A Roadmap to Renewable Adaptive Recyclable Environmental (R.A.R.E.) Architecture

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ABSTRACT: R.A.R.E. stands for Renewable Adaptive Recyclable Environmental Architecture; the acronym expresses a demand that is becoming increasingly important today in the eyes of designers and clients. The paper draws on the contents and the pedagogical methods applied in a Building Technology Unit (SRT 450) – at forth year level – at the School of Architecture and Building, Deakin University, Australia. The unit is basically structured upon eight subjects derived as relevant to the research and development for a R.A.R.E. Architecture: Sustainable Site & Climate Analysis; Flexible & Adaptive Structural Systems; Renewable Adaptive & Environmental Building Materials; Modular Building Systems; Innovative Building Envelope Systems; Renewable or Non-conventional Energy Systems; Innovative Heating, Ventilation & Air Conditioning; Water Storage & Systems. The overall objective of the unit is to present a comprehensive overview of all these Sustainable Building Categories (SBCs) so that the students can produce a guide towards the design of a R.A.R.E. Architecture. The push towards a holistic and integrated approach will contribute to the definition of an innovative architecture, which is both progressive and sustainable.

Keywords: Sustainability, Architecture, Building Integration

1. INTRODUCTION

R.A.R.E. Architecture, in its most basic concept, can be considered as the oldest, albeit nowadays scarcely exploited, form of architecture in the world.

The very term R.A.R.E. already signifies a demand that today is becoming increasingly important in the eyes of designers and clients. In the acronym, actually, the four letters stand respectively: “R” for *Renewable*, energy-conserving and energy-producing products and materials; “A” for *Adaptive*, topography-, weather- and season-sensitive, climate responsive; “R” for *Recyclable*, flexible, reusable, simple to construct, relocate and de-construct; “E”, finally, for *Environmental*, working with Nature and its forces, touching and/or impacting upon the earth lightly. Obviously, the principles behind each letter are not to be considered individually, but rather it is the combination of all principles (letters) together that has to be regarded as an integral part of the design and construction processes on all architectural projects.

The acronym R.A.R.E. and the term Architecture, hence, do not have to be considered as an oxymoron. Actually, architectural forms based on adaptation to human needs and environmental changes can be seen around the world and from every culture and age. The *Tepee* of the North American Plains Indians, the *Bedouin Tents* of Northern Africa, or the *Yurt* of the Mongolians, were, and still are, easily constructed of pre-made pieces, completely built of renewable materials, and easily taken-apart or disassembled.

Nevertheless, while these structures manage to exemplify some of the concepts that lie behind a R.A.R.E. Architecture, for the typical modern human a more interrelated and sophisticated interface between the building components and the external elements is required to satisfy all the complex functional needs that are inherent to a contemporary construction.

The paper draws on the contents and the pedagogical methods applied in a forth year unit, Building Technology (SRT 450), at the School of Architecture & Building, Deakin University. The unit is structured upon eight subjects (Sustainable Building Categories or SBCs) derived as relevant to the research and development of a R.A.R.E. Architecture.

2. R.A.R.E. ARCHITECTURAL EDUCATION

2.1 The demand for R.A.R.E. Architecture

Today we are trying to develop a new form of architecture that is expected not only to serve the simple task of a filter “against” the elements, but is also required to provide the service functions which we are accustomed to. Many different environmental themes are quickly pushing their way to the front of the architectural design process: we are beginning to realise the limitedness of the resources of our planet.

It is in R.A.R.E. Architecture that we can identify the realisation of environmental design concepts and technologies. However, this innovative and integrated approach to building design cannot further develop and gain higher social acceptance without correct planning and smart, clear, presentation of its benefits.

A major problem faced with achieving a R.A.R.E. Architecture is the rather difficult inclusion or consideration in design prerequisites of “green” principles such as water collection, renewable and effective power systems, optimised operational performance of strategies, and so forth. Too often, in fact, their implementation occurs only after the pre-design scheme of the building has been sketched, making the integration of such techniques difficult to the extent that ESD mandates are often considered just as an added bonus to gain more points in green rating tools (something is then easy to sacrifice when, during construction, budgets run high).

