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Architecture as an Energy System

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Abstract— *The content of this paper consists of excerpts from the lectures given by the author on the course "Architecture as an Energy System" which, as an optional subject, was introduced (2003) into the curriculum according to the Bologna system of study at the Faculty of Architecture of the University of Sarajevo. As the course is situated at the very end of the master's study, it was assumed that the students have mastered the complete basic material of the study of architecture, and that at the end of the study they can approach the consideration of architecture as an extremely complex activity. One of the (according to the author) most effective approaches to understanding complexity is treating architecture as a system. Since the author also dealt with some other topics in architecture (in bachelor's, master's and doctoral studies) in the way of treating architecture as a system, the topic dealt with in this paper is the mutual relationship between architecture and energy. This topic became one of the fundamental questions of architecture at the end of the 20th and beginning of the 21st century. This approach to understanding and studying architecture was founded by the author (1988) in his doctoral dissertation. Architects must not only be transmitters of investors from their wishes and messages to physical architectural structures, but always creators of the framework for a fuller and richer life of people, which always implies an awareness of the relationship to the natural and social environment. In architecture, there are no problems and small tasks, but good and bad solutions. This work has the message that good solutions are those that confirm the generic essence of man, values that are common to all people, coexistence with nature and respect for everyone's cultural and historical heritage.*

Keywords— *Energy, Life, Man, Architecture.*

I. INTRODUCTION

The author's many years of experience in working with architecture students, on the topic of conceptualization and materialization of the boundaries (envelope) of an architectural object in accordance with the concrete requirements of the architectural object, on the one hand, and the climatic environment, on the other hand, can be summed up in the attitude: students used to designing in a certain social and natural environment, they find it very difficult to understand and solve tasks in different social and natural environments [1,2,3,4]. The author realized that, at first glance, the solutions of conceptualization and materialization are more fully and correctly understood when they are seen in a different context. In other words, they wanted to show that a concrete architectural object is a kind of more or less complex 'mathematical equation' whose solution varies with the change of some of its parameters. In this way, we wanted to underline the more or less noticeable (for architecture students) empirical dimension of architecture. The topic of "Architecture as an energy system" is simultaneously approached as an architectural-creative and mathematic task, where it is obligatory to achieve its 'mathematical accuracy' with the possibility of exact verification of its result, and only then to evaluate the 'artistic beauty' of such a solution. Figure 1 shows the dependence of the required heat-insulating performance of the outer wall on the ambient temperature (t_e). The author set this 'architectural-mathematical task' as the clearest way to represent architecture as an energy system. Namely, the task assumed optimal conditions for the comfort of man, wherever he is (at the North Pole, in the desert, in the tropics, on the Moon...). The task requires the heat-insulating performance of the outer wall (U-value) in order to ensure the performance of optimal comfort, for different external temperature environments (Figure 1). The mathematical solution to this problem is the U-value curve (that is, the heat transfer coefficient). The architectural realization of this mathematical result can offer countless solutions, depending on the availability of materials from which we will make the envelope [2]. In the same way, mathematical-architectural tasks can be set and solved for other requirements of the limits of the architecturally defined space: thermal stability in the summer regime, vapor diffusion, sound protection.

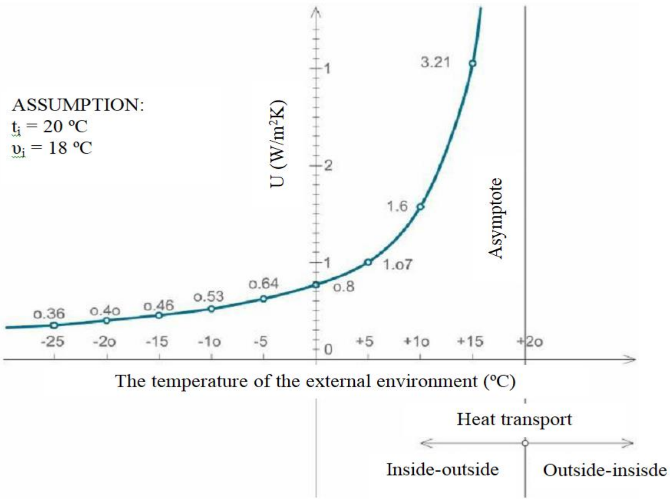


Figure 1. Scientific determination of the thermal-insulating performance of the Architecturally Defined Space (ADS) guarantees (A. Hadrovic, 1996)

It is very important that the student of architecture (and every participant in defining the architectural space) is aware of the unity of the Universe and the place of man and architecture in it. In fact, the awareness that the laws of the organization and functioning of the Universe, no matter how well a person knows them, are the same in its macro and micro-plan. Philosophy, physics, mathematics, biology (...) are different disciplines only at first glance; each of them interprets one and the same thing, the Universe, from a certain viewpoint of human viewing. The content of this work calls for viewing the Universe from the perspective of architecture. The work refers to finding harmony between man (society) and nature. From this approach, it is possible to understand the possibility of setting, at first glance, 'impossible', architectural tasks[1], as well as the possibility of their mathematical-technological solution, i.e. architectural realization. When solving architectural tasks, it is always instructive for architects to analyze a variety of living organisms in a certain natural environment, since they are always 'correct solutions' of the organization of matter into different forms of life. The ultimate goal of the conceptualization and materialization of architecture is to reach such solutions that will be sustainable in the manner of living organisms.

II. Definitions of key terms

A precise definition of that term is a prerequisite for its correct and complete understanding. Once we understand the basic terms, it is possible to create and understand complex systems whose components are those terms.

Matter. Matter is the subject of interest, research and interpretation of philosophy, art and science. In philosophy, matter is understood as any objective reality that exists, independent of human presence, independent of human consciousness and knowledge about it. However, matter touches man in various ways, where he establishes his relationship to matter through senses, consciousness (thinking) and feelings. Art is a human interpretation of the world, which, along with the artist-creator and his work, necessarily includes the audience, that is, the observer and evaluator of the work of art. Science views matter as an objective phenomenon in the universe that simultaneously manifests itself as matter, waves, energy and information.

Constuction materials. In the materialization of an architecturally defined space, both natural materials and materials produced by man through more or less complex technological processes from the base of natural materials are used: concrete, plasters, metals, glass, synthetic materials... From the aspect of the title of this work, any material that we use in architecture should also be viewed from the energy aspect, to determine its 'energy load', i.e. its embodied energy. It is important to note that artificial materials for the production of which more energy has been invested have targeted, more emphasized certain characteristics that predestinate them for the appropriate role in more or less complex assemblies of an architectural object. Each material has certain properties that predestinate it for a certain place within the architectural object. These features have their exact value, which is determined by precisely prescribed methods. The most important properties of materials are: state parameters and structural properties, physical properties, physical-mechanical properties, constructive properties, technological properties, rheological properties, chemical properties and exploitation properties. All properties of a material are in a cause-and-effect relationship, and are always a reflection of the composition of elementary particles (atoms and molecules) and the quantitative ratios of its individual components from which it is made [4]. From the perspective of the title of this work, architecture is focused on physics, chemistry, technique and technology, that is, on research into new materials that are introduced or will be introduced into architectural practice. These are so-called supermaterials and nanomaterials[2]. These are, for example: Self-healing Materials-Bioinspired Plastics, Thermoelectric Materials-Heat Scavengers, Perovskites-Cheap Solar Cells, Aerogels-Superlight and Strong, Metamaterials-Light Manipulators, Stanene-100 percent efficient conductor, Self-Cleaning Materials, Graphene , Stanen...

Energy. Energy is defined as the body's ability to do work. In other words, work represents a change in energy. Work manifests itself in several ways: change in temperature, change in speed, change in position... Hence, work and energy have the same unit of measurement, the joule (J). Every body in the Universe possesses energy, and this fact is expressed in several ways, through the postulates (laws) of thermodynamics. The first postulate of thermodynamics [5] expresses the stated fact about the existence of internal energy of every body (system) in the Universe. Stated analytically, this law reads:

$$dU = \delta w + \delta q$$

where is:

- w, „useful“ mechanical work,
- q, heat,
- U, internal energy.

The first postulate of thermodynamics is also called the law of conservation of energy.

The second postulate of thermodynamics reflects the nature of energy. Namely, if two closed thermodynamic systems (each in an equilibrium state at the observed moment) are brought into contact via the diathermic boundary surface (DBP), their energy states will be disturbed: energy (heat) from system I will cross the diathermic boundary surface switch to system II (until equilibrium is established). The new equilibrium state between systems I and II will not change, both with the existence of the contact surface (DGP) and if the contact is broken. Temperature represents the degree of thermal state of the body (thermodynamic system). This is also the definition of the so-called Zero Postulate of thermodynamics. In practice, there are several scales for determining temperature: Celsius, Reomir, Fahrenheit. For all of them, the same fixed points were taken as a basis - the equilibrium state of water and ice, that is, water and water vapor, at the same pressure (of one physical atmosphere)[3]. The International System of Measurements (SI) adopted the one proposed by the famous physicist Lord Kelvin as a valid temperature scale. Kelvin took as the basis of his scale the

[1] For example: 1. „winter center“ project in desert climate conditions, 2. „tropical center“ projects in polar climate conditions, 3. „exclusive underwater hotel projects“, 4. „underground residential building projects“, 5. house (settlement) projects on the Moon, Mars or in space...

[2] Nanotechnology studies materials with morphological properties at the 'nano-scale', especially those materials whose properties derive from their nano-dimensions. 'Nano-dimensions' are those on the scale of 1-1000 nanometers (nm), but in this case 1-100 nm is common (1 nm = 10^{-9} m).

[3] The physical atmosphere (1 At or 1 atm) is an invalid unit according to the SI system. 1 At = 1 atm = 101302.178 Pa.

triple point of water (indifferent state of water with precisely determined pressure and temperature). He added the value of 273.15 K to that energy level of water, thus defining the unit value of temperature as:

$$1K = \frac{1}{273.15} T_t$$

where is:
T_t - temperature of the triple point of water.
The starting point of the Kelvin scale (0 K) is at -273.15 °C. This temperature is called absolute zero[4]. The temperature expressed in K (kelvins) is called the thermodynamic temperature (T). Obviously, absolute zero is the theoretical limit state of a body that has no energy. In the Universe, there is no temperature lower than zero kelvion (0 K), that is, -273.15 °C. At the same time, the temperature values on individual scales are linked by the relation:

1 °C = 4/5 °R = 5/9 °F = 1 K.

