Proceedings of ICAD2014
The Eighth International Conference on Axiomatic Design
Campus de Caparica – September 24-26, 2014
ICAD-2014-05

AXIOMATIC DESIGN APPROACH FOR THE CONCEPTUAL DESIGN OF SUSTAINABLE BUILDINGS

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ABSTRACT

Architectural design needs systematic approaches to manage complexity in the early design process stage and to address sustainable building requirements. Architects often use previous experiences and knowledge to stimulate the early conjecture of possible solutions repeatedly until a satisfactory solution is defined. Possible use of an engineering design framework such as Axiomatic Design (AD) is studied with a case study on a small sustainable house design. High-level requirements are defined and decomposed into a manageable set of requirements. This study shows the potentialities of applying AD to support the initial architect's decision-making activity for the development of sustainable solutions.

Keywords: axiomatic design, sustainable building, decision-making

1 INTRODUCTION

The complexity of architectural design has been ever increasing due to the need for designers to address environmental and energy issues along with social-economic considerations. As the demand for sustainable buildings continues to increase, the need for a better understanding of how these buildings are designed has also increased. In the sustainable building design, the aim is to reach an overall sustainability in which design solutions satisfy the specified requirements regarding quality, cost, time and also efficient use of resources and consideration of context, environment and local culture [European Community Commission, 2005]. Therefore several aspects have to be considered right from the initial phase of the design process. The solution has to be optimized with consideration for a large number of different (sometimes conflicting) requirements and constraints, and it has to be selected from different available alternatives.

In order to address the key issues explained above, the design phases of the architectural design reviewed by the Royal Institute of British Architects (RIBA) is considered and shown in Table 1 [RIBA, 2012].

Table 1 Architectural design process [**RIBA, 2012**]

1	Development of Initial Project Brief according to project objectives, client's business case, sustainability aspirations and other constraints	
2	Preparation of **Concept Design** including proposals for mechanical, structural design, site landscape, specifications and preliminary cost plan along with environmental strategies.	
3	Preparation of Developed Design including coordinated and updated proposals for structural design, services systems, site landscape, outline specifications, cost plan and project strategies.	
4	Preparation of Technical Design information including all architectural, structural and mechanical services information and specifications	

In the initial and concept design phases, the design activity is more important and challenging than in the later design phases since architects have the greatest opportunity for good decisions as well as the risk of bad decisions for addressing the complexity of sustainable building design and influencing the project outcomes. Usually, during this initial phase of the design process, architects use previous experiences and knowledge and define a rather simplified problem in order to stimulate the early conjecture of possible solutions (Figure 1) [Marchesi et al, 2013].

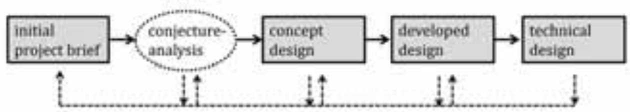

Figure 1. Concept generation in the architectural design process

Therefore very early in the design process, architects identify a rough quick concept based on a limited set of design objectives and developed by a conjecture-analysis cycle in which both problem and solution are refined in parallel

[Marchesi et al, 2013]. During these loops of iteration, the form of the building is slowly generated. The conjecture-analysis cycle often results in serial formulation of design problems and iterative search for solutions. Initially defined problems are constantly reformulated, co-evolving together during the design process until the relevant issues of the specific task and the related design solution are defined [Marchesi et al, 2013]. This approach is explained below by a case study analysis of a roof concept generation, the Lord's Cricket School roof, reviewed by its own designers [Spence et al, 2013]. The crucial requirement for this project was a high and steady degree of natural lighting inside the building. In order to guarantee this requirement, saw-tooth north-lights were proposed on the roof. Then the designers proposed to soften the roof-light shape for improving the internal reflections of the daylight. Afterwards the design solution was redefined moving the light glass line according to the requirement of daylight entrance improvement. Since in this last solution the sunlight enters directly, an internal solar blinds layer was proposed that obstructs the sunlight, but allows the daylight entrance.

Systems design tools and methods in engineering can be useful to minimize this kind of serial and iterative design process in architectural design [Sohlenius, 2000; Sohlenius and Johansson, 2002]. AD, one of these engineering design approaches, is distinguished from other systematic design methods by having a framework for mapping through top-down and zigzagging decomposition between functional and design parameter domains and two design axioms that guide the decision-making activity during the design process, especially in the early design phase, towards good design decisions [Suh, 1990, 2001]. In order to demonstrate the benefits of applying AD to the architect's approach, AD is applied to the roof design case study. Using AD, a minimum set of independent FRs is defined for a sustainable building design: supporting of loads, optimization of daylight inside and protection from rainwater among others. Then, a solution is conceptualized by mapping between domains, from the functional domain to the physical domain and it is expressed in terms of design parameters (DPs) that satisfy the established FRs. Later, coming back in the functional domain, a lower level is generated, and the process is pursued until the design is completed. A comparison between architect's approach and AD approach is showed in Figure 2.