To overcome this situation, a basic change of attitude has to happen in the mind of designers. To become R.A.R.E., the design of a building has always to be considered as an iterative and holistic process able to thoroughly integrate in architecture the opportunities offered by technological advances, optimizing the exploitation of the accessible resources and contributing to the physical, physiological and psychological well-being of occupants.

2.2 A R.A.R.E. Building Technology Unit

Building Technology (SRT 450, run by the authors) is a design-oriented unit investigating the planning implications of technical systems applicable to edifices of medium to high complexity. The design of buildings as total systems, energy efficiency and principles of sustainability form the agenda for this unit. SRT 450 aims to bring technology and design together within the framework of the Building Systems Integration (BSI) model described by Richard Rush, which considers buildings as holistic systems [1].

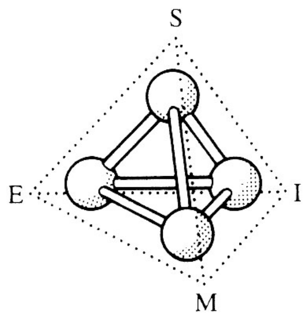

Figure 1: R. Rush's four building integrated systems (Structure, Envelope, Mechanical, Interior)

In substance, the final aims of the unit are, firstly, to emphasize the opportunities offered by design and technology decisions to improve the overall sustainability of built environments, contributing to energy efficiency and making an effective use of the available resources; secondly, to make the students understand that building technology is neither an obstruction to design nor is it incidental.

In Rush's agenda, the building systems are to participate in fulfilling the performance of several mandates: spatial and thermal comfort; indoor air quality; acoustical and visual performances; building integrity; human well-being criteria; physiological, psychological, sociological and economic needs, etc.

Although these mandates are deemed useful, the recognition of the environmental pre-design influences as well as the analysis of climate and site remains a bit vague in the BSI model. As a response to this, the theoretical framework of the unit is structured upon eight *Sustainable Building Categories* (SBCs) derived as relevant to the research and development of a R.A.R.E. Architecture:

- Sustainable Site & Climate Analysis;
- Flexible & Adaptive Structural Systems;
- Renewable Adaptive & Environmental Materials;
- Modular Building Systems;
- Innovative Building Envelope Systems;
- Renewable or Non-conventional Energy Systems;
- Innovative Heating, Ventilation & Air Conditioning;
- Water Storage & Systems.

In order to guide the students towards the design of a R.A.R.E. Architecture, the course structure offers a comprehensive overview in all of these categories.

A particular subject begins with a two hour lecture, followed by a workshop where ideas and techniques are analyzed and implemented by small groups of students within larger tutorial classes, under the guidance of lecturers. The workshop tutorial mode facilitates three to four groups of students who brainstorm a particular solution. At the end of the session, each of the groups presents its results with feedback from the rest of the class. Finally, a single group is left to compile the combined outcomes to be presented to the class the following week.

Other than disseminating and consolidating notional principles, this pedagogical system provides the by-product of enhancing analytical skills of students, with a scope that possibly goes beyond the confines of an academic course in architecture. In a sense, this teaching method tries to give to the students confidence that they can consider a R.A.R.E. approach in their future design process.

At the end of the semester, the students are required to submit a comprehensive report formulating their own program guide to a R.A.R.E. Architecture, informing of a mind-set and/or methodology to the selection of particular materials and systems, while also generating and activating innovation in the design process. In addition to the report, and in order to translate theoretical principles into practical skills, students are also asked to apply the developed techniques in the analysis of the environmental functioning of an exemplar building of their choice or a previous Design Studio project of their own. The assignment can be accomplished through a diagrammatic analysis (also hand-drawn) of the strategies employed and can also benefit of the tools (Fluid Mapping Table) and simplified softwares illustrated in the tutorials (EcoTect, Energy 10) [2, 3].