Energy appears in nature in various forms: thermal energy (internal energy), mechanical energy (that is, potential and kinetic energy), electrical energy, solar energy, nuclear energy... In architecture, as well as in everyday life, the terms: energy from non-renewable sources and energy from renewable sources. As the name suggests, non-renewable energy sources are those whose quantities in nature are finite and cannot be renewed. These are: coal, oil and gas. By burning them, heat is obtained, which can be converted into other forms of energy (electricity, for example) through certain technical and technological processes. Renewable energy sources are self-regenerating, renewable. These are: solar radiation energy, hydro energy, wind energy (eolian energy), tidal energy, wave energy, hydrogen, fuel cells, geothermal energy, biomass energy (wood, reed...), biogas, biofuel... Uses energy from renewable sources has followed architecture since its beginning. Today, and especially in the future, this requirement, in the circumstances of a high level of energy use and with a growing human population, has become ultimate, and in order to meet it, architecture becomes a field of new ideas and concepts that have not been seen before. Treating architecture as an energy system implies, among other things, all concepts in which architecture is not only a consumer of energy that we need to deliver from somewhere to a specific architectural object, but a system that uses energy from the immediate environment in a new way or itself generates energy through new spatial concepts, a new materialization and new subsystems.

Embodied Energy. By the term Embodied Energy, we mean the total energy that is invested in all the processes of building an architectural object, from the mining of ore in nature, through all the technological procedures of its processing, the production of a certain material, transportation and installation in a certain place within the architectural object as a physical structure. This is a very important dimension of every material and must not be overlooked in studies and all budgets and calculations when determining the price of an architectural object and its categorization from the aspect of its 'energy and ecological load'. Ecologists M.T.Brown[5] and S.Ulgiati[6] proposed the term "sustainability index (SI)" and defined it as the ratio of the degree of emergy gains[7] (EYR) and the degree of ecological burden (ELR):

$$\text{Sustainability index} = \frac{\text{Energy gain ratio}}{\text{Ecological load ratio}} = \frac{\text{EYR}}{\text{ELR}}$$

Brown and Ulgiati also called this index the "sustainable energy index" (ESI), as an index that explains gain, renewability and ecological burden. Table 1 provides an overview of embodied energy for individual materials[8].

TABLE 1. Embodied energy for some materials (Australia)

Material	For Embodied energy (MJ/Kg)
Dried sawn soft wood	3.4
Dried sawn hardwood	2
Air-dried sawn hardwood	0.5
A hard board	24.2
Lesnonite	8
MDF	11.3
Plywood	10.4
Laminated wood with glue	11
Laminated veneer construction	11
Plastic (at all)	90
PVC	80
Synthetic rubber	110
Acrylic paint	61.5
Stabilizing soil	0.7
Imported granite	13.9
Granite of local dimensions	5.9
Stucco	2.9
Dry mortar	4.4
Fiber cement	4.8
Cement	5.6
Concrete prepared at the place of use	1.9
Pre-preserved concrete with steam	2
Prestressed concrete	1.9
Clay bricks	2.5
Concrete blocks	1.5
AAC	3.6
Glass	12.7
Aluminum	170
Copper	100
Galvanized steel	38

Source: Lawson, 1996

Matter-energy. The equivalence of matter and energy was discovered and established (1905) by Albert Einstein (1879-1955), expressing this relationship with one of the most famous equations in the world of nature, that is, physics: $E = mc^2$.

[4] At this temperature, all movement stops, that is, the energy of the system is equal to zero.

[5] Mark T. Brown is a professor of Environmental Engineering Science at the University of Florida where he teaches courses: System Ecology, Ecological Engineering, Emergy, Wetlands...

[6] Sergio Ulgiati is a professor at the University of Napoli, Department of Science and Technology

[7] Pronounced „m", not „n": „embodied energy", not just „energy".

[8] When reading data on embodied energy for some materials, you should always keep in mind the specific location to which this data refers. It is understood that the level of embodied energy for wooden beams on a building in Sarajevo, for example, will be different from the levels of the same wooden beams in Cairo, for example.

Life. Life is a term we use to distinguish physical entities that have biological processes (living entities) from those that do not (non-living entities). There are various forms of living entities: animals, plants, fungi, algae, protozoa and bacteria. Biology is a science that studies living entities. For philosophy, life is its most important and fundamental question that it deals with, and that in the way of thinking about its meaning. Bioethics is a scientific discipline that studies life from the aspect of moral principles. From the point of view of biology, life is a complex event made up of numerous partial processes that take place in a living entity (individuals) during its lifetime. One of the basic properties of living entities that distinguishes them from non-living entities is the possession of complex compounds with carbon. At the same time, the cell is their smallest structural and functional feature. The basic conditions for the realization of life are: water, air, heat and light. It is believed that life on Earth is about 3.7 billion years old [6], and that about 300,000 plant and several million animal species live on Earth today. At the same time, there is a huge number of extinct species. From the point of view of biology, life is a characteristic of organisms, which show all or most of the following characteristics[6]: 1. Homeostasis: means the maintenance of constant conditions in the internal environment of cells. Almost all organs and tissues in the body perform functions that contribute to the maintenance of these constant conditions, 2. Organization: the body of living organisms is made up of one or more cells, which are the basic units of life, 3. Metabolism: a set of chemical reactions that take place in living organism, in order to maintain life. Living things need energy to maintain internal organization (homeostasis) and to produce other life-sustaining processes, 4. Growth: building the body and increasing body volume 5. Adaptation: the ability to change over time in response to changes in the environment. this ability is of fundamental importance for the process of evolution, 6. Responding to stimuli: it can be very diverse, from simple contractions of unicellular organisms to external chemicals, to complex reactions involving all the senses of multicellular organisms, 7. Reproduction: The ability to produce new individual organisms, either asexually from one parent organism or through sexual intercourse between two organisms. Koshland lists seven characteristics of life: 1. Program (DNA), 2. Improvisation (response to the environment), 3. Compartmentalization (possibility of divisibility into parts), 4. Energy, 5. Regenerativeness, 6. Adaptability, and 7. Isolation (chemical control and selectivity[7]. Although other scientific disciplines and philosophy and religion deal with the question of life. From the aspect of the title of this paper, life can be defined as a material system that undergoes reproduction, mutations and natural selection.

Metabolism. Metabolism is a complex process of chemical reactions in which substances are exchanged, exclusively in living beings. These processes are a prerequisite for other functions characteristic of living beings. With regard to metabolic reactions, two types of metabolism are distinguished: catabolism and anabolism. Catabolism is the process of breaking down organic substances, which is accompanied by the accumulation of energy through cellular respiration, while anabolism is the process of building cellular parts (biosynthesis of organic substances, such as proteins and nucleic acids) with the use of energy. Chemical reactions of metabolism take place in individual metabolic pathways where one chemical compound is converted into another, with the help of enzymes as accelerators (catalysts) of metabolic reactions. The following metabolic pathways are important in humans: water metabolism, amino acid metabolism, carbohydrate metabolism and fat metabolism. The term 'basal metabolism' implies the amount of energy needed to maintain the basic life functions of a living being. The value of a man's basal metabolism in function depends on his age, body weight and gender, and is around 7.56 MJ/d for a 65-year-old man and about 5.98 MJ/d for a 55-year-old woman [8] (Table 2). In order for metabolism to take place in living beings, it is necessary that they take in certain substances (food, water, oxygen) and that certain conditions prevail in their environment, of which temperature is one of the most important. At the same time, all substances introduced into the body have their own energy potential, i.e. 'caloric value'.

TABLE 2. Division of work according to energy consumption for the average man and woman

The weight of the work	Man (KJ/min/65 kg)	Woman (KJ/min/55 kg)
Easy work	14.7	10.1
Moderate work	26.0	18.9
Hard work	36.5	27.3
Very hard work	47.0	37.7

Source: http://www.vasdoktor.com/medicina-rada/1338-misicni-sistem-i-energetska-potronja, Accessed: August 10, 2023.

TABLE 3. Heat release of the human body during various activities

Activity	Heat emission	
	met	W
Sleeping	0.7	75
Sitting	1.0	105
Walking at a speed of 3.2 km/h	2.0	210
Walking at a speed of 6.4 km/h	3.8	400
Office work	1.0-1.4	105-150
Cleaning the house	2.0-3.4	210-355
Dancing	2.4-4.4	250-460
Basketball	5.0-7.6	580-800
Maximum (short-term)	11.5	1200

Source: Adapted from Thermal Comfort, http://www.labeee.ufsc.br/antigo/arquivos/publicacoes/Thermal_Booklet.pdf Accessed: August 10, 2023.

Biology distinguishes two types of animals with regard to their ability to maintain metabolism: homeothermic and poikilothermic. Homeothermic animals and humans have a (mostly) constant body temperature (mammals 37 °C - 38 °C, birds 40 °C), even with external temperature fluctuations, while poikilothermic animals have a body temperature depending on the temperature of their environment. Regardless of the ability to maintain a constant temperature, the temperature of its natural environment is extremely important for human comfort. In accordance with the title of this paper, it is extremely important to know the values of environmental elements that ensure the normal metabolism of living beings, that is, life as the most complex phenomenon in the Universe. In this sense, it is necessary to know the amount of heat that living beings emit into their environment, since it is essential in the overall energy balance of the observed architecturally defined space (Table 3).

The energy dimension of metabolism in animals is expressed by the equation [9]:

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + 678 \text{ kcal}$$

where is:
$C_6H_{12}O_6$, hexose (monosaccharide with six carbon atoms),
O_2, oxygen,
CO_2, carbon dioxide,
H_2O, water,
678 kcal (2,838 65×106 J), the amount of heat generated by the combustion (oxidation) of hexose. The connection between the animal's mass and the heat released by their metabolism has been scientifically investigated:

$$Q_{mb} = cW^{b}_{kg}$$

where is:
Q_{mb}, energy of basal metabolism,
c, constant,
W_{kg}, animal weight (kg),
b, exponent (~ 0.75).

By applying the above equation to individual animals, the emitted heat of the animal's basal metabolism per kilogram of its mass will be obtained. It is interesting that smaller animals have a higher heat emission per kilogram of their mass (Figure 2).

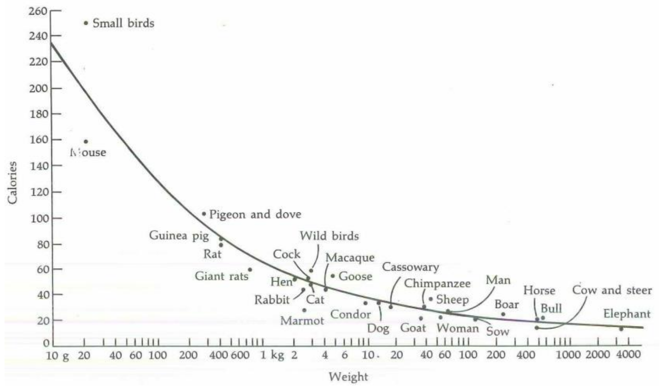


Figure 2. Semi-logarithmic graph showing heat generation per kilogram of animal body mass (masses range from 20 g to 4000 kg)
Source: ENERGY, METABOLISM, https://www.d.umn.edu/~rmoen/docs/WE/WE_Ch_7.pdf, Accessed: August 10, 2023.

