will be small and cost effective enough to simply "dump these things in a can of paint, and paint them on the walls" (Manjoo, 2001).

With manufacturing costs lowering, the precision of sensors increasing and their power requirements being met, the use of sensors in a building environment using existing sensor technologies used for smart dust and swarm uses, the number of sensors deployed in a building can be increased without becoming visually intrusive. Sensor costs and sizes are minute allowing this system of sensors to be established, sensing entire contexts and not single conditions.

Layers

The application of sensors cannot continue to be attached to buildings like conventional sensors today (such as thermostats and motion detectors). With the use of vast arrays of sensors in the layers of a building, deployed as a harmonious system, the sensing of entire contexts emerges. Buildings have many layers similar to an organism and each layer offers an opportunity for expression. In regards to building and material lifecycles, Stichting SLA writes about seven system based layers (Hinte, 2003).

As they describe it, a building can be divided up into these seven layers, and each layer has a timeline associated with it; ranging from a few years to centuries. Their analogy of layers includes: location, facade, structure, access, services, dividing elements and furniture. That concept of layering done by SLA in 2003 is an extension of the work of Steward Brand in 1995 with his Shearing Layers of Change, who expanded his work from Francis Duffy in 1990 who illustrated Layers of Longevity. Duffy started with five layers: shell, services (circulation), scenery (partitions), and set (furniture). Brand explored and expanded the layers to site, skin, structure, services, space plan, and stuff. As each rendition of these layers has gone on, the number of layers have been growing and becoming more detailed and specific. I have introduced a further rendition of layers, and unlike SLA's comments on time and the differentiating qualities of their layer systems, I have separated time from each layer and made

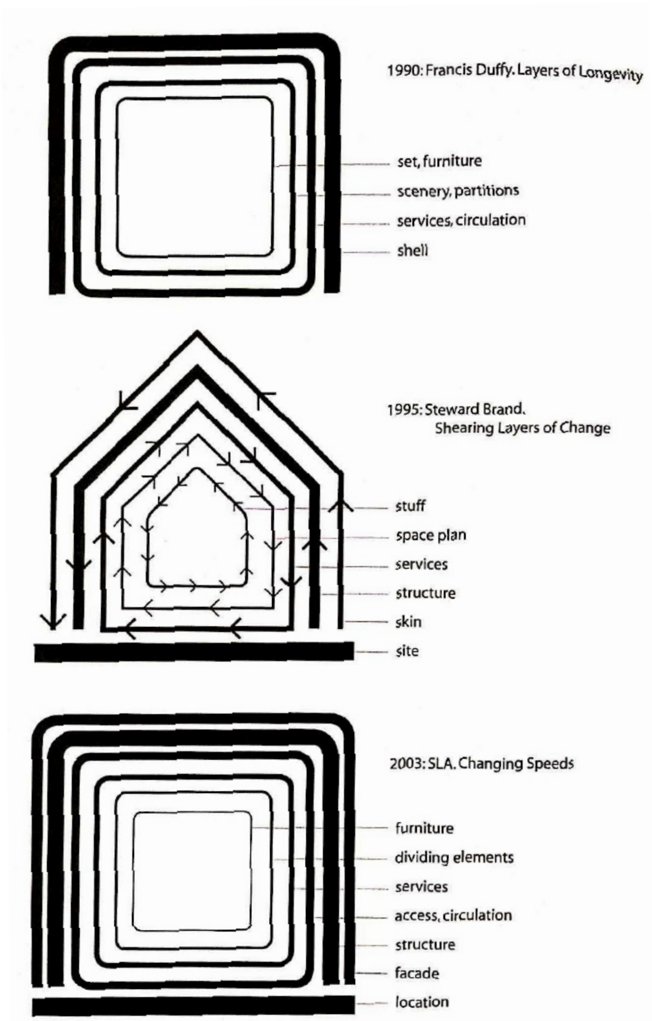


Figure 9.1 - Building Layers

it the dominating layer as the outermost ring. From that surrounding, and moving in towards the center of a building, the layers are as follows: time, environment, location, exterior partitions, access, structure, macro space, services, interior partitions, micro space and users.

One can say that these layers are ordered to be from exterior to interior as a building cross section, but can also be described as being organized by rigidness. The outer-most elements are near impossible to control while the inner rings can be changed at any moment if requested or required. In regards to time and energy, since the outer rings are considered as more rigid, they therefore must be planned and designed with greater thought in order to avoid the hardship of attempting to change them. For

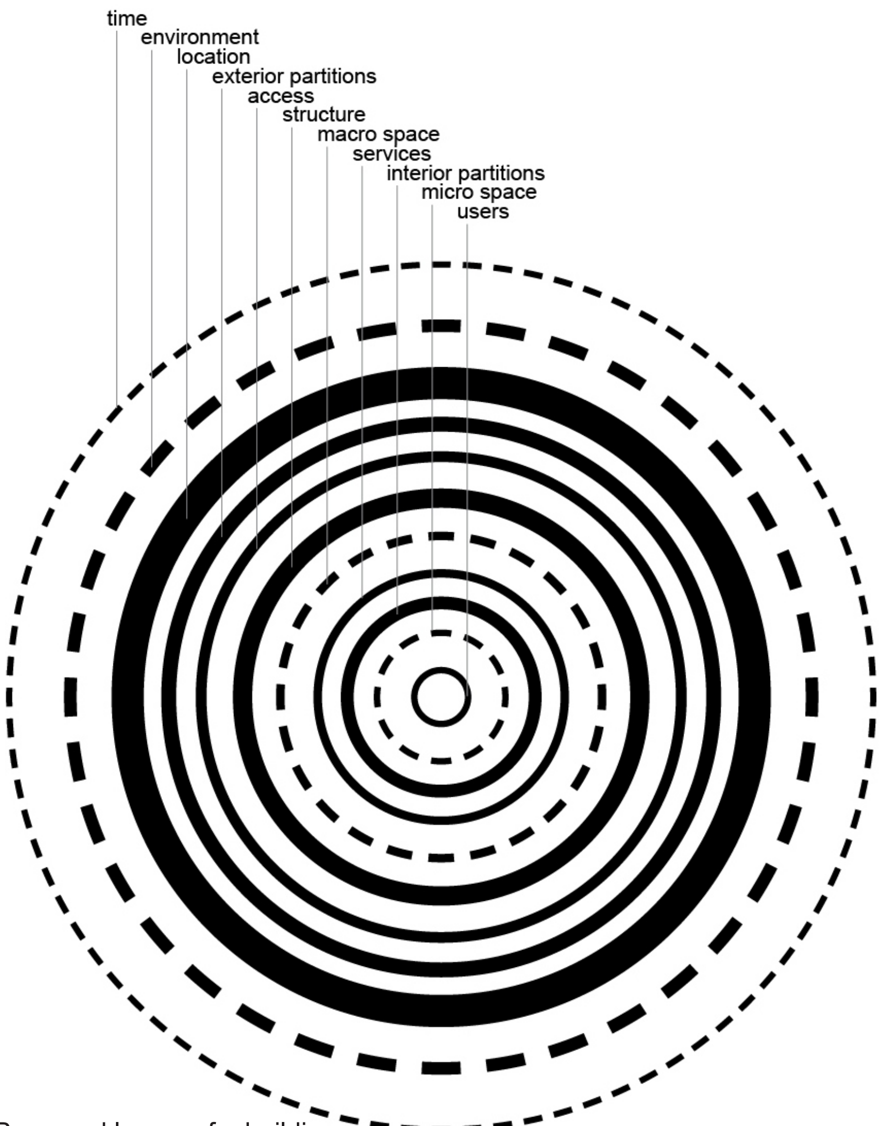


Figure 9.2 - Proposed layers of a building

example, the geographical location of a building has a very long lifespan; New York City has maintained the same street and road grid that was proposed in the Commissioners' Plan of 1811 (Gray, 2005). On the other end, in the centermost layer, users can change by the minute, and micro space can be changed with the movement of a sofa or adding a chair to the corner of the dining room.

Buildings have many layers and it is not easy to simply apply sensors in a building by designating it as another layer of a building. For sensors to achieve their full potential in architecture, they must be integrated with the entire building system. We cannot think of the many layers that make up our bodies and ignore particular, integral sensory systems. Each and every layer of our bodies are embedded with sensors. We could not function as a living organism without these sensors. Based on the adapted set of building layers that I have proposed in the above section, certain sensors have been linked to them directly such as weather forecasting with the environment layer, and humidity sensors in walls with the structure layer. Sensors are not one layer but are a part of all layers. The use of both passive and active sensors are used by designers to reveal their architectural intentions for expression. The experience of the users is now more dynamic by the changes in stimuli sensed by the building and the responses it makes expressively as designed by the architect.

Sensors

There are hundreds of different sensor types (see Appendix B) that respond to different stimuli. Those that are used in this architectural framework are categorized under 5 headings: weather, building, users, usage and energy. The majority of these sensors are actually able to fall under more than one category and are a hybrid of two or more of these categories. Just as the sensors in our bodies relate and feed information to more than one biological system, these sensors also affect the responses and characteristics of multiple categories. A sensor on our skin sensing coldness can affect the nervous system (signals sent to brain), the circulatory system (arteries tighten reducing blood flow to skin), the muscular system (muscles sent into spasm causing shivers), the respiratory system (breathing is slowed down), etc. In a building, a water sensor is related to weather (forecasting rain), building (possible moisture in the walls), users (matching user schedules to meet their water requirements), usage (monitoring and advising water usage and conservation), and also energy (water heating requirements).

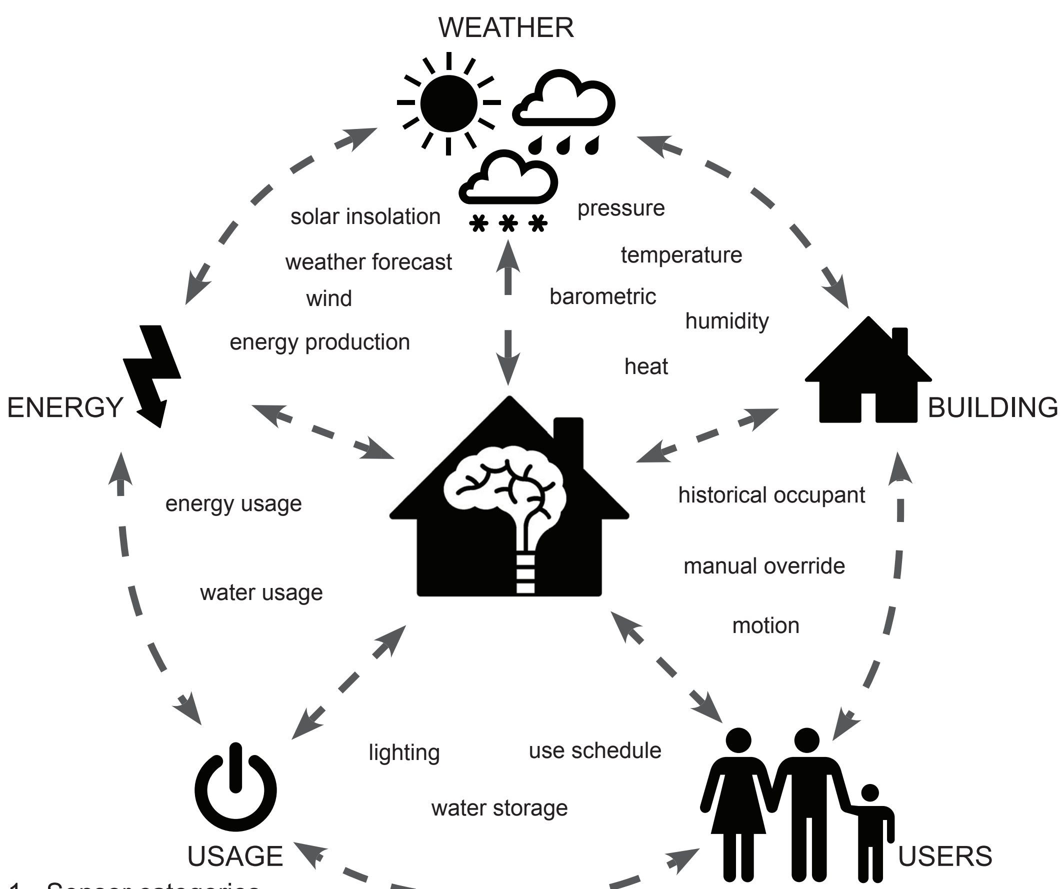


Figure 10.1 - Sensor categories

The many sensor types and number of sensors placed throughout a building, sense, detect, and measure numerous different elements, but what is sought and has been expressed as essential, is contextual and harmonious sensing which allows new expressions to emerge of normative spaces. In order for this to happen, we cannot think of a single device being placed in the middle of a house which functions alone and independent of others, integration with the many layers of a building is required. Therefore, we cannot also assume that we have a machine that acts like an organism which controls the building, but rather what we have is actually a building that is acting like an organism. With all its internal systems, and external systems working in harmony and having sensors, connecting, correlating and responding to each other, and all environmental stimuli, including the buildings users. At this point, tasks and sensors relating the organism to the building are more clear and apparent.