In general, architectural design approach emphasizes intuition and experience during the co-evolving and iterative concept design phase. But often designer's knowledge and experience are not sufficient due to the complexity of sustainable building design. In addition, the architects have to consider and satisfy also other requirements such as water protection and structural stability. Most of the available tools for designing sustainable buildings are to support late design development and evaluate the sustainability of detailed building projects providing an indication of their performances [Marchesi et al, 2013]. Architect's experience should be supported by systematic approaches to design in order to manage complex problems starting from the early phase of the process.

Using AD, a designer is able to consider all requirements, including sustainable requirements, since AD begins with the definition of a minimum set of independent functional requirements (FRs). In AD, the formulation of the problem and the solutions are developed together with constant shuttling to-and-from problem (what) and solution (how), moving down and decomposing into a hierarchy [Suh, 1990, 2001]. Also, in the architectural design, the decision-making activity is performed by intuition and experience, making decisions among conflicting parameters, defines necessary compromises and optimizes design decisions regarding a varied and complex set of requirements. In contrast, AD provides two design Axioms for designers to make decisions not to couple the FRs and not to make the design too complex. This is especially beneficial in the conceptual phase of the design of sustainable buildings.

In order to show the potentiality of applying AD to the design of sustainable buildings, the conceptual design of a small sustainable house is reviewed. Requirements defined according to the customer needs, urban and building regulations and a sustainable building protocol, CasaClima Nature are progressively considered during the design process. This analysis results in an initial design framework, supported by decision criteria, to address early the design solution toward the established objectives in a systematic way and to assure the design decision consistency along the decomposition process. The research presented in this paper intends to propose the development of a decision-making tool in a Building Information Modelling (BIM) process in which high level design decision support system for architects is integrated in a multi-disciplinary digital information store by a suitable representation [National Institute of Building Sciences, 2007]. In a BIM tool, AD may improve the decision-making activity of sustainable buildings design from the initial phase to the detail technical design phase.

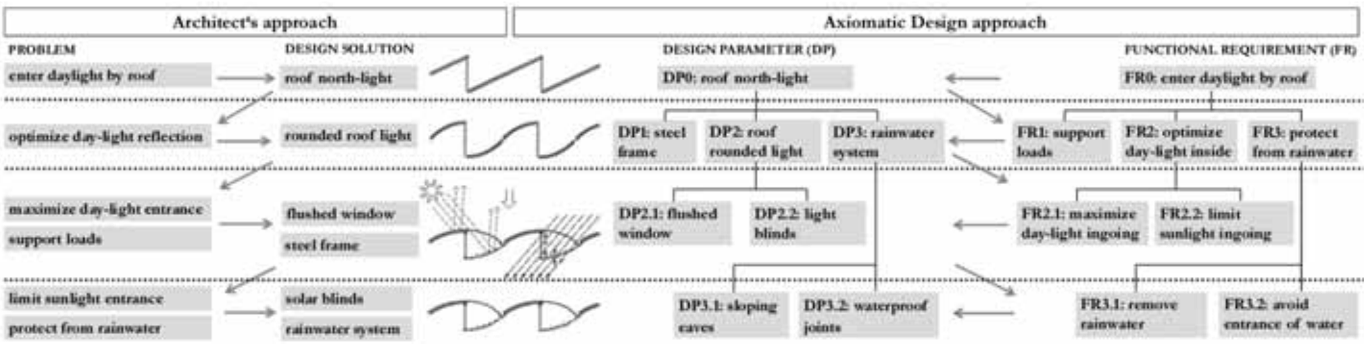

Figure 2. Comparison between architect's approach and AD approach on a roof design case