Especially for birds, the relationship between the heat generated by basal metabolism and the bird's body mass is expressed by the equation [9]:

$$\log m = \log 74.3 + 0.744 \log W \pm 0.074$$

where is:
m, metabolic rate (kcal/24 h),
W, body mass (kg).

Therefore, living beings behave as a kind of transformers of matter into energy. By taking food from their environment, living organisms take one of the assumptions of their life which, through one of their manifestations, metabolism, emit energy in the form of heat and other forms of matter created by the decomposition of previously ingested food. That is why a living organism (certainly a human as one of them) is a typical example of an energy system, and therefore architecture as its framework.

Man's place in the Universe. Architecture is a special human activity, most tightly connected with all manifestations of human life, but also set apart above it insofar as it represented a kind of 'creation', a property that only Nature has. Awareness of the exceptional role of architecture is possessed by a small number of people, including architects. The decision about the direction in which they will direct their vital energy is made by each person individually, with social circumstances, including the established value system, only having an effect to a certain extent. An architect, as a person who by his professional and life commitment belongs to the 'world of architecture' can direct his creative energy towards acquiring personal wealth, building a 'cult of his ego', living everyday life without particularly thinking about his role in the overall life.

The right time for an architect to determine the place of his role in life is when he is still studying, while he dreams of a better world and believes that he can create it.

System. A system is a set of entities (components), real or imaginary, that form a whole with mutual relations, where each of the components is in an interdependent relationship with at least one component of the system. Therefore, any element that has no relationship with any component of the (observed) system is not part of the system in question, but represents the environment of the observed system. At the same time, in a certain system, components can be observed, which, by their mutual relations, make a special system. Such a system is treated as a subsystem of a certain system. Most systems have some elementary properties, such as: 1. The structure of the system determined by the parts of the system and their composition, 2. The behavior of the system. Each system has inputs, processing and outputs of materials, energy or information, 3. Interconnection of system components. Parts of the distem (entities or components) are interconnected by structural and functional connections. Systems can be material (when they contain matter) or energetic. The part of space beyond the boundaries of the observed system is called the environment of the system. The system can exchange both matter and energy with its environment (open system), only energy (closed system), and no exchange at all (isolated system). At the same time, the boundaries of the system can be fixed or movable. Systems in which changes in their internal state towards the environment are manifested as mechanical work (while there is no exchange of matter or energy between the system and the environment) are called adiabatic systems. With these systems, the limit is a good thermal insulator. The boundary of the system through which the exchange of matter is not possible, where there are no mechanical, electrical and magnetic interactions with the environment, but only heat exchange, are called diathermic boundaries. Thermodynamics is a physical discipline "which studies the laws of heat movement of various systems in thermodynamic equilibrium, when there is no relative movement of one part of the system in relation to another, as well as the laws of achieving equilibrium state, and also generalizes these laws to non-equilibrium systems" [5]. The system is a part of the space set aside for the purpose of thermodynamic tests. It is defined by boundaries, real or imaginary, movable or immovable. A thermodynamic system is defined by a series of quantities that, in principle, can be measured and expressed quantitatively as such. They represent the physical properties of the system. These are the following quantities: volume, density, pressure, internal energy... At the same time, some quantities do not depend on the mass of the system (for example: pressure, temperature, viscosity) and we say that they are intensive quantities. If the sizes of the system depend on its mass (for example: volume, energy, surface), then we will say that they are extensive. If the physical properties of the system are the same in all its parts, we will call such a system homogeneous; on the contrary, a system consisting of two or more homogeneous areas (phases) is called heterogeneous. In an isolated system, the quantities are in equilibrium. This state is defined as the First Postulate of Thermodynamics[5]. Stated analytically, this postulate reads:

$$dU = \delta w + \delta q$$

where is:
- w, “useful” mechanical work,
- q, heat,
- U, internal energy.

Over time, System Theory developed as a special scientific discipline that studies the interrelationships of the system as a whole. System Theory has found its direct application in many scientific disciplines and areas of life: Theory of Living Systems, Organizational Theory, Software and Accounting, Sociology and Sociocybernetics, System Dynamics, System Engineering, System Psychology. Cybernetics is closely related to systems theory. It is a transdisciplinary approach to the study of the system, its structure, limitations and possibilities [10,11].

Architecture. Architecture is one of the most complex concepts in general, which in its meaning unites the complex and simultaneous understanding of several, also complex, concepts such as: man, environment, borders... The word 'architecture' itself comes from the Latin word 'architectura', i.e. the Greek word “ἀρχιτέκτων“ (ἀρχι = chief + τέκτων = builder). In the narrowest sense of meaning, architecture at the same time implies the process of planning, designing and building buildings. One of the interpretations of the concept of architecture was offered by the author of this paper in his book [3]. It is very important to emphasize two things related to architecture: 1. Architecture is the work of man. Its creator is, for the most part, an educated individual (an architect), and also a person without formal education who possesses knowledge and skills acquired in a traditional way of learning (folk craftsmen, mostly anonymous), 2. Architecture is not every built building, both with a known and an unknown architect. Only those realizations of buildings (and other physical structures) that possess a distinct architectural and artistic value can be called architecture. Since these dimensions of architecture are not exactly measurable but originate from the human-individual (sometimes from a narrower or wider social group), there is a wide and in many respects controversial debate on this issue in architecture and in life in general. The controversies go so far that the 'artistic component of architecture' overcomes its expediency and empirical dimensions (as essential properties of architecture). There are few individuals who designed and built buildings (physical structures in general) that can earn the epithet “architecture”. On the other hand, all people, as well as all social groups, have the right to evaluate architecture. At the same time, each assessment is 'correct', it is just a question of the breadth of its parameters that are evaluated [1,2,3,4,13,14,15,16,17,18,19,20]. The first treatise on architecture (which has been preserved), on the question of its content, controversies, array of meanings (...) as well as on the people (architects) who deal with it, was written by the Roman architect, civil and military engineer and theorist, Marcus Vitruvius Pollio (around 80-70 BC around 15) under the title “De arhitektura libri decem” (“Ten books on architecture”) [12]. From the time of its first appearance (1st century BC) until today, the content of the book, as well as the definition of some basic terms of architecture, as well as the understanding of the nature of architecture and the understanding of the professional-artistic profile of architects, have not lost their relevance. Since its content includes some generic (developmental-evolutionary) concepts (the concept of “man”, first of all), architecture, along with some common interpretations covered in scientific and professional literature, is subject to re-examination in every time that comes. In doing so, its past, present and future are re-examined [2,13].

III. Architecture as a system

In its broadest sense, architecture implies the enclosure of space with the aim of achieving the desired, more or less controlled, conditions necessary for the realization of a certain spectrum of human needs. The elements that define the "special conditions of the enclosed space" make up the elements of architecture as a system that are always determined by the spectrum of physiological and psychological-aesthetic human comfort. An architecturally defined space represents a special system defined by its size and character of the border. It is open by nature (it exchanges both matter and energy with the environment), theoretically homogeneous [5]. It is defined by quantities: volume, mass, amount of energy (heat), temperature, pressure (partial pressures of individual air components), lighting level, level of internal and external sound (noise)... The environment of an architecturally defined space can be any space in which man can realize his existence. In the conditions of life on Earth, the environment of an architecturally defined space can be any place on the earth's surface, as well as the space below its surface (in the soil, up to a certain depth) and in its atmosphere [14]. In all the mentioned cases, the environment has those elements that architecture as a system also possesses, that is, those elements that are the premise of human existence (air, water, energy...) [13], (Figure 3).

However, man has also 'stepped' into those environments which (according to current knowledge) do not possess the elements necessary for human existence, while at the same time possessing elements and factors of significant concentration and intensity that are unfavorable for human existence (Figure 4). It is about the open space of the Universe and (for now) the Earth's natural satellite, the Moon. In order to survive in such environments, man 'brings' from the Earth the elements necessary for his life, which means that his stay in such environments is time-limited, 'until the stock runs out' [13].

Figure 3. Architecturally Defined Space (Architecture as a system)
Source: Author (1988)

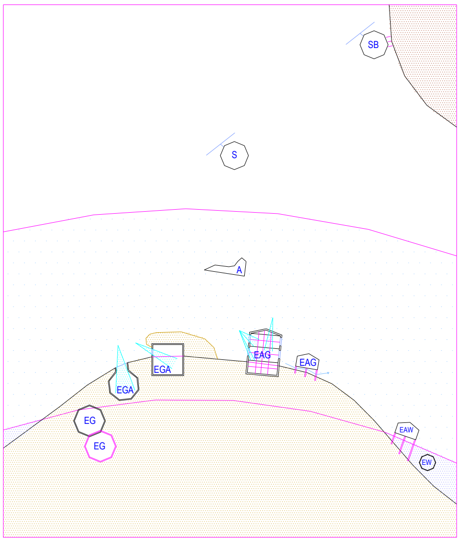


Figure 4. Architecturally Defined Space (Architecture) as a system: Type EAG (Earth-Atmosphere-Ground), Type EGA (Earth-Ground-Atmosphere), Type EG (Earth-Ground), Type EAW (Earth-Atmosphere-Water), Type EW (Earth-Water), Type EA (Earth-Atmosphere), Type S (Space), Type SB (Space-Body)
Source: Author (2011)

In his missions with or without a human crew, man makes experiments in which he searches for ways to achieve the 'generation of the desired elements and factors' in environments that do not possess such elements and factors. Such solutions of an architecturally defined space are by their nature 'autonomous', but they can exchange energy with their surroundings (mainly in the way of using solar energy). Due to its complexity, within the framework of architecture as a system, there is a smaller or larger number of subsystems that connect a certain number of closely related elements: structural system, water supply and sewerage system, electricity supply system, mechanical installation system (heating, ventilation, air conditioning - HVAC). By the very fact that architecture without man has no meaning (that is, it does not exist), it implies such a system in which life is generated. Regardless of the environment in which the architectural space should be realized, the following parameters are key for it: Thermal comfort parameters, Lighting comfort parameters, Acoustic comfort parameters. All the mentioned parameters of the architecturally defined space (architecture) are prescribed, that is, determined by the appropriate standards. They are calculated exactly by the prescribed methods, within certain subsystems of the architecture. Therefore, architecture has always been a system. However, the treatment of architecture as a system is more recent. When it comes to looking at architecture as an energy system, there are standards for individual countries, associations of countries, or at the level of the whole world. Treating architecture as a system is a holistic approach to architecture, which is the only correct approach given its complexity. In this way, architecture is viewed in its smallest detail and in its broadest context in the natural and social environment. In this way, comparisons can be made of architectural realizations from different parts of the planet Earth, from different cultures, that is, from different historical periods.