Sensors do not add to the overall experience of a building by being another layer, but integrate themselves into all layers, creating more opportunities for expression. Therefore, we cannot identify this system of sensors as a separate expressive component of traditional architecture. This system of sensory parts must be treated and integrated as a whole and once integrated, it contributes to the expressive possibilities of a normative building and its layers. Once again, multi-layered sensors acting as one harmonious system are able to sense all external and internal stimuli and communicate that with the building which intelligently responds to criteria. How it responds is a combination of designed outputs and user uniqueness.

For some functional tasks, the operation order of these sensors and how they function can be laid out in a simple command sequence order. The process of function is simplified and represented in the diagram (see Figure 8). All the sensors are constantly sensing internal and external stimuli such as weather, energy, etc. This data is sent to an information hub which reads the collection of data, analyzes it and checks for triggers. Through this analysis, if the system decides that a required set of criteria has been met, then the system proceeds. All the data sensed is always saved, and therefore it is compared with historical readings taken over time, which allows a greater understanding of scheduling to be analyzed. Then finally a notification setting is released as communication with the users, prior to any changes being done automatically, ensuring user preferences and control over the system. This is a simple warning system that the building is going to respond to a situation and gives users a chance to interfere if needed. And finally an action takes place in response to a set of stimuli or preferential parameters defined by the users. Once the action has taken place, new readings are taken which confirms correct decision making from the system and also relays new data for any additional actions if required. The following is an example of the above described sequential order command of the sensors and their responses.

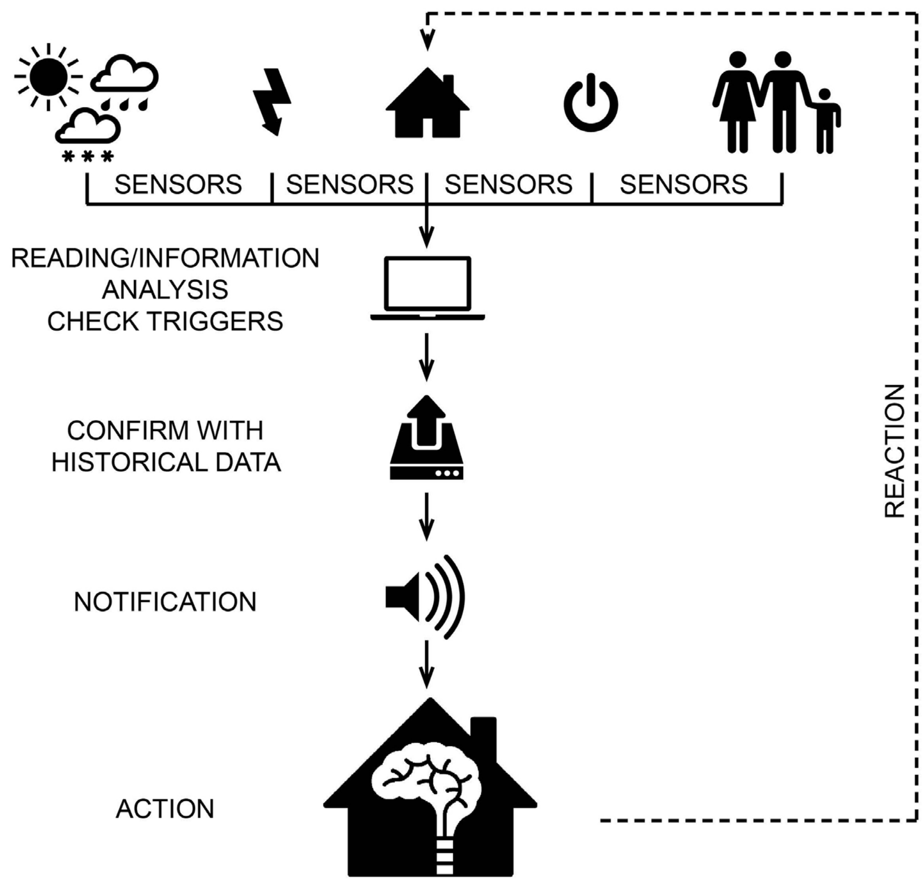


Figure 10.2 - Operation order for system decision making

In this example, the system is set to automatically shut off lighting in rooms that are not occupied. This detailed example of the sequencing of the building turning off the lights in a bathroom is a part in a matrix of other systems in other places in the house, which conveys the interactive nature between sensors and the inhabitants' activities.

This scenario describes the action procedure taken if the washroom lights are turned on. As soon as lights are manually switched on, the system waits to sense these following triggers, which can determine if the washroom is no longer occupied and therefore the lights have accidentally been left on and need to be turned off. The sensors used in this example will sense daylight, motion, pressure, time, and proximity. The first question the system will ask itself is if there is enough daylight in the room for the lights to be turned off. If it is mid day, it might notify the user immediately that the lighting requirements are already being met naturally. If it is not sufficient, the following triggers must also be met. One of the earliest triggers would be a timer, which would prevent the lights from switching off immediately in case that someone might have left the washroom quickly to tend to a kettle or grab a hair brush. The system would be programmed to allow a grace period for any reason, such as comfort, or if the users are using it as reminders for their children to save energy, and therefore want a longer grace time by the system to give a chance for the children to return and do it themselves. However, if the lights have been on over a specified period of time, then that would release a trigger for shut off. Motion sensors would detect any movements in the room, indicating occupancy and therefore keeping the lights on. A pressure sensors within the door hardware is able to relay information that the door is locked giving another indication that someone is inside the washroom. Even with all those checks, someone could, for example, be simply standing still in front of the mirror with the door open applying makeup, which would require extra lighting, therefore proximity sensors placed in the flooring give the system another degree of information warning it of occupancy in the washroom. Once all these triggers have been activated the result is compared with the historical database which could provide different parameters, for example lights in the washroom are not on for over five minutes at 3am, but the timer is set differently for 7am. Then the final step is notification before the system shuts the lights off. There are numerous ways for this to take place, but for this example, the lights would dim from a 100% value to 60% for 3-5 seconds, which gives a chance for user intervention. So if there is a user in the washroom and has somehow remained motionless and the sensors were still unable to pick them up, the dimming would warn the user to move or hit the switches to override the shut off sequence.

Similar to an intelligent organism assessing a situation in order to react, the above example shows the filtering of conditions required by these sensors for an accurate response to take place. There are some products on the market now which have taken steps with sensors, and improved existing detectors, to become integrated systems and better tools of measurement and productivity. The thermostat designed by Nest Labs, is one that introduces this level of sensor interaction for a specific purpose (Nest Labs, 2012). Another product is "Mirror of Water Life" designed by Jin Kim. This mirror records and digitally displays the users amount of water used daily, monthly and yearly. The depth of the colours represent the amount of water that runs through the sink and 4 small informing icons give inspiring notification of water usage. If water usage exceeds acceptable amounts for an ecosystem, then the icon shows a family of polar bears stranded on a melting iceberg. Another icon displays user water waste and usage by counting the number of times an African child must walk 10km each way to fill a bucket of water. These icons are meant to realize the importance of water conservation and responsible water usage (Burns, 2010).

The expressive nature of water usage displayed with this one product, is what a whole building can accomplish with sensors. The experience of users washing their hands and brushing their teeth is now influenced by this mirror that reminds them through digital means of the amount of water they consume and how that can translate into a social and environmental issue. A building with sensors is able to demonstrate similar ideals through expressive means of its architecture and services. For example, instead of water collection being hidden in downspouts, exposing the water allows users to see the collection and be reminded that they are dependent on the natural environment, creating a shift in their water usage. Sensors play passive roles in the expressive manner water is collected by actuating sounds off roof collection as well as digital roles in detailed monitoring and warning when supplies are reaching lows.

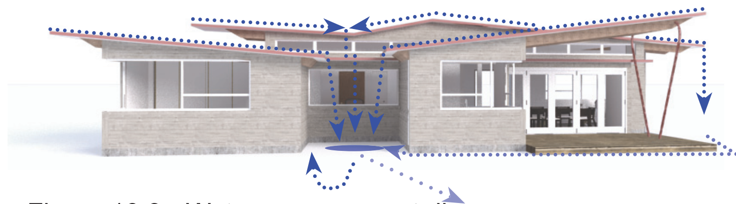


Figure 10.3 - Water management diagram

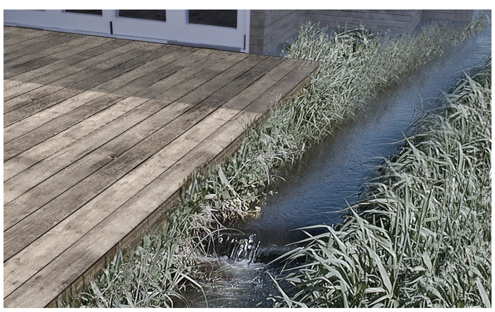


Figure 10.4 - Designed stream expresses water collection process

Figure 10.5 - Water collected off roof celebrated as waterfall over reading nook and gathered into collection stream

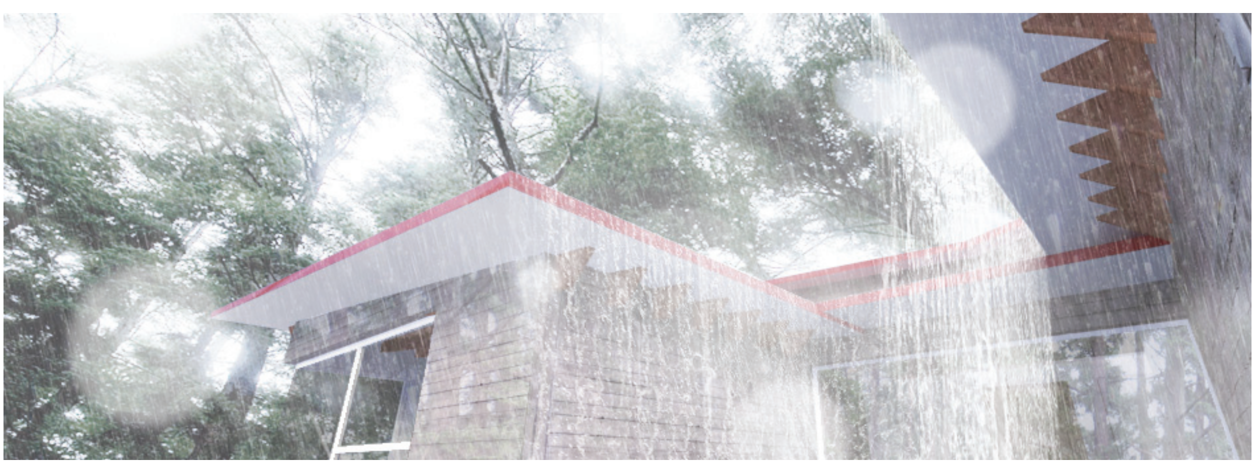


Figure 10.6 - Rainwater collected by stream and cascading waterfalls over office area into pond for treatment and use

Expression

As designers we are responsible for artifacts, which users engage with to create their own experiences. The expression of that armature is what creates greater experiential possibilities. If we have 2 identical spaces (white cubes for examples) (see Figure 11.1), and 2 different users are engaged with those spaces, the experience of each users starts the same way. But as they occupy that space, the expression of the space transforms because of them and as they engage different parts and elements of those spaces, their experience grows into a collection of expressive memories. In the end, 2 identical spaces have different identities and expressive qualities because of the users habitation, not because of the designers intentions. Sensors add a dynamic to the traditional design solutions allowing those intentions to be expressed easier.