Drawing from lectures, tutorials and students presentations, the contents of the unit - as presented next in detail on the eight SBCs - provide insight to an integrated approach directly related to the production of a progressive and sustainable architecture.

3. SUSTAINABLE BUILDING CATEGORIES

3.1 Sustainable Site & Climate Analysis

The development process of a R.A.R.E. Architecture needs first to start with the analysis of the site, exposure, orientation, the existing vegetation, climatic and topographical factors, local constraints and the range and availability of ecologically sustainable forms of energy seen in relation to the duration and intensity of their use. There are three main sub-categories that need to be evaluated: *Microenvironment* (latitude, orientation, vegetation, landform, landscape, climate, surrounding elements), *Natural Resources* (solar, wind, water and material accessibility) and *Operational Parameters* (building parameters, local habits, culture, metabolic activities).

The *Microenvironment* category deals with the understanding and the evaluation of the natural elements and parameters that directly affect the characteristics of a building. Actually, it is realistic and practical to confine a particular design to a specific climatic region, taking advantage of its natural forces for the benefit of the edifice and the occupants. Next, the *Natural resources* category builds directly on the first and involves the exploitation of local assets for energy production and building purposes. However, caution has to be taken in order to ensure that the natural resources are not used up and can be sustained over time. Finally, the *Operational parameters* category realizes that it is important to always give the right consideration to the final users of a building. When designing, it is imperative to carefully consider the specific needs and requirements of the occupants together with the particular activities to be hosted in the building, rather than create standard aseptic spaces that do not reflect the intrinsic characters of a place or a culture.

The consideration of the above categories and how they can influence the design of a building are fundamental to create an architecture that is responsive to its environment. Through an approach founded on a direct site analysis and the exploitation of software packages such as EcoTect, students are taught that the achievements of comfort attained in an edifice are always strictly related to the thorough understanding of the context, strategic decisions, and optimized building design and control [4].

3.2 Flexible & Adaptive Structural Systems

The structural system of a building is constituted of the elements or members that act as a *supporting skeleton* resisting lateral and/or gravitational forces.

There is an infinite number of materials (and combinations) that can be used to create the structural frame of a building, eventually addressing ideas of prefabrication, versatility, impermanence, relocatability and recyclability. In fact, beside the obvious standardisation and structural adequacy principles – necessary to design a supporting skeleton – alternative systems may also include the consideration of environmental sensitivity, recycled or increased performance criteria, and so forth.

The structure of an edifice can potentially reach a high level of integration with the other elements and components constituting a complex building system. As already mentioned, Richard Rush in his BSI theory describes four basic systems that all building elements are considered to fit: *Structure*, *Envelope*, *Mechanical* and *Interior* [1]. His methodology provides five basic relationships amongst these systems, that respectively can not physically touch (*Remote*), touch but without a permanent connection (*Touching*), be connected by a physical means but still keep their individual character (*Connected*), be woven together and occupy the same space (*Meshed*), or combine to produce one entity (*Unified*).

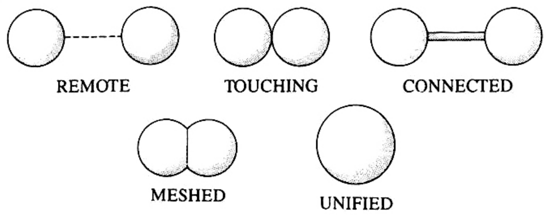

Figure 2: R. Rush's five levels of system integration

Within the structural framework, various levels of integration may occur depending on the scope of the structure, its permanence or temporariness, the fixing to the footings system or founding materials and, obviously, the desired aesthetic "effect". The most common form of combination is with the envelope, considering its ability to be load-bearing and thus contributing to the stability and rigidity of the building. However, also HVAC systems (e.g. hollow core slabs), service and mechanical plants (e.g. voids for cable and hydraulic services) or water storage systems (e.g. tanks) can easily reach a complex level of integration with the "back bone" of the edifice.