Architecture-energy transfer. The circulation of matter is always accompanied by the circulation of energy. In an architecturally defined space as a system, the circulation of energy is treated by its special subsystems: mechanical installations and electrical installations. The circulation of energy in an architecturally defined space as a system is related to ensuring those parameters of the architectural space that define the space of human comfort, from its thermal, light and acoustic aspects. The area of human comfort has been researched, determined and prescribed at the level of states, state communities and at the global world level. In order to ensure the parameters of human comfort from the thermal aspect, it is necessary to know all forms of energy necessary for life within an architecturally defined space, on the one hand, and all relevant parameters of the architectural environment as a system. Between the architecturally defined space and its surroundings, according to the Second Postulate of Thermodynamics, there is a permanent exchange of energy due to the more or less constant change in the intensity of certain parameters, both within the architectural space and in its surroundings. Sometimes this change is periodic (daily, yearly), and sometimes completely stochastic. However, the ideal of comfort within an architecturally defined space is for it to be permanent (Figure 5).

The intensity of certain environmental parameters of an architecturally defined space (air temperature, air humidity, amount of oxygen in the air, amount of carbon dioxide in the air, intensity of smell) is sometimes higher and sometimes lower than the optimal intensity of these parameters within the architecturally defined space. Hence, the role of the boundaries of the architecturally defined space is to 'dampen' the fluctuation of the intensity of certain parameters in the environment, that is, to keep the intensities of certain parameters constant within the architecturally defined space.

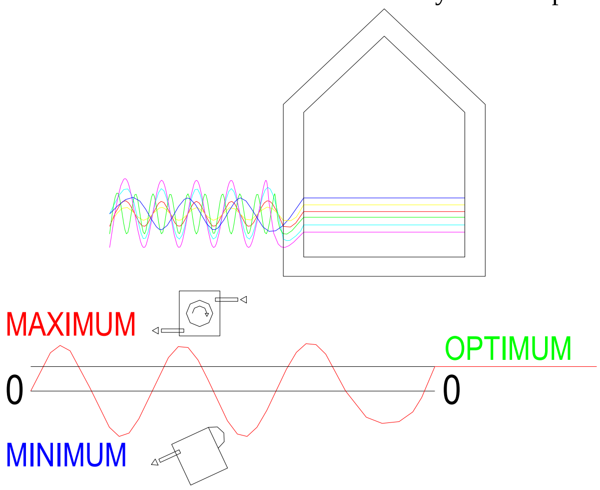


Figure 5. Changing the intensity of the environmental parameters of the Architecturally Defined Space (ADS)
Source: Author (2017)

We are fully aware of the properties of the boundaries of the architecturally defined space, which ensure the constancy of the internal comfort parameters: we are talking about the heat transfer coefficient (k, i.e. U-value, W/m^{2}K), the external temperature oscillation damping factor (υ, -), the stationary flow of water vapor in the process of parodifusion (adequate arrangement of boundary layers and the size of their relative resistance to water vapor diffusion...). There are also well-known methods of calculating heat flow and water vapor flow through the boundaries of an architecturally defined space, which allow us to arrive at valid solutions for the materialization of their materialization (Figure 6).

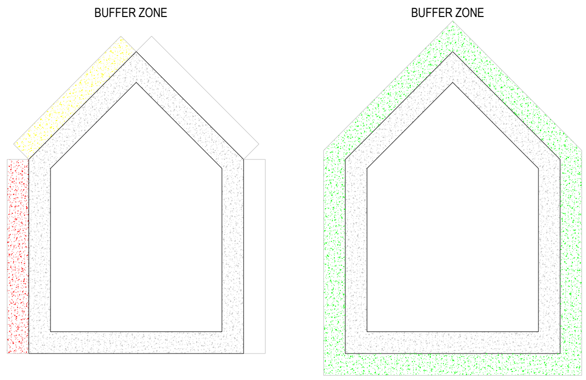


Figure 6. The materialization of the boundaries of an architecturally defined space is a complex empirical and creative process
Source: Author (2017)

The very process of calculating heat flow and water vapor flow through the boundaries of an architecturally defined space is not abstract, but is always related to the concrete concept and materialization of its boundary. It is precisely here that the complexity and contradiction of architecture is reflected, where architecture must be realized as a work of art with strict respect for empirical requirements. Similar to the circulation of heat and water vapor through the boundary of an architecturally defined space, it is possible to empirically monitor the behavior of light and sound, that is, to determine the necessary performance of the boundaries for a comfortable feeling of a person within the architectural space. When it comes to light, it is important to know its spectral composition, while for the border of an architecturally defined space, its behavior towards light is important, which is expressed by the corresponding values of its reflection (ρ), absorption (α) and transparency (τ) factors. Since the spectrum of sunlight also includes infrared rays (which are the 'carriers' of heat), the control of the intrusion of solar radiation into an architecturally defined space also has its effect on the circulation of heat between the building and its surroundings. Sound represents the phenomenon of oscillation of particles around their equilibrium position under the influence of some physical stimulus.

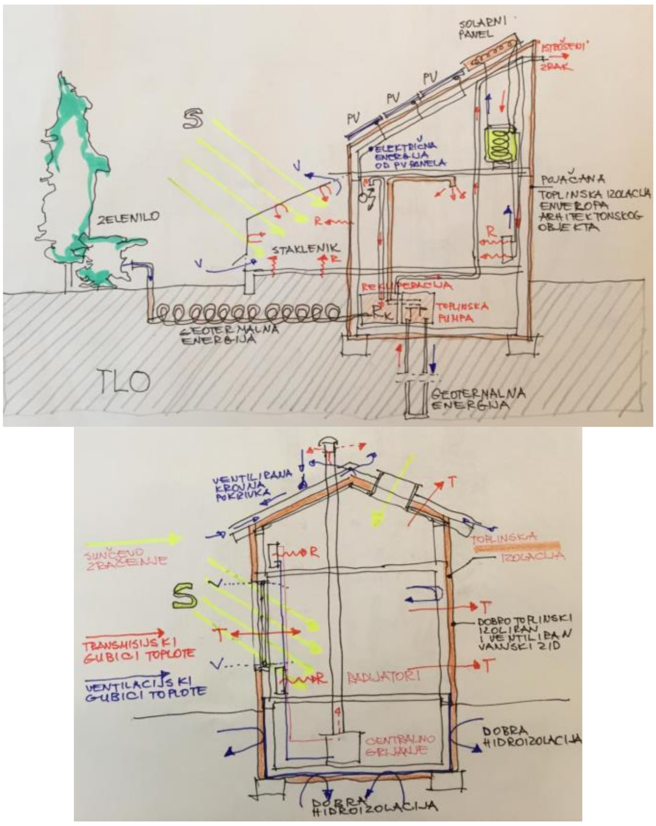


Figure 7. Architecture as an energy system
Source: Author (2017)

So, it is about mechanical vibrations and not about electromagnetic radiation (which is heat and light). Although sound (even that which we perceive as very intense) has little energy[9], it is an exceptional input in the process of conceiving and materializing the boundaries of an architecturally defined

[9] The power of an ordinary incandescent lamp is 60 W to 100 W, and the power of some sound sources is as follows: speech (2 x 10^{-3} to 7 x 10^{-6} W), violin (10^{-3} W), piano (2 x 10^{-1}W), organ (1 to 10 W), drum (10 W to 100 W). This information also speaks about the precision of the ear with regard to the size of the external stimulus: the energy required to heat 1 gram of water by 1 ^{o}C (that is, by 4 J) is sufficient to maintain audible sound at the threshold of hearing for 2,000 years. At the threshold of hearing, the size of the tympanic membrane oscillation is about 10-11 m, which is 1/100,000 part of the wavelength of light or 1/10 the diameter of a hydrogen atom.

space, due to the exceptional sensitivity of the human auditory system. There are exact methods for designing the correct distribution of sound in space (which is what architectural acoustics deals with), as well as methods for conceiving and materializing the boundaries of an architecturally defined space from the aspect of controlling sound flows from the environment to the architectural object and vice versa. It is important to emphasize that valid concepts and materialization of boundaries of architectural space from the aspect of heat flow control are not always compatible with the best solutions of conceptualization and materialization of boundaries from the aspect of sound flow management. This circumstance makes the process of conceptualization and materialization in architecture even more complex [1,2] (Figure 7).

IV. Architecture as an Energy System Based on Some Examples of Vernacular Architecture

Yurt (ger). A yurt is a traditional assembly-dismantling and portable house of nomadic herders on the vast steppes of Central Asia (Figures 8-12). It is the geographical area of the states: Mongolia, Kazakhstan, Uzbekistan, Kyrgyzstan, Afghanistan, part of Russia and China[10]. The construction of a yurt has a tradition of at least 3000 years, and the first records about it were made by the Greek historian Herodotus (484-424 BC). The yurt has a circular base (diameter 3-5 m). The walls of the yurt are made of a type of single-layer lattice (when developed on site) made of wooden sticks, stacked parallel to each other, in a package, during transport. Stronger wooden frames are built into the walls of the yurt, which carry the doors. Instead of the usual door construction, a curtain is often used that opens upwards, as a 'ventus window', or just deflects to the side, as a curtain. The roof of the yurt is in the shape of a compartment, and is made of specially shaped sticks that are placed radially, resting at their base on the wall of the yurt, while at the top of the roof they are fastened to a central, rigid, wooden hoop. Sometimes the wooden hoop is free, stabilized by the pressure forces generated by the radially placed rods of the roof structure, and sometimes it is supported on two vertical wooden columns. The horizontal forces generated by the circular shape of the roof base are absorbed by thicker woolen rope or strips of woolen mesh, which are exposed to tensile stresses. The central ring at the crown of the roof is exposed to compressive stresses, and its form is stabilized by wooden rods placed crosswise within the contour of the beam. The top of the conical roof is the highest point of the yurt space, and through it the smoke and exhausted air from the yurt is removed and natural daylight enters the space. Animal skins (on the outside) and woolen rugs on the inside are added to the skeleton of wooden slats of the perimeter walls. As a 'filling' of the skeleton of the walls, 'mattresses' filled with sheep's wool are sometimes made. The floor on the ground within the yurt is made as a platform of wooden billets and planks, to which, in the final state of the yurt construction, one or more circular rugs are added. The wooden platform of the floor is supported at points and balanced on stones, which allows for controlled air flow in the floor of the yurt. It should be noted that most of the connections between individual elements of the yurt construction are made with rope made of wool or goat hair. In all the details of the construction of the yurt, and especially in the processing of its surfaces, the effort to achieve 'beautiful' is noticeable. Everything needed to make a yurt is done on the spot: production of structural elements, production of skins, wall carpets and decorative strips, carpets for the floor [21].