2 CONCEPTUAL DESIGN DEVELOPMENT OF A SUSTAINABLE BUILDING

The conceptual design development of a sustainable building case study is reviewed using AD: the design requirements and the related design solution are decomposed down coherently in a systemic way transforming the design goals into a concept design solution through the process of mapping, zigzagging and decomposition. AD decomposition is performed starting from the defined customer attributes (CAs). In order to ensure that all needs are addressed, all people involved in the design process should be initially considered. In this case study, the initial set of CAs is defined collecting data from the end users that are also those who make the buying decision about building and maintenance, the government and local municipality and the sustainable building assessment agency. The owners require a sustainable house for 2 people in a timber panel structure with zero energy consumption and zero carbon emissions annually, also known as a zero net energy building (NZEB). It should be an energy efficient house with passive energy use and grid connection, enabled to generate energy from renewable sources to compensate for its own energy demand. Moreover the customers require that the design is pleasantly integrated in the natural and architectural context; the cost is less than 200 000 euro and the construction is built within 3 year The design solution must also satisfy design requirements defined by local and national rules regarding safety (earthquake risk), comfort (thermal, hygrometric, acoustic, light) health (radon, electromagnetism, air quality pollution) usability, maintenance and energy efficiency [Comune di Bolzano, 2005, 2013; Repubblica Italiana, 1991, 2000, 2001, 2008]. In order to satisfy the demand for a certified sustainable design solution, a green building certification assessment, CasaClima Nature, developed by Agenzia CasaClima in Italy, is adopted. CasaClima Nature protocol consists of a set of eight requirements regarding skin energy efficiency, overall energy efficiency, environmental impact of construction materials, water impact, indoor air quality, daylight comfort, acoustic comfort, radon protection expressed in terms of parameters and limit values [Agenzia CasaClima, 2013]. Specifications about the site and context where the design is located are collected in order to generate a solution integrated in the surrounding and to define specific site features according to urban, building and environmental regulation requirements. The site is a rectangular piece of land in a semi-rural and low density zone on the border of the city in the north Italy composed of green spaces and sparse rural constructions. Typical local architecture is characterized by rock basement, timber balcony at upper levels and timber pitched roof. The area presents a low risk of earthquake and no-risk of landslips with loose and low resistant ground. The climate is evaluated cold (E climate zone) according to the national climate zone classification [Repubblica Italiana, 1993]. The site is oriented toward south; it is a well-sunny area without visual obstructions. The area benefits by regular wind from south in summer and occasional wind from north in winter and spring. Regarding the renewable energy sources available, in the site it is possible to have available energy by solar energy panels and photovoltaic panels, by ground probe and by biomass. In regard to environment aspects, the presence of radon is low in this area and specific protection measures are not required. The noise level is also low and the electromagnetism does not exceed the law limits above which specific measures are compulsory. Anyway there is a problem of air quality pollution in winter due to the smog stagnation for absence of wind.

Based on customer's requests, the top-level design goal is described in terms of FR, and the corresponding DP as follows:

FR0 = provide a sustainable house for two people, energy efficient, grid connected, able to generate renewable sources energy to make up for its own energy demand

DP0 = sustainable NZE solar two-room house project

According to the Italian technical rule UNI 10838-1999 [UNI, 1999], a building must provide usable space to accommodate the user activities and assure the permanence of safe, healthy and comfortable conditions for the users with regard to varying behavior of the external environment. Building design is composed of two systems: space system and technology system. Space system defines a combined set of inside-outside usable spaces in their functions, dimensions, shape, reciprocal position and position with consideration for the site. It includes the circulation within these spaces to allow the flow of habitants and things and the connectivity between inside and outside. Technology system consist of an integrated set of building components providing partially or totally specific functions to guarantee and maintain conditions of safety, health and comfort. Space and technology systems should be composed together and in relation with the physical surroundings to create aesthetic harmony. The aesthetic quality of architectural design is given from proportion, light, texture and color of both systems combined in an ordered form and integrated with the surrounding [Ackerman, 2013].

The top-level FR0 for a chosen DP0 is decomposed:

FR1 = accommodate client's living activities for two people

FR2 = support client's activities (protect the internal environment, relate to the external environment, provide resources and equipment)

At the highest level of the design process, a design solution determined by the architects must satisfy the two FRs by a physical system that combines space and technology into a harmonious entity. The definition of the design solution is constrained by urban and building regulations regarding maximum height, maximum covered surface and minimum inside surface and by user's aesthetic requirements such as the maintaining of some features such as inclined roof typical of the local traditional architecture (Table 2).