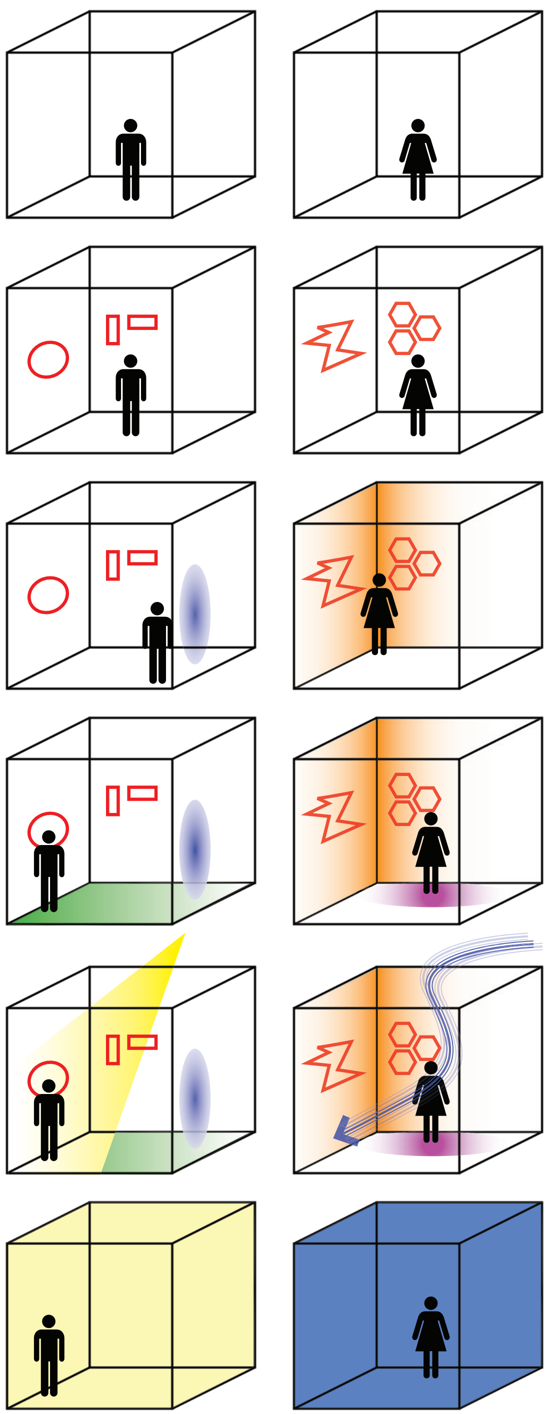


Figure 11.1 - Experience of users

Providing a normative armature limits the expression of the building and the experience of its users. Adding sensors in all aspects of the buildings make that expression richer by allowing the designer more control over the buildings reactions to elements, such as how to respond when it's sunny compared to raining. That expression in a normative building is limited as the building is designed for both situations with one result, but sensors allow the building to have a different expression for each scenarios.

The sensors used in this project include both passive and active strategies, as well as an integration into all aspects of the building which allows for a richer experience. Sensors are implemented and used in different parts of this designed house, such as: access control, fire safety, temperature and user tracking, ventilation, visual connections, danger prevention, lighting, personalized aesthetics, security, structural monitoring, water usage, etc. The individual sensors are categorized under their technical groupings such as energy, weather, users, etc, but the sensors themselves have their own expressive qualities about them as well. This sensory output characterization is not applied to individual sensors, but because of their integration with one another, and with the building systems, this characterization represents the output potential of the sensors and acknowledges the different levels of user intervention. There are 3 sensor characterizations: safety, cyclic and expression. These three characterizations bring three levels of user intervention.

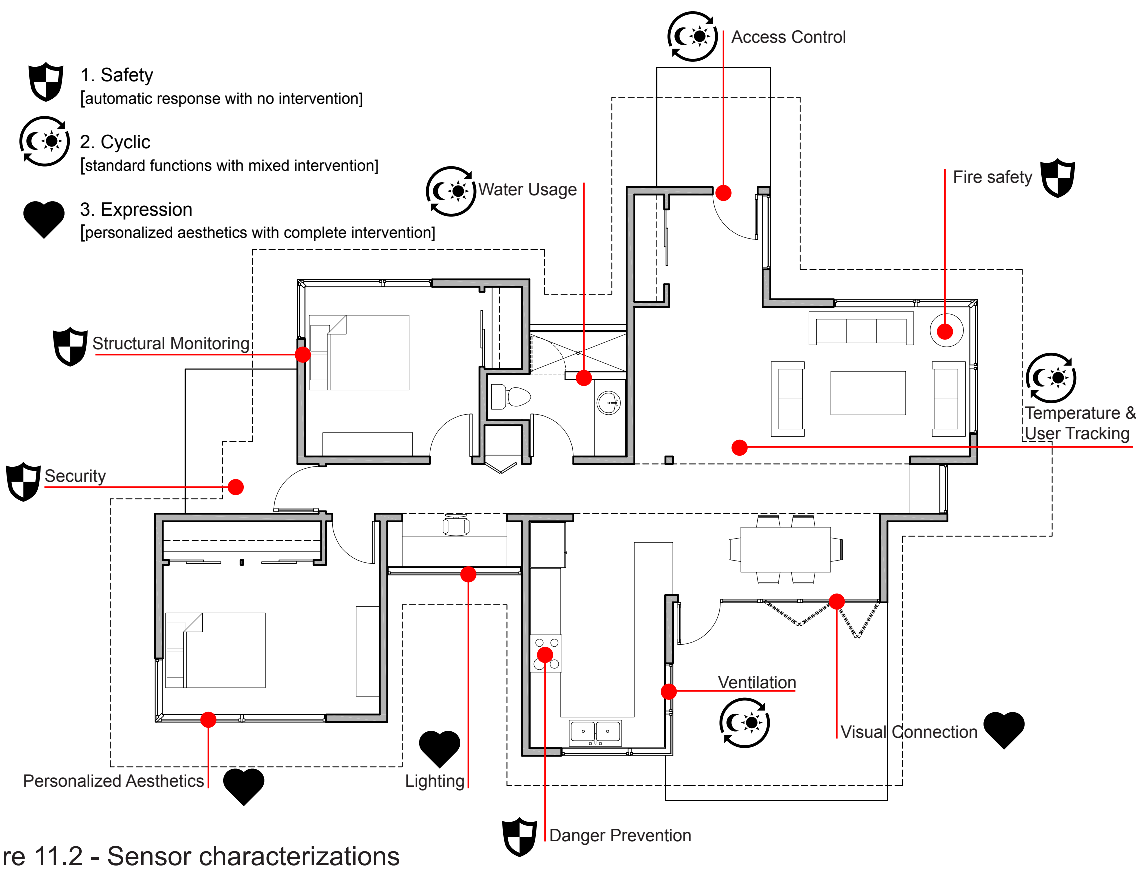


Figure 11.2 - Sensor characterizations

"Safety" characterization is given to elements that sense and respond to safety issues and have automatic responses, such as: fire safety, danger prevention, security and structural monitoring. As an example, structural monitoring would include sensors that are placed within walls, ceilings and other structural elements to monitor any type of failure (moisture, etc). Moisture sensors placed within the walls can gather data and relay any warning signs to the users of any moisture and humidity buildup in the wall cavities which can lead to mold and serious health issues. Similar sensors are also placed around fixtures and appliances to inform users of their performance and any possible failures with them as well. Sensors placed in wall cavities will also be responsible for reading any changes in the structural integrity, from wind forces, snow loads, earthquakes, etc. Sensors in Japan are being commercialized and introduced in residential buildings to sense approaching earthquakes which trigger an air compressor that lifts the structure and keeps is floating in the air up to 3cm off its foundation, protecting the building from potential damage (Babalola, 2012). This characterization has the lowest amount of user intervention. Users are not required to change the elements that are covered under the "safety" characterization. Smoke detectors, fire alarms and moisture meters don't have much customization involved with them and function fully automatically.

The "Cyclic" characterization represents those elements that are temporal, such as access control, water usage, ventilation, and temperature control. These elements respond differently depending on their scheduled programs, either daily, weekly, or annually and also have mixed and moderate levels of user intervention as they control standard functions. As each users schedule is different, each of these elements responds to their needs by user input and historical recollection and educated assumptions. The difficulties with precise temperature readings in a room has already been discussed, and a solution is to increase the number of thermometers in a room to increase the amount of data, which will cause better mechanical system judgments to be made when heating or cooling a space. To increase the precision of temperature readings, thermal lasers and sensors are installed in the ceiling and at the floor level within the baseboards. This creates an entire thermal grid of the building. These lasers also function to track user movements throughout the house. The sensors installed in the ceiling as well as a horizontal grid located at the floor level, allows much more accurate room temperature readings and user location and identification. Identification is required to confirm custom preferences are met and history of scheduled use is kept. All this data results in more accurate responses from the network.

The importance of user identification and location is much more apparent with the last characterization, "Expression", which has complete user intervention and is used for personalized aesthetics. Elements such as visual connections, custom experiences and lighting. Lighting, as an example, is controlled with requested user light levels at certain spot locations like the office space. A lighting grid of LEDs installed within the ceiling also follows users as they move through the house. For example, as a user wakes up in the middle of the night to get a glass of water or use the washroom, low level and soft coloured lights follow and guide the user to their destination by predicting their movement, furthermore, the path is lit again to guide them back to their bed. This spotlight focuses the users vision within this small radius, expressing the hallway, for example, in a much smaller space of a few meters, rather than the larger linear axis it expresses in the daytime (see Figure 11.3).

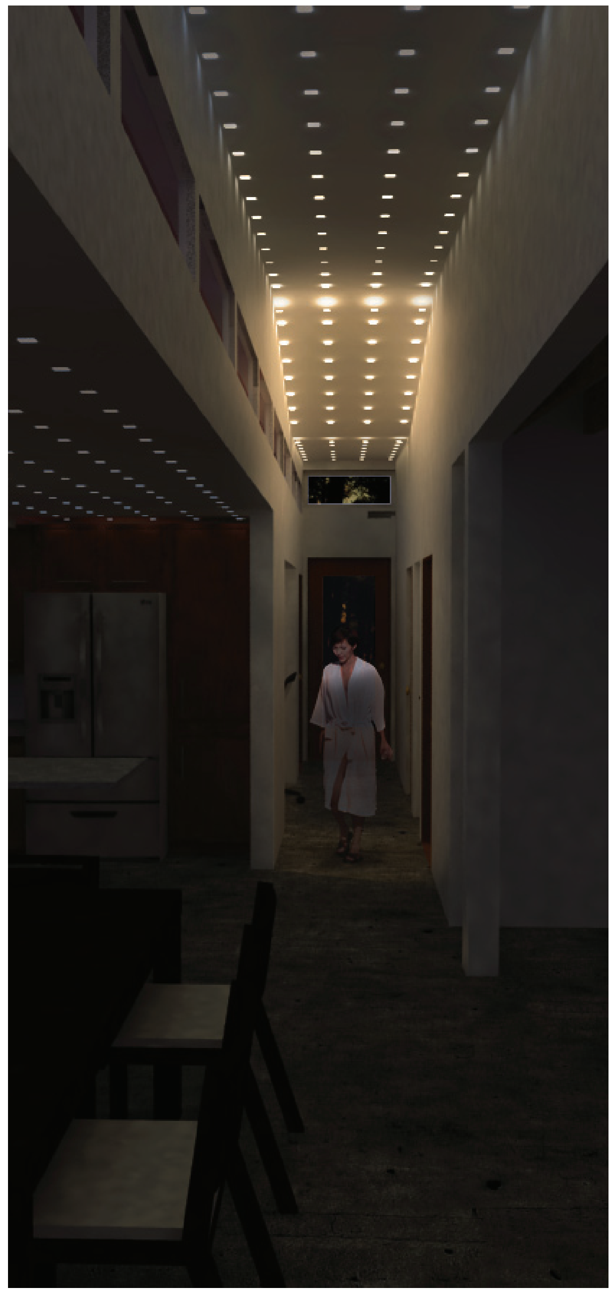


Figure 11.3 - Night, light tracking of users

The introduction of different users is the most dynamic element of any space. Even in a house where the users remain relatively the same, their movement and varied activities creates different experiences for themselves and each other. With sensors we can design for specific situations. For example; As the designer, I want anyone that sits at the desk to have a view of the ocean. So sensors will adjust the shades as required to maximize the view while maintaining comfortable work lighting. The ideal condition is when the sun is not shining directly on the work surface, therefore the shades are folded up. But once the sunlight gets stronger, the shades drop only to cover what is needed maximizing the view and then depending on the season, the shades angle themselves while still maintaining views as much as possible. As the designer I also want the expression of the open water to be carried through, so I have programmed the matrix to open the window and allow a fresh breeze to come in after 30 minutes for 20 minutes and cycle this pattern. And finally task lighting turns on to balance the