[10] The yurt is so important in the culture and in the life of the people of Central Asia in general, that some of its elements are found in the state coat of arms (Kazakhstan) or flag (Kyrgyzstan).

Figure 8. Left: A yurt in the wide expanse of the steppe. Right: Yurt - the house of a nomadic man
Source: https://www.bloomberg.com/news/photo-essays/2015-06-04/why-you-need-to-go-to-mongolia-now-in-16-stunning-photos
Accessed: August 10, 2017.
Source: https://www.pinterest.com/onkruid/yurt-living/, Accessed: August 10, 2017.

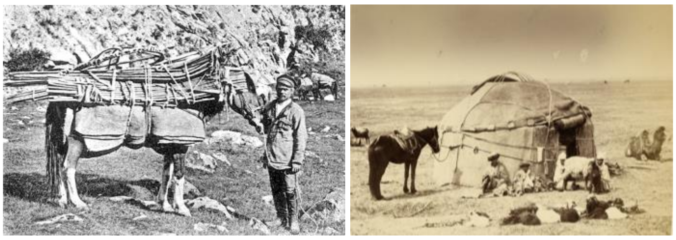


Figure 9. Left: Elements of the yurt. Right - Architecture integrated into nature
Source: https://depts.washington.edu/silkroad/culture/dwellings/dwellings.html, Accessed: August 10, 2017.
Source: https://en.wikipedia.org/wiki/Yurt, Accessed: August 10, 2017.

Figure 10. Yurt. Assembly of elements
Source: http://www.plataformaarquitectura.cl/cl/02-326671/arquitectura-vernacula-yurtas-viviendas-nomades-en-mongolia
Accessed: August 10, 2017.
Source: https://ich.unesco.org/en/RL/traditional-knowledge-and-skills-in-making-kyrgyz-and-kazakh-yurts-turkic-nomadic-dwellings-00998
Accessed: August 10, 2017.

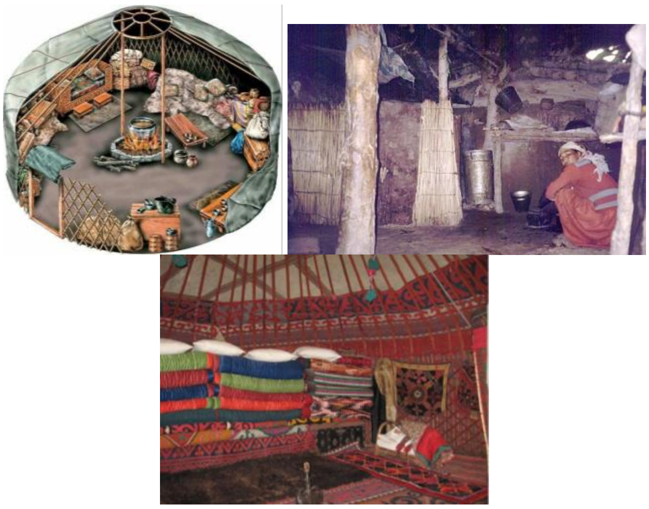


Figure 11. Yurt. Organization of space
Source: https://www.pinterest.co.uk/pin/435090013983929843/, Accessed: August 10, 2017.
Source: https://depts.washington.edu/silkroad/culture/dwellings/dwellings.html, Accessed: August 10, 2017.
Source: https://www.pinterest.com/onkruid/yurt-living/, Accessed: August 10, 2017.

Figure 12. Interior of a yurt in Kazakhstan
Source: https://www.rferl.org/a/uzbekistan_zarafshan_kazakhs/27291427.html, Accessed: August 10, 2017.

Chinese round house (Fujian tulou). Chinese round houses "tulou" (with the literal translation "earth objects") are village houses, located in several locations in the southeastern Chinese province of Fujian (Geographic coordinates: 24º39'48.53"N, 117º00'15.41"E, Elevation: 511 m). Most of them were built in the 19th and 20th centuries [22], as a 'community of equal people' (Figures 13,14). Changqilou tulou in Yongdin Province was long thought to be the largest traditional Chinese round house, with a diameter of 62.5 m, until Huang Hanming discovered that Shunyu lou in Nanjing Province was larger, with a diameter of 74.1 m. This tulou was built in 1933, and consists of four concentric rings. Its outer wall is 15 m high and 1.6 m thick. This house has 64 residential units. However, currently the largest tulou is Fushangu lou, built in the village of Chandong in Yongding province, from 1968 to 1981, which has a base diameter of 77.42 m. These are real small fortified cities, closed on the outside by thick massive walls, and on the inside by maximum open. They are made with a round or rectangular base, with three to five floors. They can be solved with one circular ring, when they have a spacious inner courtyard in their interior, or with several concentric rings separated from each other by a narrow street. In this case, the outer ring has a higher height than the inner rings. Chinese round houses are the Chinese solution for collective housing of hundreds of people (once more than 800). In addition to apartments, they also have other facilities: larger and smaller production areas, shops, a ceremonial hall, shared bathrooms, a laundry room, various warehouses... The massive walls of these megastructures (sometimes up to 1.80 m thick) were made of earth to which stones were added. Reinforcements of these walls, in case of uneven settlement, are made of bamboo and wooden beams. Narrow openings (10-13 cm wide) were left in the walls for defense against potential attackers. The verandas facing the inner courtyard are made of wood and bamboo. The roof covering is mainly tiles. This building is a typical expression of Chinese culture and outlook on the world. In contrast to the world-wide expression of social hierarchy in all areas of life (even in housing), China's Fujian tulou-house architecture expresses its attitude towards people as completely equal and equal, with the same conditions for housing. All the rooms in this building were the same size, they were built of the same materials, they had the same exterior decorations, the same windows and doors. A small family had one vertical set, from the ground floor to the top floor, while larger families, depending on the number of their members, had three or four vertical sets. There are cases where one whole tulou is inhabited by one large family made up of several generations. Such a tulou symbolized 'one roof' or the unity of the family. The land around the tulou belonged to the commune made up of its tenants. The Chinese round house, Fujian tulou, can be understood even better if it is compared with similar solutions from different areas of the Earth, as well as from different historical epochs.

Figure 13. Chinese round house in Fuian
Source: https://www.flickr.com/photos/jijis008/502789040, Accessed: August 10, 2017.
Source: http://www.masterfile.com/search/en/hakka+round+house+in+fujian, Accessed: August 10, 2017.

Figure 14. Left: Chinese Round House in Chengqilo. Right: Well in the center of the inner courtyard
Source: https://www.redbubble.com/people/vincci/works/3386115-the-king-of-hakka-tulou-chengqi-lou, Accessed: August 10, 2017.
Source: http://www.clikbing.com/index.php?page=Tulou, Accessed: August 10, 2017.

House in Ghadames (Libya). Ghadames (Ghadamis) is a city of about 10,000 inhabitants, located in an oasis on the edge of the Sahara desert, Nulut-district, in the northwestern part of Libya, 462 km away from Tripoli (Geographic coordinates: 30º07'33.18"N, 09º29'24.39"E, Elevation: 350 m). Due to its exceptional vernacular architecture, this city is called the "pearl of the desert". It was included (1986) in the UNESCO list of world cultural heritage, but due to the civil war (2011-), it was included (2016) in the list of world cultural heritage in danger [23]. The city has (according to the Köppen classification) a hot desert climate (BWh), which is characterized by long and extremely hot summers and short and warm winters. Summer temperatures reach values of over 50 °C, while the average minimum winter temperatures are 13.80 °C (the record low recorded temperature is -8 °C). The average annual precipitation is low, only 33.10 mm. On the basis of archeological findings, it was established that the site of today's city of Ghadames has been inhabited since the 4th century BC. The reason for this is the existence of a generous source of drinking water, that is, the existence of an oasis in the desert. During the reign of Emperor Augustus (lived 63 BC-14, reigned 27 BC-14), the Roman army led by Lucius Cornelius Balbus occupied this city, and it was visited (202) by Emperor Augustus. In the 3rd century, the Romans withdrew from this city. In its basic conception, the city consists of physical structures with narrow streets. The buildings have three levels: ground floor and two floors. On the ground floor, there are mainly business facilities (workshops and shops), on the first floor there are living spaces for families, and on the second floor rooms for women and spacious terraces (flat roofs of the first floor). The roofs are exclusively flat and can serve as terraces. The ground floor is arranged in such a way that the floor of the first floor is covered everywhere, which gives the impression that it is dug into the ground, and not built on the ground. In this way, open spaces with lots of shade are created within the physical structures. The basic building material from which the architectural buildings of this city were built is earth (brick). Thick walls ensure good performance of thermal stability in the summer regime. The mezzanine structures are made of beams of palm trees, with a thick charge of earth. All surfaces (boundaries of architecturally defined space) that are exposed to solar radiation are painted white, which achieved its significant reflection (albedo) from the surfaces of physical structures (Figures 15,16,17).

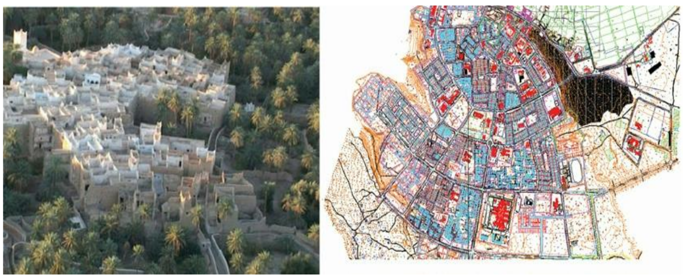


Figure 15. Zračni pogled na Ghadames i masterplan grada
Source: https://www.researchgate.net/figure/266742524_fig1_Fig-1-Aerial-view-of-old-town-and-master-plan-of-new-town
Accessed: August 10, 2023.

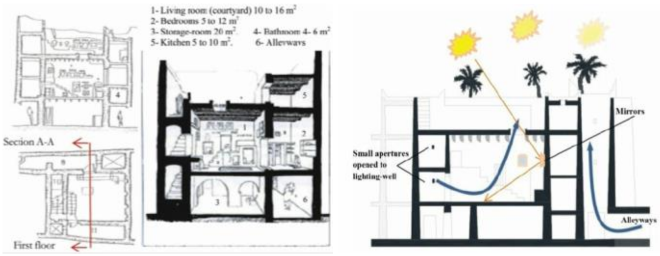


Figure 16. The old city of Ghadames. Part of the physical structure of the city
Source: https://www.researchgate.net/figure/266742524_fig2_Fig-2-Plan-and-sections-in-old-house-in-Ghadames-Ealiwa-2000-C-De-Montfort, Accessed: August 10, 2023.
Source: https://www.researchgate.net/figure/266742524_fig4_Fig-4-Natural-ventilation-and-lighting-in-old-house
Accessed: August 10, 2023.