Within SRT 450, students workshop the principles of structural systems and analyse their attributes through an evaluation matrix. This diagnostic approach assists in developing a program of criteria to be considered when addressing structural options.

3.3 Renewable Adaptive & Environmental Building Materials

The selection of materials to be used in a specific building is a choice based on a number of aspects that need to be collectively considered according to the nature of the project. Some of these generic considerations include the efficiency of a product, size available, standardization, structural adequacy, the degree of integration with other building components, complexity, appropriateness, cost, labour involved, other than, obviously, aesthetic concerns.

These factors refer primarily to the interests of economy and are fundamental to meet the budget of a building. However, materials can actually entail significant health and environmental hazards that extend far beyond the context of their end use. The cumulative effect of seemingly small local impacts over the life cycle of a product can yield substantial consequences on a global scale. Hence, a more environmentally sensitive analysis has to consider, in material use and product manufacturing, also life-cycle factors such as plantation origin, method of growth (especially for natural products), embodied energy (i.e. total energy required to create, harvest, transport, use, maintain and dispose a component), recycled and reused content (deconstruction, adaptability), toxicity level (wastes, pollution), etc.

In general, natural materials, needing little or no processing, are considered more "environmentally friendly" resources, provided their growth or harvesting method is sustainable. Man-made products, on the other hand, have in general a high process rate which implies enormous embodied energy and often a higher environmental impact. In both cases, in terms of safety and maintenance, it is important to consider that, overtime, materials will inevitably degrade, releasing particles, gases, and, if not properly processed, chemicals, VOCs and other toxins in the environment. The choice of a material should then consider what is actually in the product and how to replace it, fix it and eventually seal off-gassing of dangerous substances into spaces [5].

All things considered, the selection of materials is a difficult task, basically relying on the application to dictate their suitability. Through an environmental sensitive approach, therefore, the unit invites students to always estimate both operational and whole life-cycle properties of materials, according with the "three Rs" (Reduce, Reuse and Recycle) method that can guide designers to minimise wastes, save energy and resources and build in a more sustainable way.

3.4 Modular Building Systems

A modular system consists of a series of standard units - the module - repeated in whole or in part in a way that standardises and gives logic to the whole unified structure. Modular building systems, therefore, need appropriate consideration in terms of joints, connections, adaptability and interchangeability of elements, in order to perform effectively and make the whole being *greater than the mere sum of its parts*.

Modular Building Systems are primarily characterised by the capacity of being adapted, modified and replaced easily. Amongst the various available systems, examples are the *Wall Panels Modules*, where the module consists of an envelope plan of standard size and shape acting respectively as flooring, roofing and walling, the *Structural Frame Module*, simply comprising the construction elements necessary to provide the form and resist to external forces, and the *Cellular Module*, consisting of an entire integrated unity that can be reproduced into a series to create larger scale structures with provisional or permanent fixings and foundations.

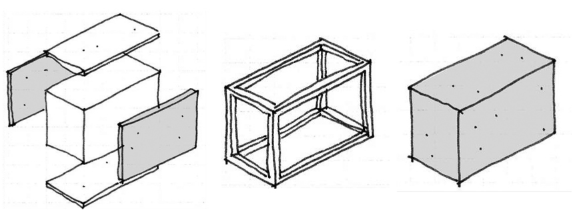

Figure 3: Wall Panels, Structural Frame and Cellular Module Building Systems

The order of composition of modules may be altered and adapted according to the specific need and/or circumstance. This characteristic means that a single component can eventually be removed and/or replaced with the remaining modules still being able of providing the service. Modular systems allow all the units that compose them to be isolated without adverse complication to the whole. In addition, modular building systems allow for shorter times of construction (temporal and physical efficiency), a property easily translatable into reduced energy consumption and wastes. Finally, modularity facilitates maintenance and/or replacements of components and also allows for flexibility and interchangeability of spaces, assets that often can prolong the life-cycle of an assembled built structure.