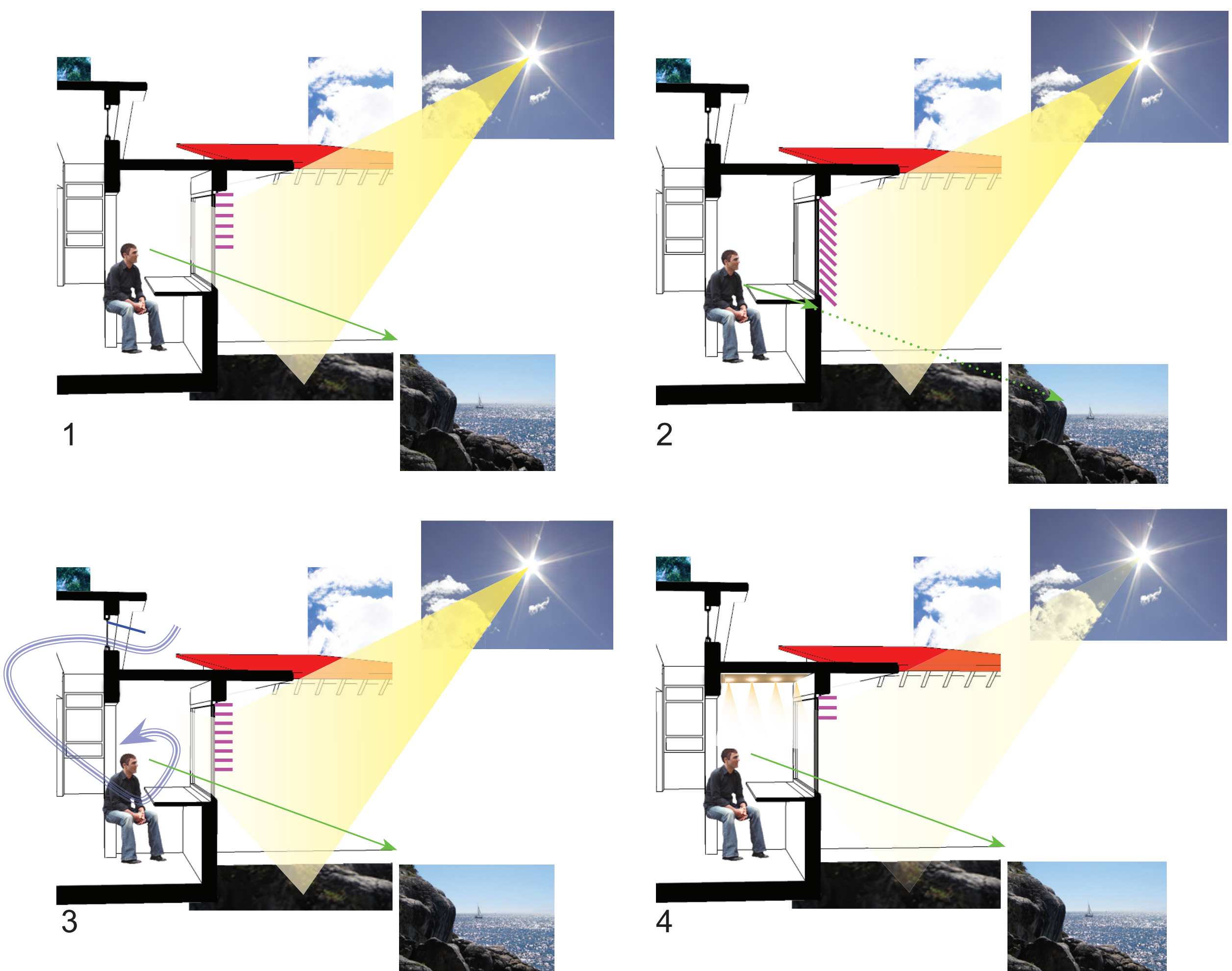


Figure 11.4 - Designed work space

lighting once more maintaining a workable lighting surface . By designing the building to respond this way, with this situation, I have given this space different expressions. The experience of the user is now richer because of my intentions. The building responding in this manner shows the user that he does not need to close the blinds completely to enjoy his workspace.

A normative building has been designed using all the traditional design elements and strategies such as form, material, colour, etc. and takes into consideration context, site, climate, and so on. It has been introduced with users, who now occupy the building and now have an interactive relationship with the building. The users create their own experiences from the expressions of the house that they discover. With a normative house, the experiences that they have created are as simple as different colours; but with sensors which give designers more opportunity for expression, which is then shared with users, these experiences that they come to have are more vibrant, rich and poetic.

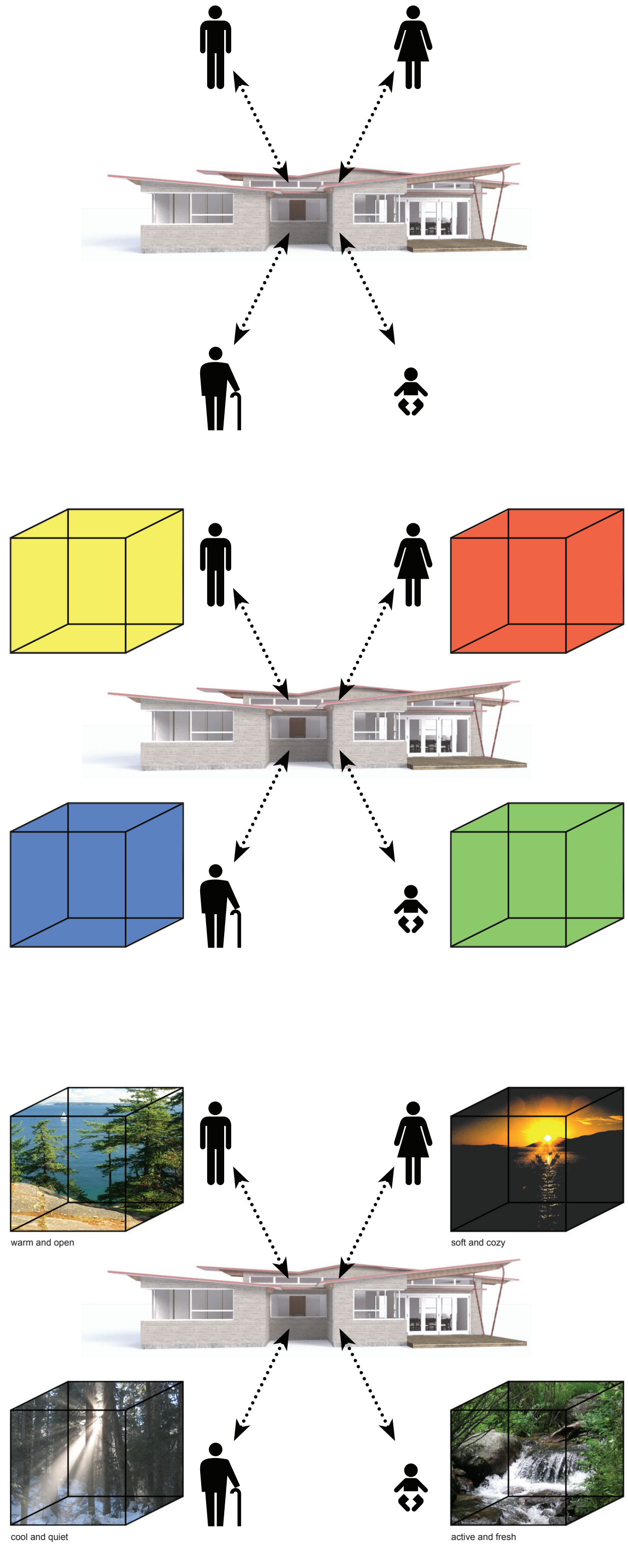


Figure 11.5 - Comparing the experience of users interacting with a normative building and with one designed with sensors

Therefore, a designed building in its context may be captured like this (Figure 11.6) but because of sensors it is experienced by children like this (Figure 11.7)

Figure 11.6 - South elevation of designed building and site context

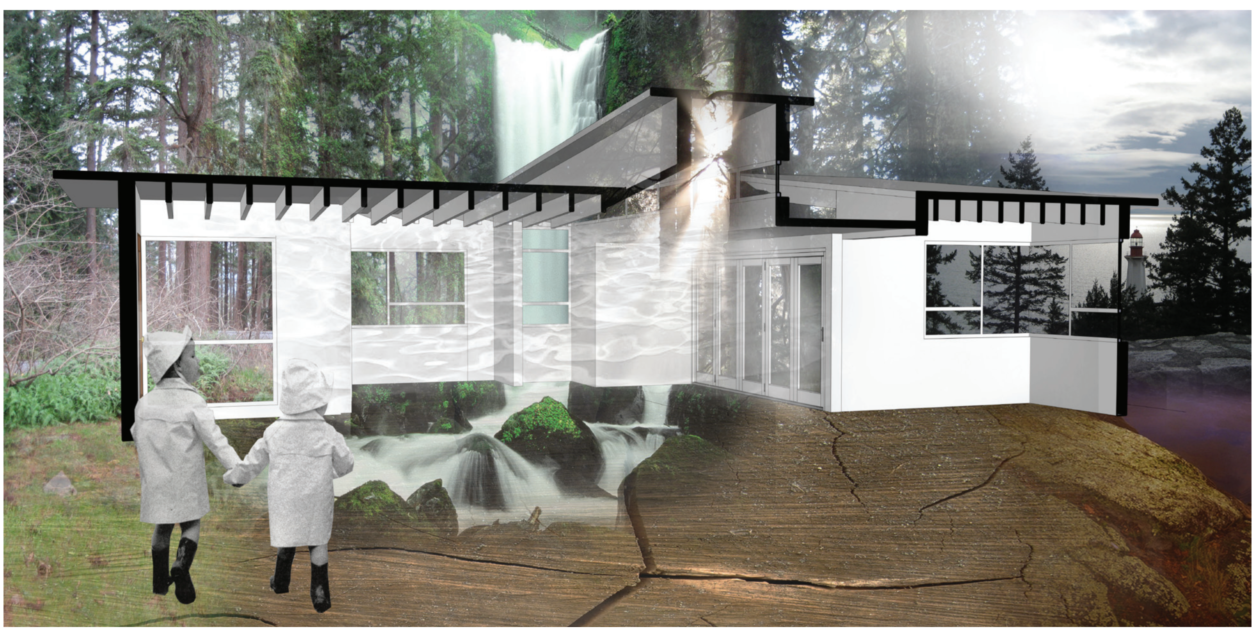


Figure 11.7 - Building and site context experienced by users

The office nook may be designed like this (Figure 11.8) but because of sensors it is expressed differently and the user experiences this (Figure 11.9)

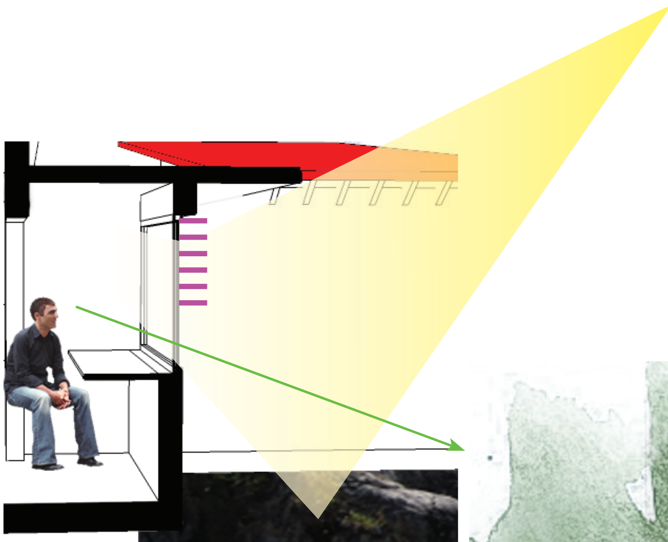


Figure 11.8 - Schematic of work space

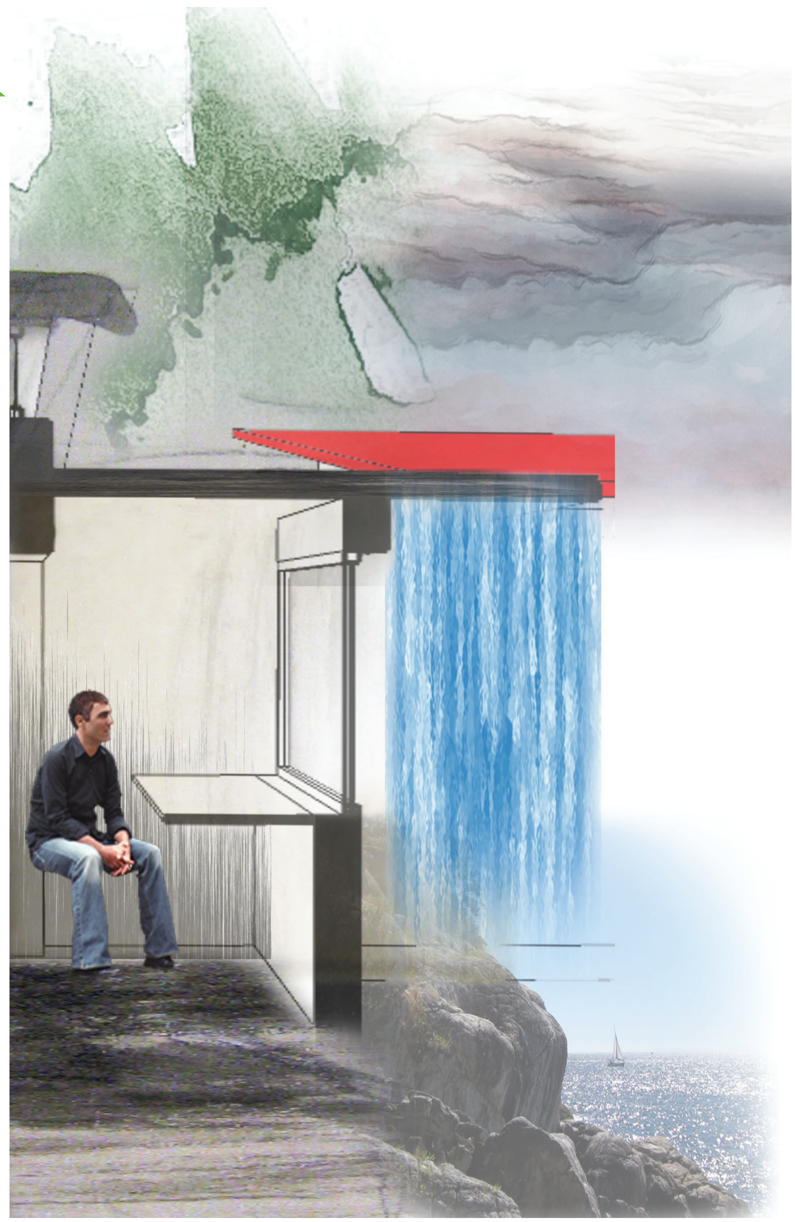


Figure 11.9 - Office space of house experienced by user

When she gets up in the middle of the night for a glass of water, the house may seem like this (Figure 11.10) but her experience is this (Figure 11.11)