Figure 17. House in Ghadames
Source: http://whc.unesco.org/en/list/362/, Accessed: August 10, 2023.

Indigenous residential construction in the Alps. Indigenous residential construction in the Alps is an architecturally defined space created in the conditions of a mountain climate characterized by long, cold and snowy winters and short and cool summers. An important climatic factor in this zone is the wind. In this zone, people need to protect themselves from low temperatures for a long period, solve the problem of heavy snowfall and, very often, strong winds. Wood, stone and straw are the basic building materials. The house in Algna Valesisia, Italian Alps, has a basic structure made of wood and a roof made of stone slabs. The perimeter buffer around the human habitation area is used as a cattle shed. The heat generated by animals through their metabolism during the winter raises the temperature of the immediate environment of people's living space, which makes it easier to heat that space and more easily maintain the optimal internal temperature (Figure 18).

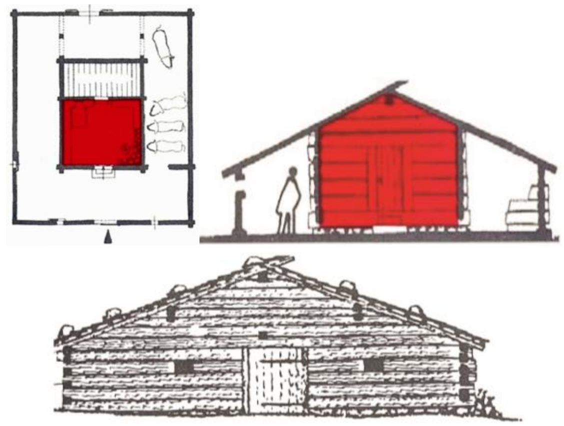


Figure 18. Indigenous residential construction in the Alps (Italy)
Source: Behling, S. & S. (1996). Solar Power, The Evolution of Sustainable Architecture, Munich-London-New York, Prestel

Bosnian Chardaklia House. In the Bosnian Chardaklia House, we encounter the solution of the protective (buffer) zone of the house, a spacious air space in which an open hearth is organized [15,16,17,18,19,20] (Figures 19,20,21). The fireplace area on the ground floor is open to the roof. The smoke from the hearth permanently surrounds the roof shell and thus 'impregnates' the roof covering-shingles. The open space is a protective buffer of the basic construction body, which in the winter period (when the roof badges are closed) functions as a thermal insulation buffer of closed air, while in the summer period (the badges are open) it is a space for intensive ventilation (cooling) of the basic building body. Divanhanes on the first floor are semi-open spaces for rest and leisure, but also a double facade solution that provides shade in the summer and a protective buffer in the winter. The function of this space in contemporary architectural concepts is a double-skin façade.

The Kantarevic family house in the Klupe village near Velika Kladusa, according to the disposition of the horizontal plan, belongs to the type of two-tracts bosnian chardaklia house with the specifics of the houses in the Bosnian Krajina. These specifics refer to the arrangement of the ground floor of the house as a barn and the first floor as a space for housing, the existence of a cantilevered annex on the main body of the house in which the water storage ('waterhouse'/'vodnica') and sanitary facilities are located, and the cantilevered letting of the residential level of the floor into the space, outside the contour of the ground floor, on all sides of the horizontal plan. This house, however, also has its own specifics: a cantilevered divanhana on the front of the house (which in the horizontal plan of the house stands symmetrically with the usual annex of a Krajina house, in relation to the central plane of symmetry), and one entrance to the house, for the apartment and for the barn. On the ground floor of the house, as already mentioned, there is a barn, and a single-legged wooden staircase leading to the floor where the living quarters are arranged.

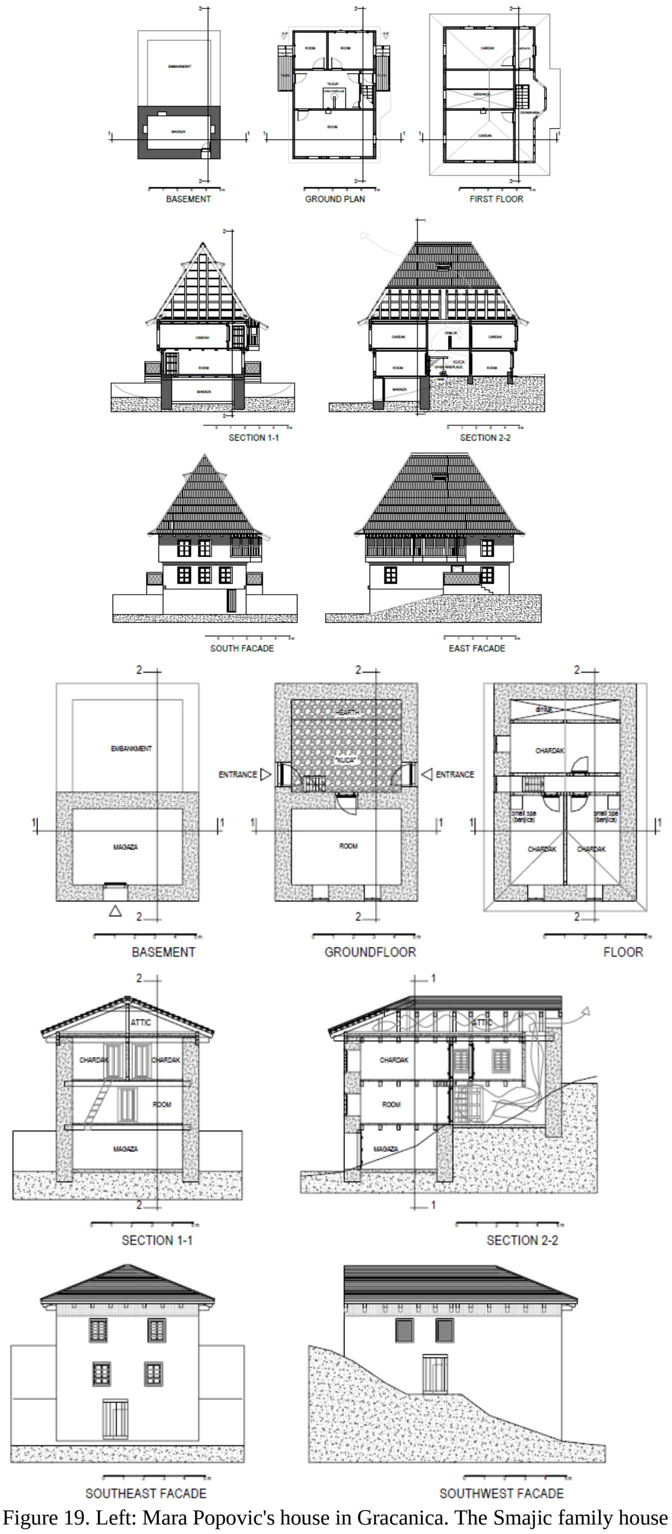


Figure 19. Left: Mara Popovic's house in Gracanica. The Smajic family house in Gorani near Konjic
Source: Author (2016)

A single-legged wooden staircase from the ground floor leads to the first floor area, to the first section, where the 'house' area with a fireplace, i.e. the living room area, is arranged. From this space there is access to a relatively large room that occupies the entire tract of the horizontal floor plan, to the area of the sofa bed, on one side, and to the area of the annex with the 'waterhouse'/'vodnica' and sanitary facilities, on the other side of the house. Although of modest basic dimensions, the divanhana built in this house testifies to people's need to 'have a divanhana in the house', which always symbolizes a higher level of human needs, i.e. a richer housing culture. It should be emphasized that in the tract where the area of the 'house'/'kuća' is arranged, in its inter-floor construction ground floor-first floor, a relatively thick layer of compacted clay with shavings of straw and chaff is made as a floor covering, which ensures fire safety of the wooden elements of the mezzanine structure and the house as a whole. From the space of the 'house'/'kuća', communication with the space of the attic was achieved by means of a permanently installed ladder. In one wall of wooden logs in the area of the 'house'/'kuća', a special opening (similar to a counter) was made, through which food was taken, first to a wooden console on the outside of the wall, and then lowered to the ground outside with a rope. This 'service elevator' solution is unique in Bosnia and Herzegovina (Figures 20,21).

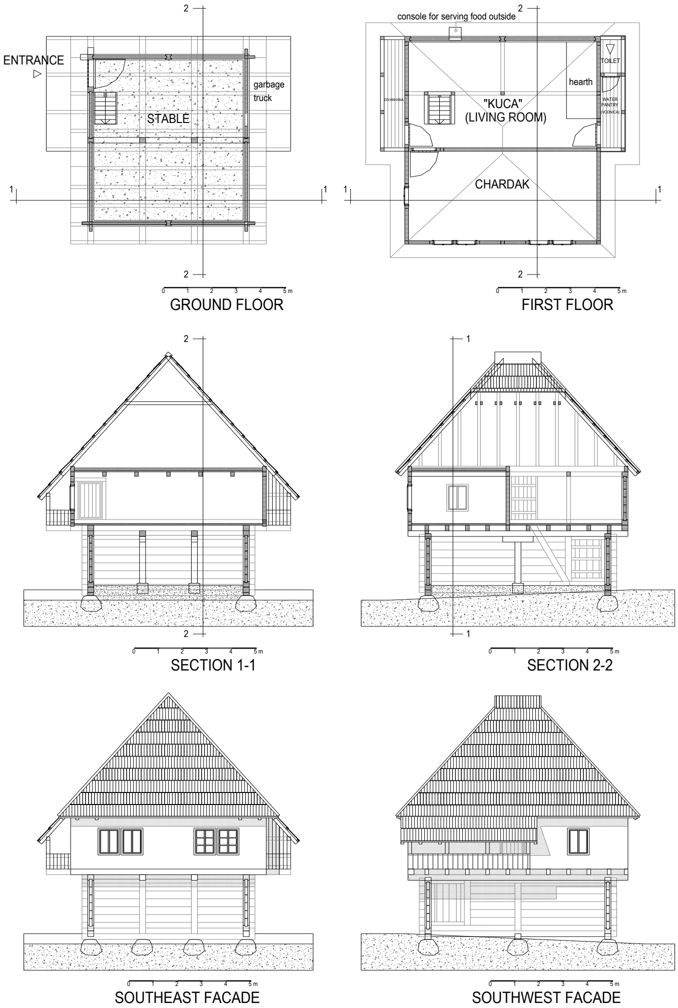


Figure 20. The Kantarevic family house in Klupe village near Velika Kladusa. Disposition
Source: Author (Drawing, 2016)

Figure 21. The Kantarevic family house in Klupe village near Velika Kladusa. Today's appearance of the house
Source: Author (July 25, 2016.)