3.5 Innovative Building Envelope Systems

The building envelope provides a fabric that act as an interface, a filter between interior and exterior able to control the whole of the energy flows that, directly or indirectly, enter (or leave) an enclosed volume. From a functional point of view, a building envelope should be designed in order to provide for illumination of spaces (daylight), privacy/view, mechanical security, acoustic and thermo-hygrometric comfort, thermal insulation and safety/protection.

Traditionally, the external skin of the building has been considered as a barrier against atmospheric agents, protecting the internal volume from the outside elements and reducing heat losses and/or gains. This passive, *conserving*, envelope was based on the use of thick and massive walls, with just a few openings, in order to accumulate heat during the cold season and avoid excessive intrusiveness of solar energy during warmer times of the year.

Nowadays, technological and environmental research, together with a more mature awareness of our role on a planet of finite resources, considers the skin of the building not as a static shelter, but rather as an open membrane, permeable, selective and in interaction with climatic factors. An innovative building envelope system has to establish an "agreement" with its surrounding environment, varying its functioning and adapting to contextual situations (climate change) to regulate energetic exchanges through form, orientation, exposition, openings, etc. A dynamically-interacting *anisotropy* of solutions often means lower energy use in a building and lower greenhouse gas emissions. To achieve these objectives, the design of a building envelope may be based on the exploitation of passive, active or inter-active techniques.

Passive envelopes use basically energy from the sun (in the form of light, heat and wind) to maintain desired interior conditions. As a consequence, no mechanical device is used in the façade to control the comfort parameters, while everything is regulated by passive physical laws or by direct input from the user (i.e. closing a blind or opening a window).

Active external skins employ mechanical plants to regulate thermal conditions inside the building and to ventilate the enclosed spaces. The systems may also partially exploit passive forces to achieve their objectives; however their basic functioning principle is based on the import of energy to power their engines.

Finally, *inter-active* envelopes are based on a thorough combination of the mentioned passive and active techniques to respond to the dynamic requirements of the inhabited spaces. Essentially, these systems are capable of using natural methods of sourcing fresh air or heat or cool, even though their ability is more completely regulated through the incorporation of fully-integrated mechanical devices, often automatically controlled by a central computerised BMS (Building Management System).

3.6 Renewable or Non-conventional Energy Systems

Renewable or non-conventional energy systems are represented by sources that can be exploited without reducing or exhausting their point of origin. Their use represents fundamentally an attempt to replace traditional fossil fuels (oil, gas, coal) with replenishing forms of energy collected on site or in centralised areas with little environmental impact.

Although similar in concept, the utilization of renewable energy systems differs radically from the passive techniques of thermo-hygrometric regulation already mentioned, since in this case the natural forms of energy are directly exploited to produce the electricity needed to run appliances or mechanical devices. The power generated can be employed directly on site or (in case of excess production) sent to the grid. Currently available renewable energy sources are portrayed by the four elements identified by the Greek philosophers in the 4th-5th century B.C. as the basis of our globe: Fire, Air, Earth and Water.

In detail, *solar energy* (Fire) can be exploited *actively* to produce electricity by PV cells, to heat water by solar panels, to aliment solar chimney generators and steam turbines, or can be utilised *passively* via direct solar heat gain. Moreover, a rational design of daylight intakes and advanced light-distribution devices such as light shelves, laser-cut panels, etc., can make the most of the available luminous portion of the solar radiation. *Wind kinetic energy* (Air) can be easily transformed into electricity by the use of stand alone horizontal/vertical axis wind turbines or building-integrated systems. *Geothermal energy* (Earth) can be utilised via heat and steam generators, radiative transfers, bio mass (plant matter and animal waste combusted to produce heat or anaerobically “digested” to generate methane-rich biogas), landfill (production of methane when organic wastes decay), and so forth. *Water kinetic energy* (Water), finally, can be exploited by hydro-generators, wave and tidal power, flowing supply generations, etc.