Figure 11.10 - Rendering of user night-light tracking

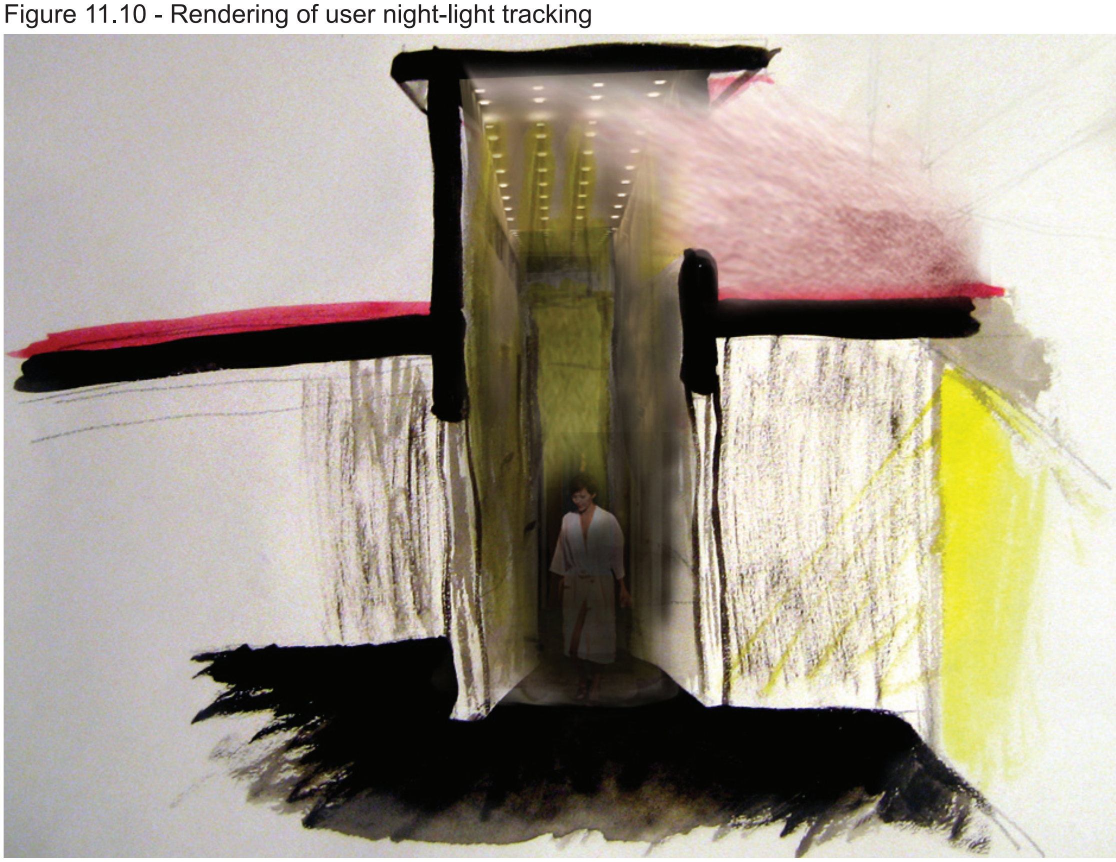


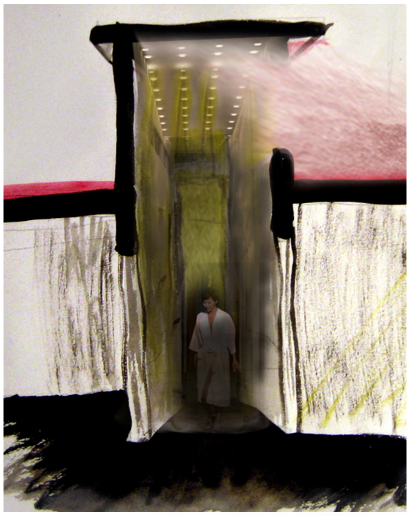
Figure 11.11 - Rendering of expression sensed by user

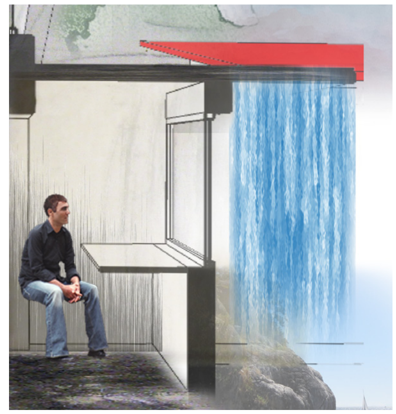
And the dining area may look like this (Figure 11.12), but expressively is feels like this (Figure 11.13)

Figure 11.12 - Rendering of dining area looking East at sunset

Figure 11.13 - Expressive rendering of dining space

Then when 2 individual expressions come together, the same building is experienced completely differently as a merger of both expressions and experiences (Figure 11.14)





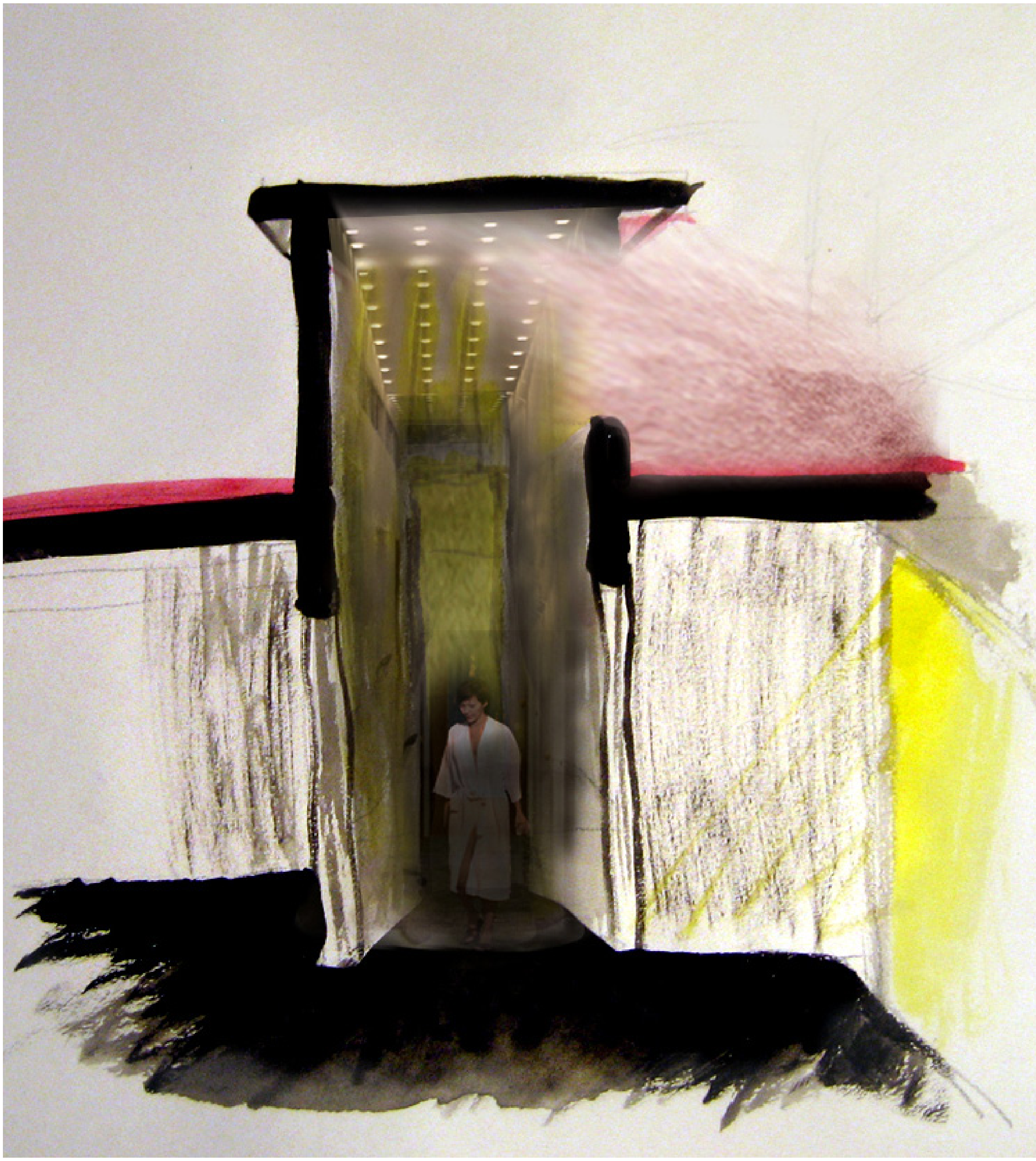


Figure 11.15 - Expressive rendering

Conclusion

All biological organisms have sensors and need them to survive. In addition to having organic sensors as a natural part of our external and internal bodily systems, humans have incorporated electro-mechanical sensors and actuators into all aspects of our lives through the use and advancement of technology. These technological sensory advancements have not yet been fully integrated into buildings. Instead of a separation between buildings and technology, sensors bring a level of integration and union between user and building creating opportunities for expression.

By using a large number and variety of sensors, single conditions are not read by the sensor and responded to, but rather entire contexts are interpreted. Sensors, distinguished by one of the three characters mentioned (safety, cyclical and expression), allow specific tasks and results to be organized and orchestrated. By having different levels of user intervention, a space changes aesthetically as per each interaction, without compromising essential monitors.

The value of using sensors integrated with an entire building, within all its layers, is one that results in a subtle and near invisible realm of operation. It leads to an approach and result that the entire building acts like an organism, in the sense of an organization of technical devices. The expression of the building is a result of the unique and constantly changing criteria and involvement of users and the building/environment interface. The utilization of sensors creates a building that is poetic, which stimulates human senses, and uses sensors to support those experiences.

Combining sensors with the traditional design strategies that form and design space, such as the deployment of light and colour in a project, we now have another layer of sensors to further work with these traditional elements to produce poetic spaces by adding layers of expressive opportunities. With sensors, a designer has the opportunity to create further representations of their expressive intentions, leaving users with richer experiences. Sensors become an element that further drives architecture within this expressive dimension.