V. Architecture as an Energy System on Some Examples of Modern and Contemporary Author's Architecture

Dymaxion House. The American architect, engineer and inventor, Buckminster Fuller (1895-1983), designed a house in 1927 that he called the “Dymaxion House”, highlighting its main characteristics - “dynamism + maximum efficiency”. Dymaxion House is a “dwelling machine”, a kind of 'zippered house', the embodiment of the application of technique and technology in architecture, and that on its most subtle program - a residential house (Figure 22).

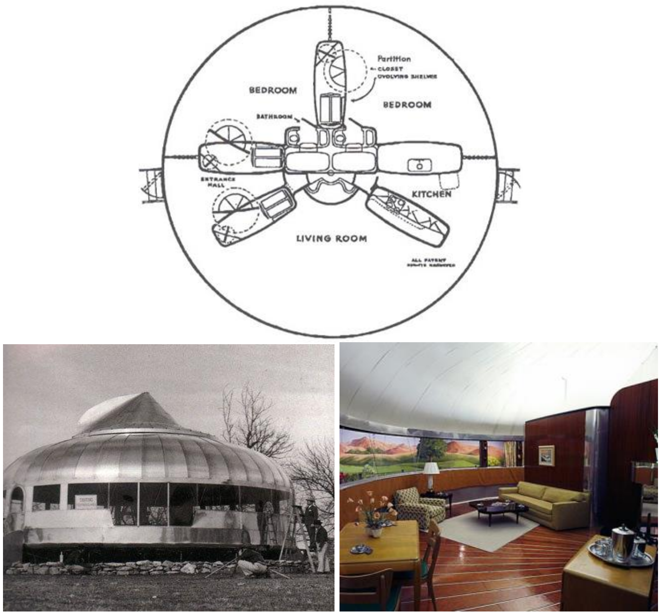


Figure 22. Dymaxion House (1945), (Design: Richard Buckminster Fuller)
Source: http://expandingouthouse.blogspot.ba/2013_02_06_archive.html, Accessed: August 10, 2023.
Source: https://www.pinterest.com/raiexpo/osaka-expo70/, Accessed: August 10, 2023.
Source: http://retrorenovation.com/2013/06/18/dymaxion-house-buckminster-fuller/, Accessed: August 10, 2023.

Buckminster Fuller went a step further with the design and realization of the “Dymaxion car”, making the house a moving object. Designing and realizing the famous maxim "less is more" formulated by the architect Ludwig Mies van der Rohe (1886-1969), one of those ideas that best reflects the spirit of the industrial age of the 20th century, was the guiding idea of the architect Buckminster Fuller, who led to patents and the realization of the famous geodesic dome and tensegyti structures. All of these are examples of architectural realizations with a visible methodological approach characteristic of the “Architecture as an energy system” approach[11].

2015 Prototype Home (Solar Decarhlon 2009). The American Department of Energy established (2002) a special competition of 10 student teams (Solar Decathlon) to design and build a prototype of an energy-efficient building (Figures 23-26). The winning solution should be characterized by innovative design, innovative generation of the necessary energy, energy efficiency, efficiency in water use and the market potential of the solution. The experience gained so far has shown that this project has encouraged architecture faculties in the USA and around the world to offer their ideas, while the 'competition itself' has become the best way of learning and exchanging ideas and knowledge of students on the plan of a new approach to the conceptualization and materialization of architectural space. Here is presented the winning solution (Solar Decathlon 2009), a facility of the Technische Universitat Darmstadt team. In the explanation of their concept, the team from Technische Universitat Darmstadt listed four basic fields of implementing energy efficiency on their solution: 1. Reduction of energy consumption by passive materialization solutions, 2. Reduction of energy consumption by active solutions, 3. Reduction of energy consumption by partially active solutions and 3. Increasing energy gains with active solutions.

At the same time, Reducing energy consumption through passive materialization solutions includes a number of individual solutions: the optimal relationship between the external surface (envelope) of the object and its volume (S/V), the concept of Single room (one-room object), the concept of minimizing connections, i.e. the realization of the object's envelope as compact as possible, thermal mass of the material. Reducing energy consumption with active solutions includes individual solutions: efficient building equipment, heating and cooling of the building with a heat pump (air), minimizing the consumption of technical resources in the building. The reduction of energy consumption with partially active solutions includes individual solutions: solar radiation shading systems, controlled air conditioners that ensure heat recovery, air humidification and reduction of its humidity. Increasing energy gains through active solutions includes individual solutions: rooftop photovoltaic systems, facade photovoltaic systems, rainwater harvesting.

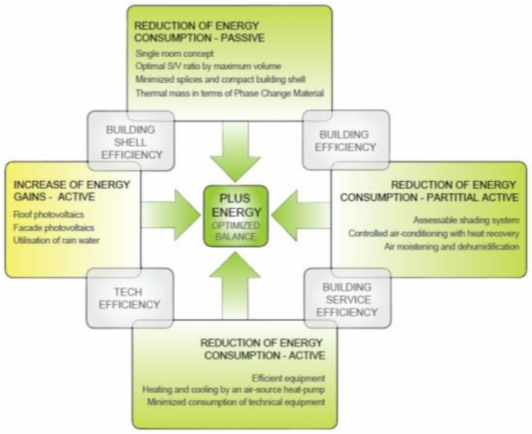


Figure 23. 2015 PROTOTYPE HOME: Technische Universitat Darmstadt team building (2009)
Source: https://www.solardecathlon.gov/past/2009/technical_resources.html, Accessed: August 10, 2023.

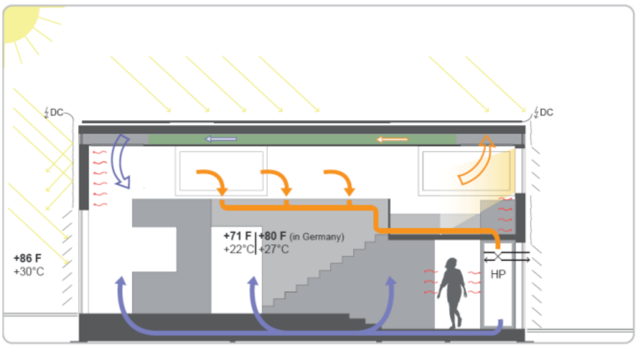
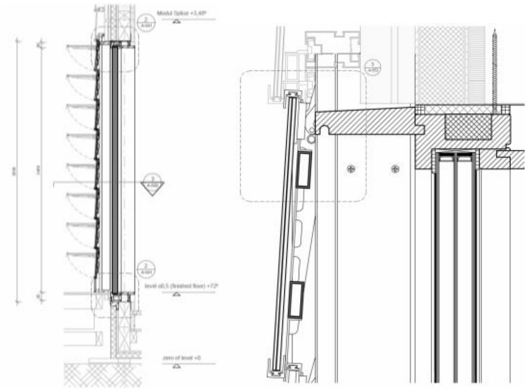
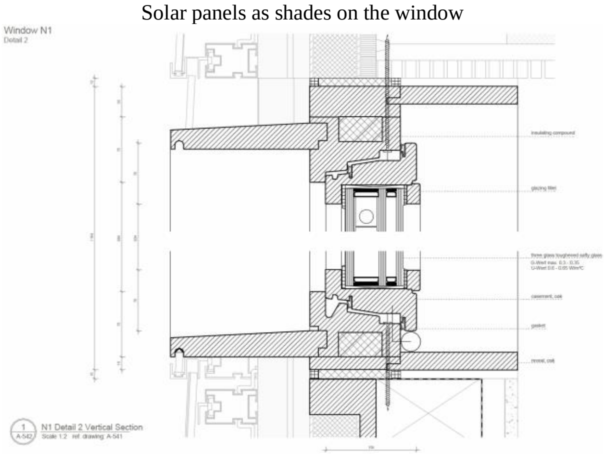


Figure 24. 2015 PROTOTYPE HOME: Technische Universitat Darmstadt team building (2009). Energy performance of the facility
Source: Hegger M., Smart Buildings – Smart Cities. Sustainable and Energy Efficient Architecture, Boston, 8 February 2011
Accessed: August 10, 2023.

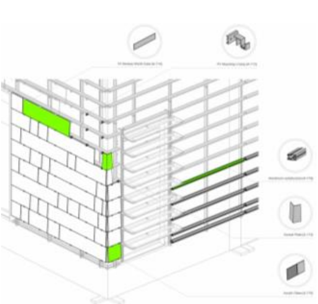
[11] Dymaxion House in its appearance, construction concept and vision of its use, has similarities with the traditional house of Central Asian herders-nomads - yurt.



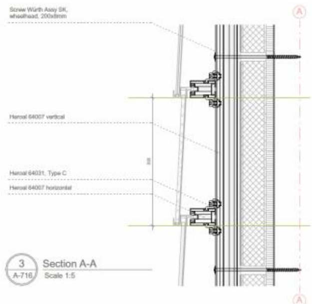
Solar panels as shades on the window



Detail of the window



Facade



Detail of the facade

Figure 25. 2015 PROTOTYPE HOME: Technische Universitat Darmstadt team facility (2009). Elements of the physical structure of the building
Source: https://www.solardecathlon.gov/past/2009/technical_resources.html, Accessed: August 10, 2023.

An essential feature of the presented solution is the possibility of its assembly and disassembly, i.e. lifting it in different environments (Figure 26).

Ski Dubai Snowpark. Ski Dubai Snowpark is an artificially arranged ski center in desert climate conditions (Geographic coordinates: 25º07'00.66"N, 55º11'55.13"E, Elevation: about 0 m). The ski center with the Mall of Emirates, one of the largest shopping centers in the world, forms a unique business unit built by its owner, Majid Al Futtaim Group. Ski Dubai Snowpark was designed and built by Thinkwell Group from Los Angeles. Considering the natural environment, one can naturally expect sand skiing, or sand boarding in the area of Dubai. At first glance, the construction of a ski center looks like an adventure and an exhibition, however, it is a financially justified job for its investor and owner.

Figure 26. 2015 PROTOTYPE HOME: Technische Universitat Darmstadt team facility (2009). The building is prefabricated and dismantled and can be built in different environments
Source: https://www.solardecathlon.gov/past/2009/technical_resources.html, Accessed: August 10, 2023.

The very idea of building a ski center in the climatic conditions of Dubai, in its beginning, resembles a mathematic-physical task that needs to be solved (a task) in an architectural space characterized by two key data: Air temperature of the interior space: t_i = -20 °C, Air temperature of the exterior space (environment): t_e = +40 °C. The temperature difference (60 °C) to which the boundary of the architecturally defined space (building envelope) is exposed should be noted. 6000 tons of artificial snow was artificially produced in the ski center. The area of the center is 22,500 m^2 and it is in operation all year round.