The above systems all ensure reasonably good levels of performance. Obviously, more specific renewable energy systems have also been identified (such as *fuel cells*) and some of them are already marketed, even if their working principles are often more complex and not yet applied on a large scale.

According to these considerations, students are taught that almost every building location can have easy access to one or more non-conventional energy source, although often a more environmentally-aware attitude in our day-by-day habits, design decisions and appliances management can represent the more renewable of all the available energy sources.

3.7 Innovative Heating, Ventilation & Air Conditioning

Heating, Cooling, Ventilation and Air Conditioning of buildings are all fundamental strategies to provide acceptable interior conditions for the occupants in terms of thermo-hygrometric and air quality comfort.

There are a number of systems available to perform such functions that may include mechanically regulated or totally passive techniques. Unfortunately, too often contemporary buildings rely solely on stand alone oversized motorized plants to compensate for poor design intents. However, it is the integration of the above techniques that seems to represent a valid alternative to overcome these deficiencies, a choice that is both economic (reduction of energy bills), other than environmentally sensitive (less CO_2 emissions).

Thoroughly designed *hybrid* HVAC systems in fact exploit natural forces (when available) to assist, if not totally replace, traditional mechanical services, relying on passive principles to the benefit of the building and its users, while also reducing initial and ongoing costs due to a significant cut in the dimensions of installations and smaller maintenance requirements.

Amongst the passive principles that can be exploited for an energy-sensitive approach to the thermal and air quality regulation of inhabited structures, probably *natural ventilation* represents the oldest, albeit effective, method available. Passive ventilation draws external fresh air in and circulates it through internal spaces. This technique can be associated with active heating and cooling modes to direct incoming air as needed. Ventilation can be induced by simple wind pressure (*single-sided* or *cross ventilation* of rooms) or thermal stratification (*thermal buoyancy*), and, other than by openings placement, can be enhanced by the strategic presence of *chimneys* and *atria*, that exploit stack effect, or *wind towers*, *vanes* and *scopes*, which take advantage of external breezes and negative wind pressures to exhaust polluted air and draw fresh air in, or eventually distribute warm air down the spaces.

In terms of heating and cooling, hybrid system can (at least partially) also rely on passive strategies to control the temperature inside buildings. For example, in temperate climates, *direct solar gains* through greenhouse effect (glazed envelopes, winter gardens, etc.), *thermal mass* to temporally regulate heat distribution (heavyweight construction, Trombe walls, etc.), and *solar chimneys* to create convective air circulation (double skin façades), can strongly assist mechanical fans and heaters to maintain a desired internal microclimate. In warmer climates, *roof ponds* and *gardens* (both basically relying on thermal mass and evaporative cooling techniques), *earth cooled ventilation* (sub-ground vents and labyrinths), together with innovating devices and systems such as *phase change materials* (PCMs) and *shower towers*, can effectively contribute to reduce the energy needed for cooling the buildings down to levels of well-being.

Obviously, the unit emphasizes that none of these strategies is necessarily new, nor it represents a striking revolution in the design of HVAC systems. However, in a holistic approach to design, the interest lies in how these systems can be integrated one to another, working together and assisting each other in the creation of a more comfortable space for users that is both energy conscious and also interesting and innovating in terms of its architectural qualities.

3.8 Water Storage & Systems

Water is a vital element for life and is a fundamental resource in all inhabited buildings. Its uses and functions are extremely numerous as are the potential integrations with other system elements.

Direct traditional uses such as drinking water, personal and general cleaning, sanitary purposes and garden watering, for example, can be extended to the integration with heating and cooling systems (mechanical HVAC), with envelope components (thermal mass) and with structural elements (water-filled tanks). Nevertheless, in many locations (as Australia) water is a resource as precious as scarce, so reduced consumption (water saving shower heads, tap fittings), elimination (compost toilet), improved efficiency, reusability and disposal are becoming common issues in the environmental agenda.