Appendix A - Designed

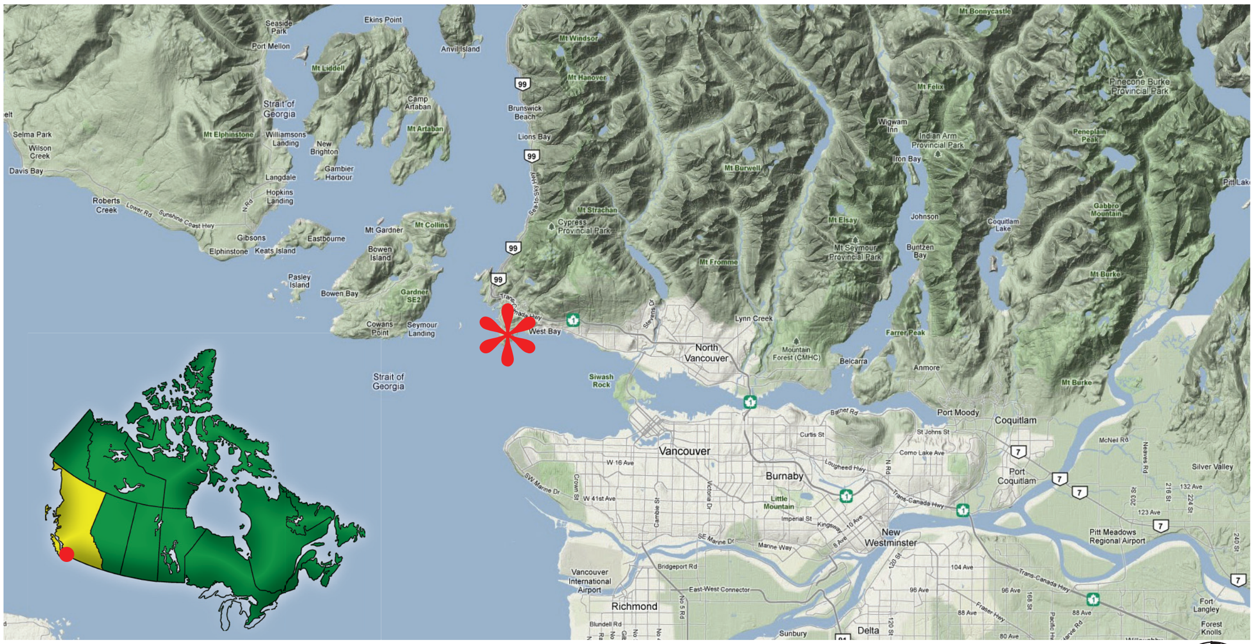


Figure A.1 - Site location: West Vancouver, BC

Figure A.2 - Site location

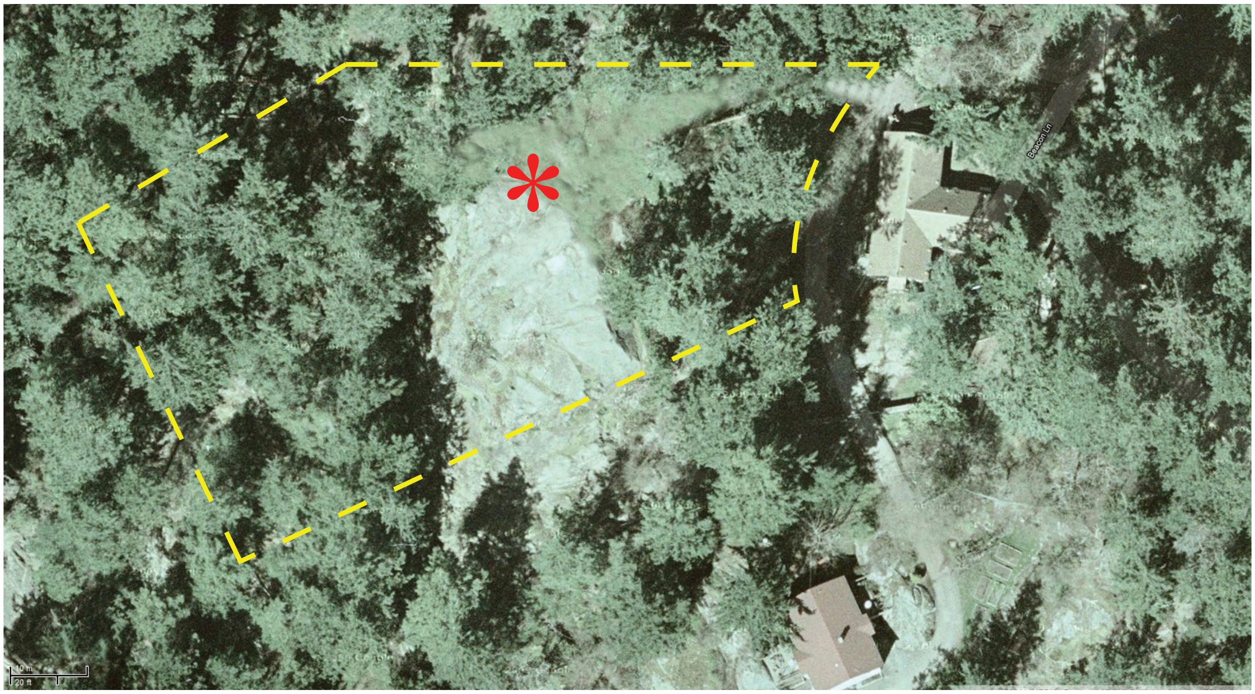


Figure A.3 - Building location on site plan

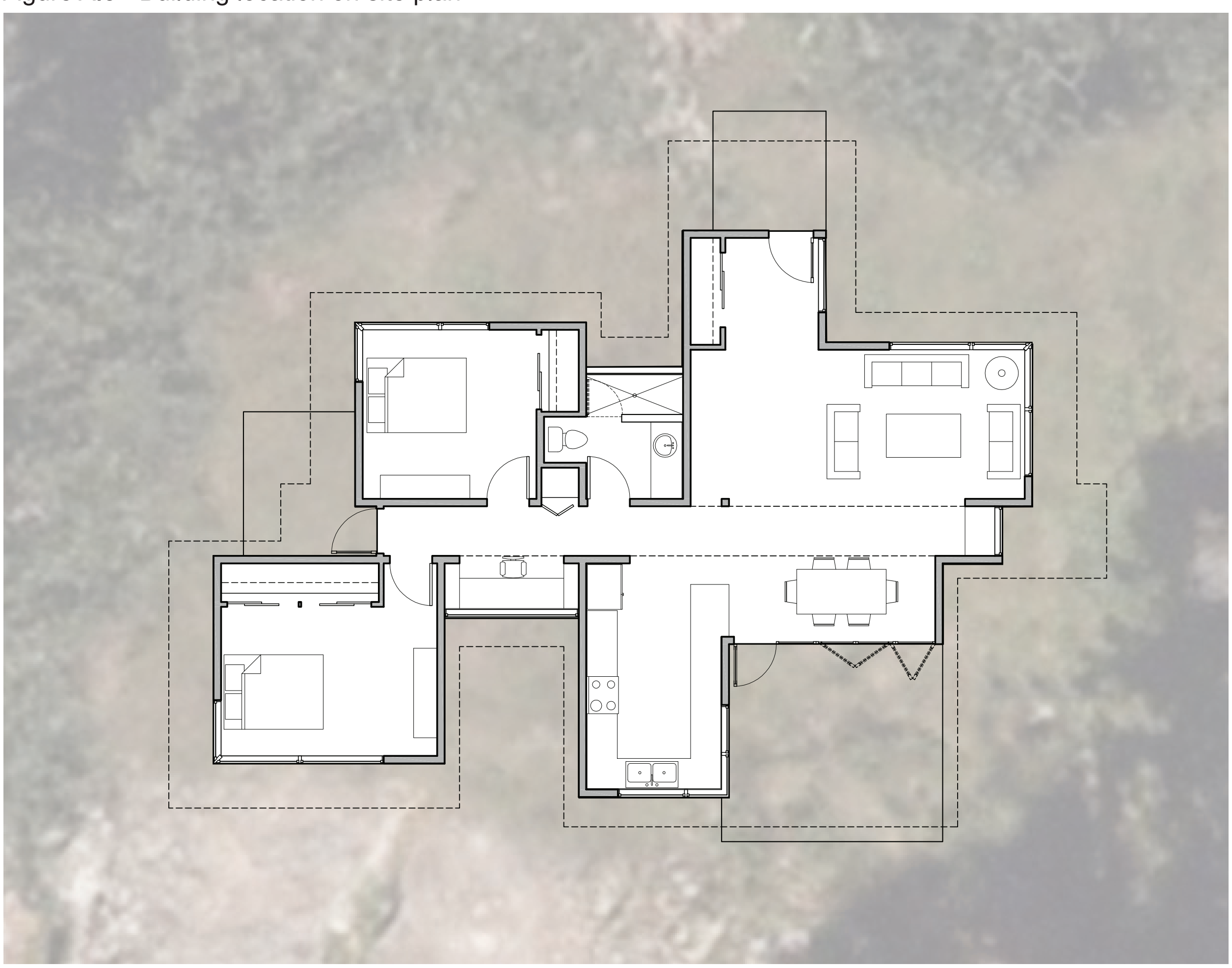


Figure A.4 - Building floor plan


Figure A.5 - South elevation of designed building looking North with site context

Figure A.6 - Exterior rendering of building looking North-West

Figure A.7 - Dining room wall designed to open in warm days to create larger open space changing the space, expression and experiences

Figure A.8 - Sensors change lighting based on outdoor conditions

Figure A.9 - Building lit at night

Figure A.10 - The red roofs of the house is an expression of the lighthouse buildings

Figure A.11 - Expressive collage of site and experience of users

Figure A.12 - (July) The metal roofs reflect a red glow indoors onto the ceiling expressing weather and light

Figure A.13 - (October) Direct sunlight increases while redness decreases expressing cooler temperatures

Figure A.14 - (January) Redness of ceiling gone and direct solar gain maximized

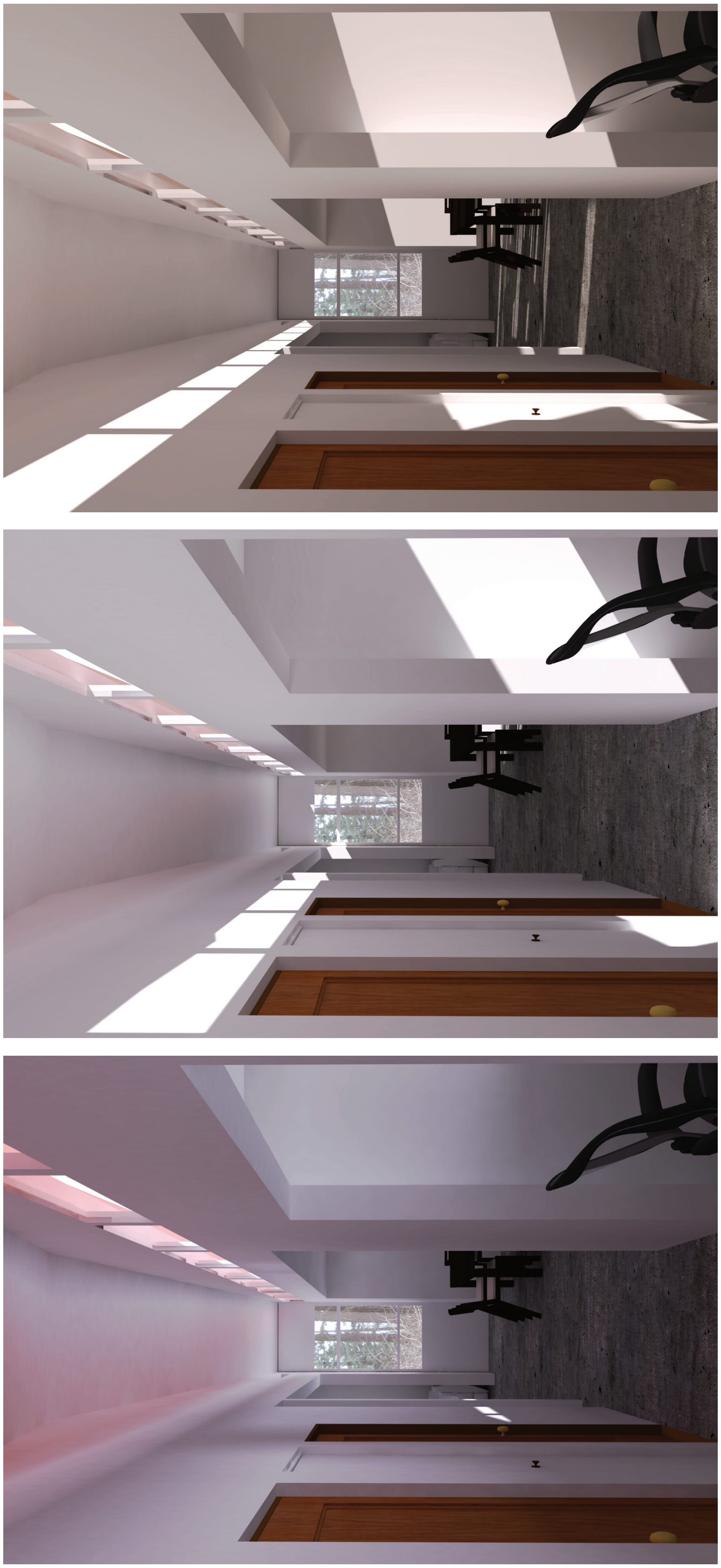


Figure A.15 - Comparison of all three sceneries (July, October, January)

Figure A.16 - Light reflects off water off flat roof and onto ceiling expressing weather change