Figure 27. Ski Dubai Snowpark
Source: https://www.viaggioadubai.it/dubai-cosa-vedere/ski-dubai/, Accessed: August 10, 2023.
Source: http://montada.sptechs.com/the-world/topic13007.html, Accessed: August 10, 2023.

The temperature inside the facility is from -1 °C to -20 °C, while the temperature in its surroundings rises to +40 °C. Inside the building, there are five ski slopes with excellent technical performance, with the longest one being 400 m. The facility is 85 m high and 80 m wide. A special attraction of the ski center is the snow cave, with an area of 3000 m^2, snow bullet (flying down a 150 m long slope) and penguins. The names of individual cafes in this center refer to the names of famous centers and people in the world of winter sports: Caffe St Moritz at the entrance to the center, Avalanche Caffe in the middle of the trail with a view of the slope. A skiing and snowboarding school works permanently in the center. The full capacity of the facility is 1,500 guests (Figure 27).

Apple Campus 2 in Cupertino. Apple Campus 2 in Cupertino (USA) is the main headquarters of Apple Inc. in Cupertino, California, USA (Geographic coordinates: 37º20'05.83"N, 122º00'32.40"W, Elevation: 48 m). The building was designed by the design company Foster & Partners according to the idea of the owner of the company, Steve Jobs (1955-2011), during his lifetime (Figures 28-31). The facility was built in less than four years (2013-2017).

Figure 28. Apple Campus 2 in Cupertino, USA (2013-2017)
Source:https://www.designboom.com/architecture/apple-campus-2-drone-video-update-cupertino-spaceship-california-01-06-2017/, Accessed: August 10, 2023.

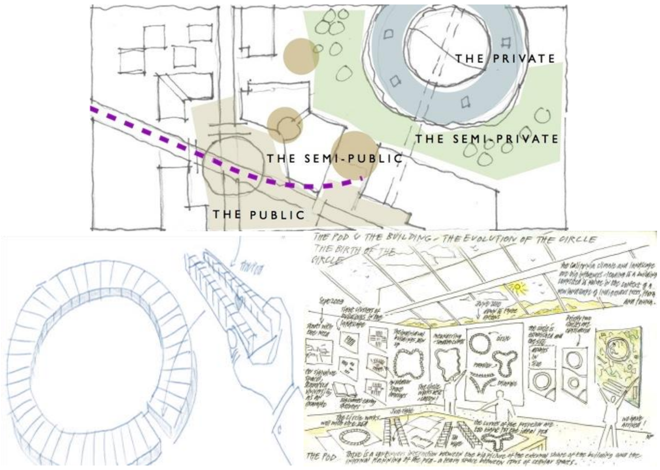


Figure 29. Sketches by Norman Foster
Source: https://www.wired.com/2017/05/apple-park-new-silicon-valley-campus/, Accessed: August 10, 2023.

This megastructure is characterized, at the same time, by a huge built-up area (with all the necessary spatial-technical and infrastructural performances) and by equally huge efforts to make the building in a 'friendly' relationship with nature, while providing optimal comfort conditions for its 12,000 employees. The owner and creator of this facility, Steve Jobs, wanted to build a facility where employees could achieve joint creativity, cooperation, innovation, development and progress. The building is in the shape of a circular ring, with an outer diameter of 461 m, built with 4 above-ground and 3 underground floors, with a total net usable area of 260,000 m^2; 14,200 parking spaces for cars (2,000 in underground garages) and 2,000 spaces for bicycles are provided for employees and guests.

The relationship of the building to its natural environment is described by the fact that before its construction there was 20% greenery on the site, and that after its construction it will be 80%. The inner yard of the building is designed as a spacious park with 9,000 trees (309 species) in the same way as orchards in California are arranged.

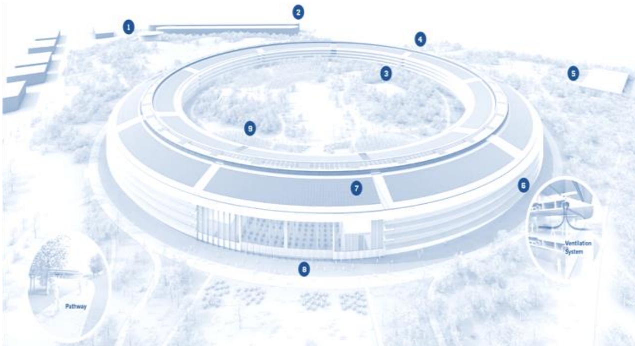


Figure 30. Apple Campus 2 in Cupertino
Main contents of the complex: 1. Amphitheater "Steve Jobs" with a capacity of 1000 seats. It consists of a glass cylinder with a height of 6 m, a roof covering made of carbon-fiber material, with a diameter of 50 m, 2. Parking area (6000 underground and 3000 above-ground parking spaces), 3. Impact absorbers made of huge steel insulating base that ensures the annular the shape of the building against any vibrational movements of the ground, 4. Local tunnel (connecting the main entrance block with the campus and the parking area), 5. Wellness center with an area of 30,000 m^2 (for employee fitness, wellness as well as medical and dental services), 6. Concept 'buildings that breathe' (optimization of the air in the rooms is achieved using optimizing devices for air regulation - the 'chimney principle'), 7. Solar systems installed over the entire roof covering of the ring-shaped building, 8. The concept of 'big doors' (sliding doors along the outer part cafes), 9. Vegetation area (According to the request and idea of the owner of Apple, Steve Jobs, that the entire complex be covered with vegetation).
Source: https://www.wired.com/2017/05/apple-park-new-silicon-valley-campus/, Accessed: August 10, 2023.

There are seven cafes within the complex, and the largest is on the third floor and can accommodate 3,000 visitors. The basic idea in interior design is to achieve transparency and openness with the aim of encouraging employee innovation and the exchange of ideas. Apple Campus 2 in Cupertino will be supplied with energy from renewable sources: the solar panels on its roof have an installed power of 17 MW, and it is the most spacious 'solar roof' in the world[12]. Four MW of electricity will be generated by Bloom Energy Server fuel cells that will use biofuel and natural gas. A very significant fact for this highly sophisticated facility is the fact that natural ventilation will be used in its premises for 9 months of the year. The object basically has the form of a circular ring, and is associated with a spaceship.

[12] For example, the installed capacity of the hydroelectric plant „Jablanica" (in Bosnia and Herzegovina) is 180 MW (six aggregates) with an annual production of 770 GWh.

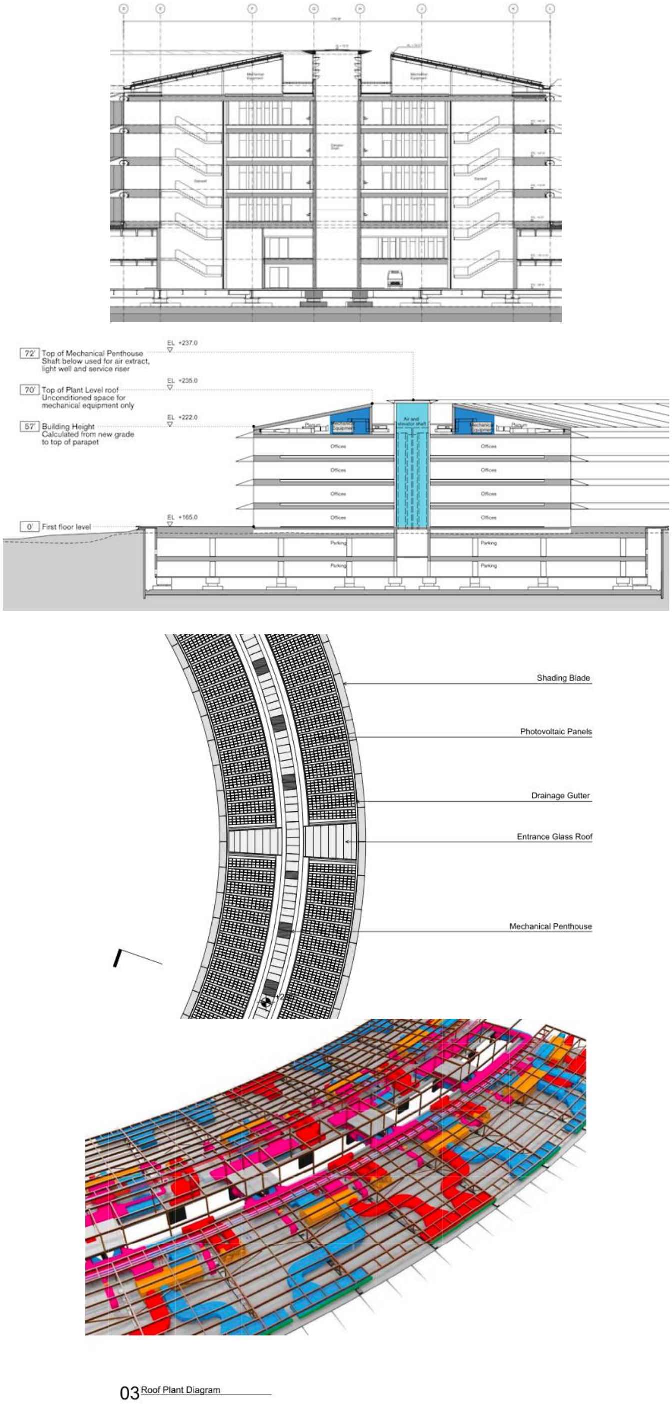


Figure 31. Apple Campus 2. Some elements of the structure of the facility
Source:
http://appleinsider.com/articles/12/03/10/apple_provides_additional_details_renders_for_cupertino_campus_project
Accessed: August 10, 2023.

VI. Conclusion

The topic "Architecture as an energy system" came explicitly into focus at the end of the 20th century. However, it has been in focus since early history as sui generis in the conception and materialization of Architecturally Defined Space (ADS). In traditional (vernacular) architecture, the focus of construction was on the use of materials from the 'site' with construction techniques that were perfected over centuries and became 'natural' and were experienced in the way of experiencing the natural environment. At the end of the 20th century, the issue of 'climate change', which (according to many scientists) was caused by man, came into the focus of the global world population [24]. The design and realization of 'energy-efficient buildings', buildings that are in a 'friendly relationship with the natural environment' ('green buildings'), for example, became the Agenda of the 21st century, and the use of 'renewable energy sources' entered architecture and everything areas of life as a way to preserve the natural environment. This approach is supported by laws in many countries around the world [25]. By focusing on the theme "Architecture as an energy system", the way is opened for new concepts and new aesthetics in architecture.

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