Even in the daily domestic use, water could be (almost) continually recycled and treated instead of being wasted after its first use (although potable water is, at present, used for practically every task). The grades of water qualities are here described.

Potable fresh water is of the highest level of pureness, and should only be used for direct drinking consumption, even if personal cleaning purposes (showers) may also be acceptable. Fresh water can enter the house directly from the mains or can be obtained through treatment (sand, UV, standard fibre, membrane filters) and appropriate storage of rain water caught off any suitable rooftop or façade.

Grey water is excess water collected from basins containing no excrement, solid or chemical contaminants. It can be initially treated and stored under specific conditions for latter uses (to avoid the growth of bacteria) or directly employed for washing machines or toilets flushing. Excess fresh water and grey water can also be used as the vector fluid in circulating HVAC systems (radiant floors or ceilings), being, maybe, pre-heated by passive solar collectors.

Black water, finally, contains solid contaminants and human excreta, so for re-use it requires treatment and disinfection through chemical or natural means (e.g. reed beds). Its uses should be concentrated on the outdoors (gardening purposes), although it could also be exploited as a renewable energy source due to its gaseous outputs (Bio Gas).

Within SRT 450, students are asked to workshop solutions at a highly integrated level, considering the complete (use and reuse) water cycle in the building with respect to the task performed. The lesson learnt from this exercise suggests that efficient water use can provide major environmental, public health and economic benefits, helping to reduce our impact on the environment, improve self-sufficiency of buildings and protect vital drinking water resources.

4. CONCLUSIONS

The eight Sustainable Building Categories have been presented here at a reasonably basic level, and eventually many of them could also have been further broken down into more precise definitions and detail. However, the intent of this categorisation is not simply to suggest the most appropriate method of analysis, a recipe applicable to every contextual situation, but rather to propose an holistic approach to the range of systems and choices that can possibly contribute to the whole, or a part, of a R.A.R.E. design process.

Essentially, in *integrated* buildings – whether the technology is celebrated or concealed – structure, services, envelope and interior form an interconnected part of the architectural design, and each system contributes and interacts with the others rather than behaving as an individual entity. Performance is the primary motivating factor for building integration as many design motives, such as comfort, efficiency and appearance, cannot be fulfilled without the entire building performing as a whole.

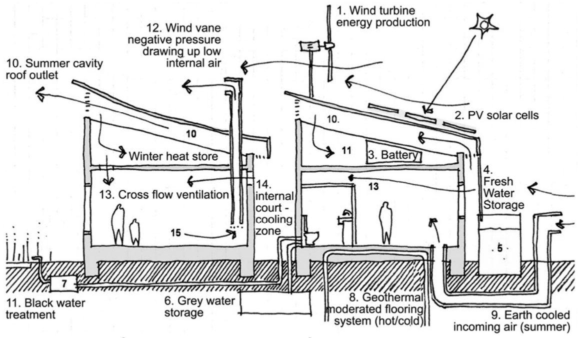

Figure 4: Student proposal for a R.A.R.E. building.

R.A.R.E. Architecture is, in substance, the product of an integrated design process, a “living organism”, a composite of both passive design strategies and mechanized adaptive technologies where all systems and categories do, whenever possible, relate and work with each other, a prerequisite that is fundamental unless we want this innovative and sustainable design process to remain actually *rare*.

To become Renewable, Adaptive, Recyclable and Environmental, buildings have to be designed according to an innovative approach where the potential implications of each component, and, therefore, of each design decision, is carefully considered in relation to climate, site and a range of other concepts, adjusting to meet challenges and requiring a minimum of external resources for continued operation. Sustainability here is assuming a wider sense: not only reduction of consumptions, wastes and emissions, but rather appropriateness to the use, adaptability, maintainability and, finally, actual “buildability” of the architectures we design.

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