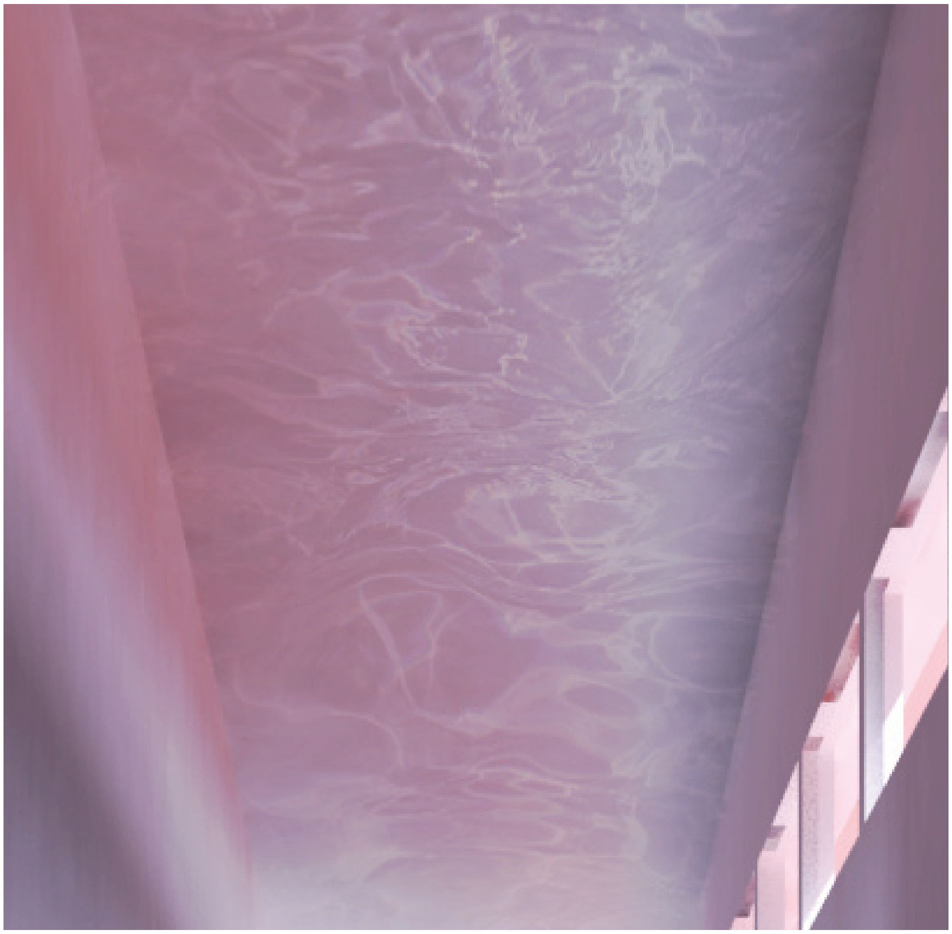


Figure A.17 - Closer look at rippled reflections

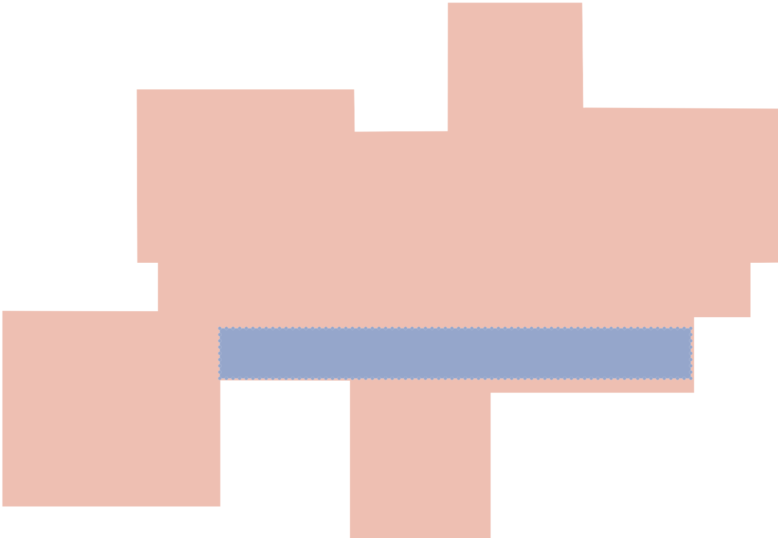


Figure A.18 - Location of flat roof indicated in blue


Figure A.19 - Sensors designed to turn lights to maximum when indoors active

Figure A.20 - Lights remain off expressing softness when indoors sensed quiet

Figure A.21 - Waterfalls created as expression of weather and water collection (looking at reading nook)

Figure A.22 - Waterfalls over office space into pond

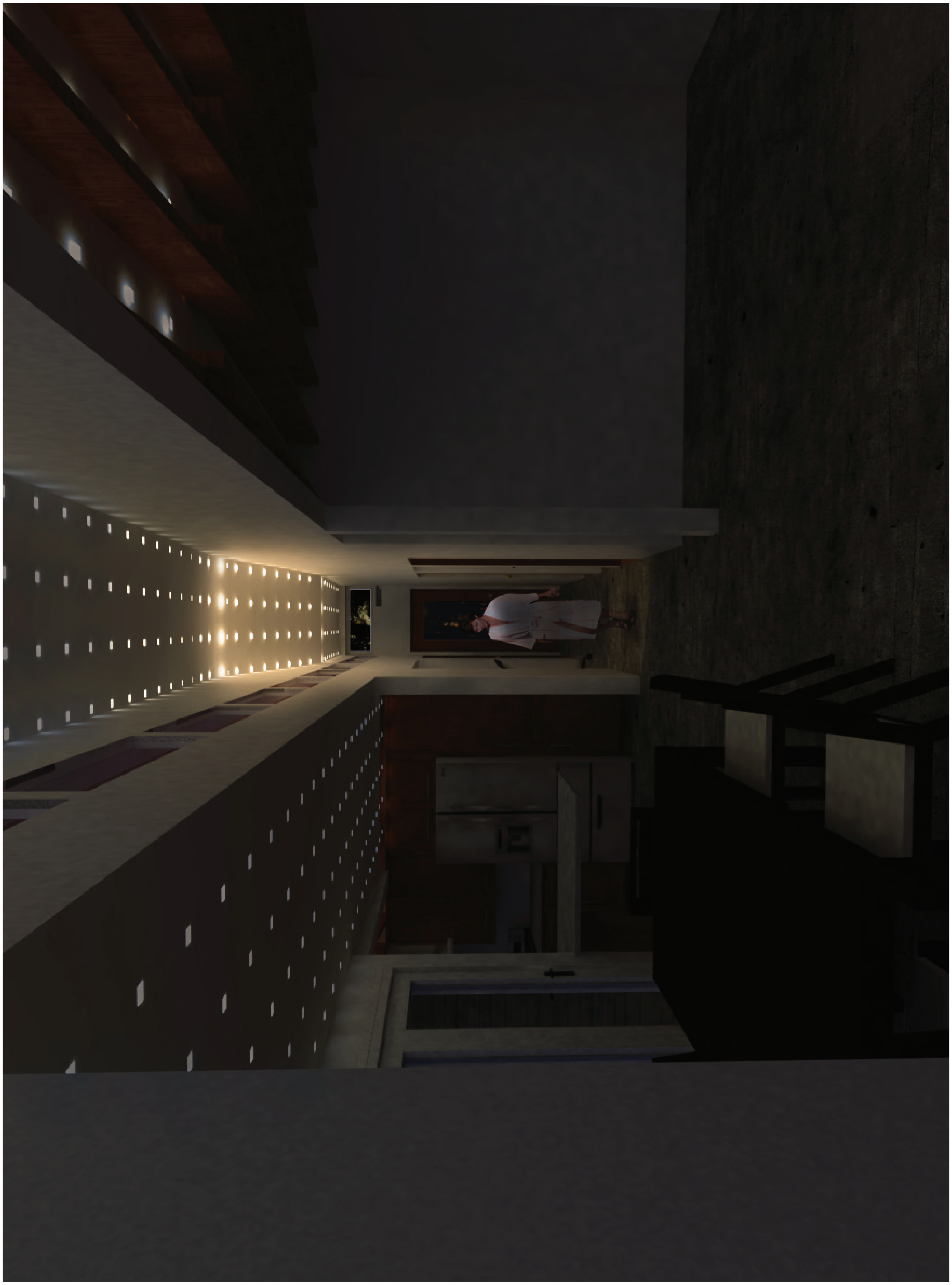


Figure A.23 - Rendering of user tracking with lighting to help guide users at night

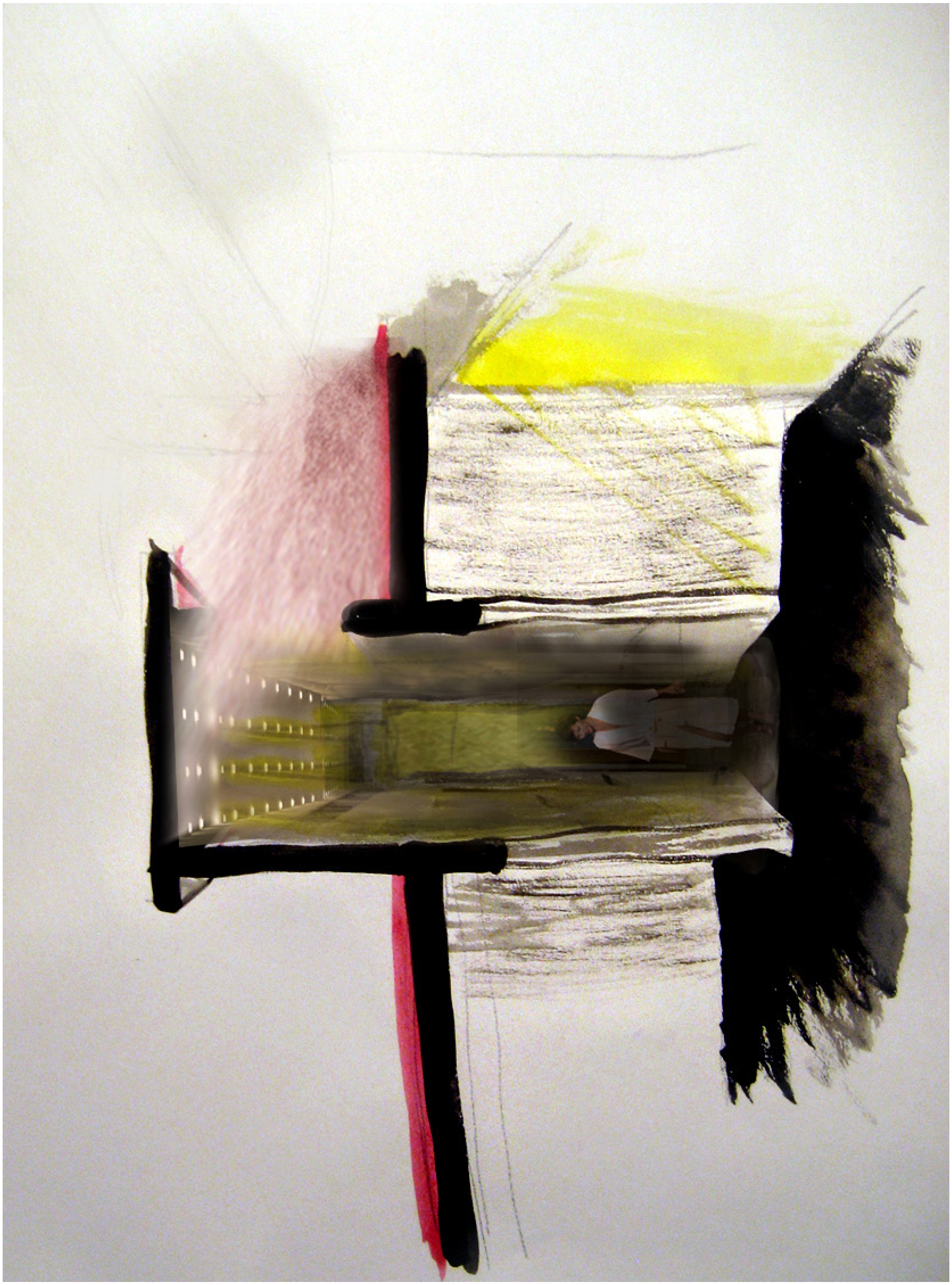


Figure A.24 - Rendering of the expression felt by users through the hallway space.

Figure A.25 - Rendering representing experience of user in dining space

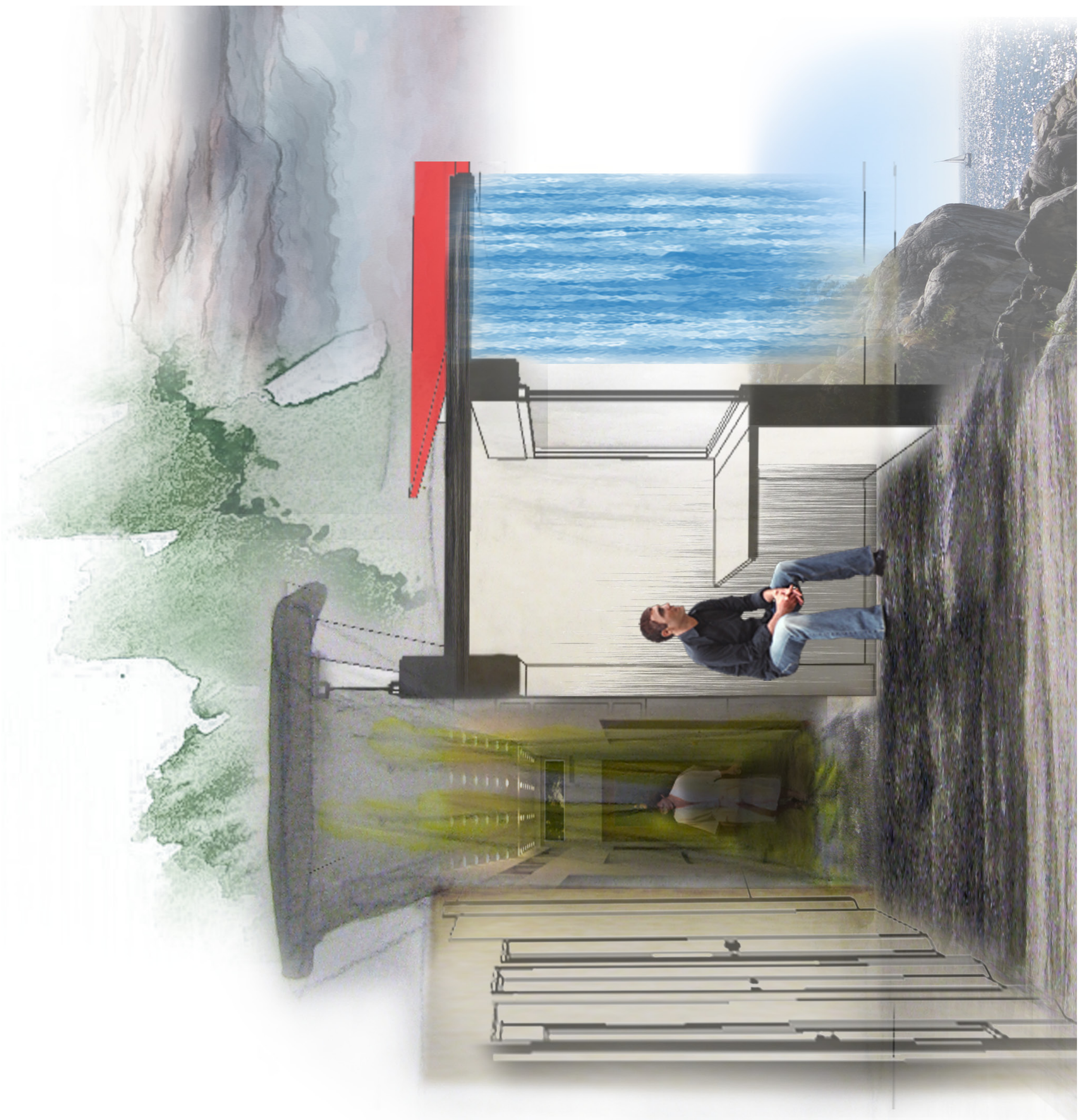


Figure A.26 - Painted collage of users as their individual experiences influence and merge with each other creating a new expression

Appendix B - List of sensors

Acoustic, sound, vibration
- Geophone
- Hydrophone
- Lace Sensor, *a guitar pickup*
- Microphone
- Seismometer

Automotive, transportation
- Air-fuel ratio meter
- Blind spot monitor
- Crankshaft position sensor
- Curb feeler, *used to warn driver of curbs*
- Defect detector, *used on railroads to detect axle and signal problems in passing trains*
- Engine coolant temperature sensor, or ECT sensor, *used to measure the engine temperature*
- Hall effect sensor, *used to time the speed of wheels and shafts*
- MAP sensor, Manifold Absolute Pressure, *used in regulating fuel metering.*
- Mass flow sensor, or mass airflow (MAF) sensor, *used to tell the ECU the mass of air entering the engine*
- Oxygen sensor, *used to monitor the amount of oxygen in the exhaust*
- Parking sensors, *used to alert the driver of unseen obstacles during parking manoeuvres*
- Radar gun, *used to detect the speed of other objects*
- Speedometer, *used measure the instantaneous speed of a land vehicle*
- Speed sensor, *used to detect the speed of an object*
- Throttle position sensor, *used to monitor the position of the throttle in an internal combustion engine*
- Tire-pressure monitoring sensor, *used to monitor the air pressure inside the tires*
- Torque sensor, or torque transducer or torquemeter *measures torque (twisting force) on a rotating system*.
- Transmission fluid temperature sensor, *used to measure the temperature of the transmission fluid*
- Turbine speed sensor (TSS), or input speed sensor (ISS), *used to measure the rotational speed of the input shaft or torque converter*
- Variable reluctance sensor, *used to measure position and speed of moving metal components*
- Vehicle speed sensor (VSS), *used to measure the speed of the vehicle*
- Water sensor or water-in-fuel sensor, *used to indicate the presence of water in fuel*
- Wheel speed sensor, *used for reading the speed of a vehicle's wheel rotation*

Chemical
- Breathalyzer
- Carbon dioxide sensor
- Carbon monoxide detector
- Catalytic bead sensor
- Chemical field-effect transistor
- Electrochemical gas sensor
- Electronic nose
- Electrolyte–insulator–semiconductor sensor
- Fluorescent chloride sensors
- Holographic sensor
- Hydrocarbon dew point analyzer
- Hydrogen sensor
- Hydrogen sulfide sensor
- Infrared point sensor
- Ion-selective electrode
- Nondispersive infrared sensor
- Microwave chemistry sensor
- Nitrogen oxide sensor
- Olfactometer
- Optode
- Oxygen sensor
- Pellistor
- pH glass electrode
- Potentiometric sensor

Redox electrode
Smoke detector
Zinc oxide nanorod sensor

Electric current, electric potential, magnetic, radio
Current sensor
Galvanometer
Hall effect sensor
Hall probe
Leaf electroscope
Magnetic anomaly detector
Magnetometer
MEMS magnetic field sensor
Metal detector
Planar Hall sensor
Radio direction finder
Voltage detector

Environment, weather, moisture, humidity
Actinometer
Bedwetting alarm
Ceilometer
Dew warning
Electrochemical gas sensor
Fish counter
Frequency domain sensor
Gas detector
Hook gauge evaporimeter
Humistor
Hygrometer
Leaf sensor
Pyranometer
Pyrgeometer
Psychrometer
Rain gauge
Rain sensor
Seismometers
SNOTEL
Snow gauge
Soil moisture sensor
Stream gauge
Tide gauge

Flow, fluid velocity
Air flow meter
Anemometer
Flow sensor
Gas meter
Mass flow sensor
Water meter

Ionising radiation, subatomic particles
Bubble chamber
Cloud chamber
Geiger counter
Neutron detection
Particle detector
Scintillation counter
Scintillator
Wire chamber

Navigation instruments
Air speed indicator
Altimeter
Attitude indicator
Depth gauge
Fluxgate compass
Gyroscope
Inertial navigation system
Inertial reference unit
Magnetic compass
MHD sensor
Ring laser gyroscope
Turn coordinator
Variometer
Vibrating structure gyroscope
Yaw rate sensor

Position, angle, displacement, distance, speed, acceleration
Accelerometer
Auxanometer
Capacitive displacement sensor
Capacitive sensing
Free fall sensor
Gravimeter
Gyroscopic sensor
Inclinometer
Integrated circuit piezoelectric sensor
Laser rangefinder
Laser surface velocimeter
LIDAR
Linear encoder
Linear variable differential transformer
Liquid capacitive inclinometers
Odometer
Photoelectric sensor
Piezoelectric accelerometer

- Position sensor
- Rate sensor
- Rotary encoder
- Rotary variable differential transformer
- Selsyn
- Sudden Motion Sensor
- Tilt sensor
- Tachometer
- Ultrasonic thickness gauge
- Variable reluctance sensor
- Velocity receiver

Optical, light, imaging, photon

- Charge-coupled device
- Colorimeter
- Contact image sensor
- Electro-optical sensor
- Flame detector
- Infra-red sensor
- Kinetic inductance detector
- LED as light sensor
- Light-addressable potentiometric sensor
- Nichols radiometer
- Fiber optic sensors
- Optical position sensor
- Photodetector
- Photodiode
- Photomultiplier tubes
- Phototransistor
- Photoelectric sensor
- Photoionization detector
- Photomultiplier
- Photoresistor
- Photoswitch
- Phototube
- Scintillometer
- Shack-Hartmann
- Single-photon avalanche diode
- Superconducting nanowire single-photon detector
- Transition edge sensor
- Visible light photon counter
- Wavefront sensor

Pressure

- Barograph
- Barometer
- Boost gauge
- Bourdon gauge
- Hot filament ionization gauge
- Ionization gauge
- McLeod gauge
- Oscillating U-tube
- Permanent Downhole Gauge
- Pirani gauge
- Pressure sensor
- Pressure gauge
- Tactile sensor
- Time pressure gauge

Force, density, level

- Bhangmeter
- Hydrometer
- Force gauge
- Level sensor
- Load cell
- Magnetic level gauge
- Nuclear density gauge
- Piezoelectric sensor
- Strain gauge
- Torque sensor
- Viscometer

Thermal, heat, temperature

- Bolometer
- Bimetallic strip
- Calorimeter
- Exhaust gas temperature gauge
- Flame detection
- Gardon gauge
- Golay cell
- Heat flux sensor
- Infrared thermometer
- Microbolometer
- Microwave radiometer
- Net radiometer
- Quartz thermometer
- Resistance temperature detector
- Resistance thermometer
- Silicon bandgap temperature sensor
- Special sensor microwave/imager
- Temperature gauge
- Thermistor
- Thermocouple
- Thermometer

Proximity, presence

- Alarm sensor

- Doppler radar
- Motion detector
- Occupancy sensor
- Proximity sensor
- Passive infrared sensor
- Reed switch
- Stud finder
- Triangulation sensor
- Touch switch
- Wired glove

Sensor technology
- Active pixel sensor
- Back-illuminated sensor
- Biochip
- Biosensor
- Capacitance probe
- Catadioptric sensor
- Carbon paste electrode
- Digital sensors
- Displacement receiver
- Electromechanical film
- Electro-optical sensor
- Fabry–Pérot interferometer
- Fisheries acoustics
- Image sensor
- Image sensor format
- Inductive sensor
- Intelligent sensor
- Lab-on-a-chip
- Leaf sensor
- Machine vision
- Microelectromechanical systems
- Micro-sensor arrays
- Photoelasticity
- Quantum sensor
- RADAR
- Ground-penetrating radar
- Synthetic aperture radar
- Radar tracker
- Sensor array
- Sensor fusion
- Sensor grid
- Sensor node
- Soft sensor
- SONAR
- Staring array
- Transducer
- Ultrasonic sensor
- Video sensor
- Visual sensor network
- Wheatstone bridge
- Wireless sensor network

Other sensors and sensor related properties and concepts
- Actigraphy
- Analog image processing
- Atomic force microscopy
- Atomic Gravitational Wave Interferometric Sensor
- Attitude control (spacecraft), Horizon sensor, Earth sensor, Sun sensor
- Catadioptric sensor
- Chemoreceptor
- Compressive sensing
- Cryogenic particle detectors
- Dew warning
- Diffusion tensor imaging
- Digital holography
- Electronic tongue
- Fine Guidance Sensor
- Flat panel detector
- Frame grabbers
- Functional magnetic resonance imaging
- Glass break detector
- Heartbeat sensor
- Hyperspectral sensors
- Intensity sensors and their properties
- IRIS (Biosensor), Interferometric Reflectance Imaging Sensor
- Laser beam profiler
- Littoral Airborne Sensor/Hyperspectral
- LORROS
- Millimeter wave scanner
- Magnetic resonance imaging
- Moire deflectometry
- Molecular sensor
- Nanosensor
- Nano-tetherball Sensor
- Omnidirectional camera
- Optical coherence tomography
- Phase unwrapping techniques
- Positron emission tomography
- Push broom scanner
- QuakeFinder, sensitive air-conductivity sensors
- Quantization (signal processing)

Range imaging
Scanning SQUID microscope
Single-Photon Emission Computed Tomography (SPECT) Smartdust
SQUID, Superconducting quantum interference device
SSIES, Special Sensors-Ions, Electrons, and Scintillation thermal plasma analysis package
SSMIS, Special Sensor Microwave Imager / Sounder
Structured-light 3D scanner
Sun sensor, Attitude control (spacecraft)
Superconducting nanowire single-photon detector
Thin-film thickness monitor
Time-of-flight camera
Trackball
Transcranial Magnetic Stimulation (TMS)
TriDAR, Triangulation and LIDAR Automated Rendezvous and Docking
Unattended Ground Sensors
Variable reluctance sensor

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