Table 2 First level **Cs**

C1	made by a timber technology *(customer need)*
C2	guarantee volume smaller than 400 m3 to limit cost to 200.000 euro *(customer need)* and at least minimum dwelling volume of 20 m3 *(building regulation)*
C3	provide renewable source energy to integrally cover its own energy demand *(customer need)*
C4	adopt typological features of local architecture: pitched roof and well-oriented balcony *(customer need)*
C5	use a semi-prefabricated technology to construct building within 3 year *(customer need)*
C6	observe plan regularity *(building regulation)* and limit span to 5 m to optimize structure construction cost *(customer need)*
C7	be oriented toward south with openings toward south to optimize passive solar energy use *(building regulation)* and south-north to foster natural ventilation *(customer need)*
C8	observe maximum built index (2 m3/m2), maximum height (10.5 m), maximum cover surface rate (33%) and minimum distance from borders (5 m) and from existing buildings (10 m) *(building regulation)*
C9	if ratio between thermal loss surface and volume is lower than 0.2, overall energy efficiency in winter (EPw) should be lower than 46.8 kWh/m2yr; if S/V is bigger than 0.9, EPw limit should be lower than 116 kWh/m2yr.. Intermediate values are defined by linear interpolation *(building regulation)*
C10	supply renewable source energy (by sun, ground, wind or biomass) *(building regulation)*
C11	integrate any photovoltaic and solar energy systems on the pitched roof *(building regulation)*
C12	locate any solar energy system on the roof surface oriented toward south *(building regulation)*
C13	obstruction absence on 60% involved roof surface in case of solar energy system (*building regulation*)
C14	use construction materials with environmental impact index smaller than 300 points *(CasaClima)*

According to the defined FRs and constraints (Cs), a rough volume is proposed. Based on the initial mapping, the DPs that satisfy the defined set of FRs are chosen as:

DP1 = two-room house
DP2 = building body in timber panels with an integrated active solar energy systems

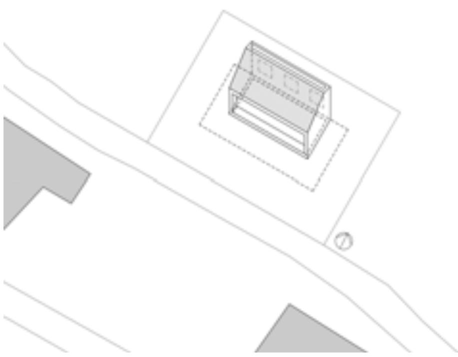

Figure 3. Initial design solution

The defined volume (Figure 3) is located on the site in relation to the access from the road, observing specific distances from the propriety line and roads according to the conditions required by the local urban plan.

In order to build an energy self-sufficient building, the volume is oriented towards south to optimize the passive and active uses of the solar energy. Also CasaClima requirements impose constraints in the initial decomposition: low environmental impact of the construction materials should be guaranteed.

In order to check the coupling of the DPs chosen, the corresponding design matrix (DM) is developed (Table 3).

Table **3** First level **DM**

	DP1	DP2
FR1	X	-
FR2	X	X

The resulting DM is triangular: the FRs are decoupled which implies that FRs can be satisfied only when FR1 is determined before FR2. Therefore if the planned space is adjusted first, the function of providing safe and comfortable conditions could be met without affecting the planned space.

The FRs and DPs are decomposed into lower level ones using the framework proposed by Italian organizations for residential building CER [CER, 1984] and the Italian organization for standardization UNI [UNI, 1981]. Regarding space aspects, the customers specify further their needs: a small dwelling area, an open area for outside living activities and a parking area for a car. The solution should provide a bright and sunny place for living.

The FR1 is decomposed further to a lower level FRs in order to provide specific areas for the user's activities. The lower level of FR1 is defined as follows:

FR1.1 = accommodate dwelling activities
FR1.2 = accommodate outside living activities
FR1.3 = accommodate outside service activities: waste collecting and car parking.
FR1.4 = connect outside-inside
FR1.5 = connect activities

The design solution is subjected to constraints imposed by the users and the local building rules as showed in the following Table 4.

Table **4 Second** level **Cs - FR1**

C1.1	locate outside living activities towards south *(customer need)*
C1.2	guarantee at least a dwelling volume of 15 m3 for each bed *(building regulation)*
C1.3	guarantee circle maneuver space of 1.5 m (diameter) in the entrance area for people with motor disabilities *(building regulation)*
C1.4	guarantee at least a pedestrian path with 1.2 m wide of and 12% slope ramp in case of level difference for motor disability people *(building regulation)*
C1.5	waste collection space must be accessible to users and waste collection service *(building regulation)*

A solution is defined according to the FRs and observing the set Cs (Figure 4). The solution is developed considering the user requests and the defined Cs. The dwelling area is located in the site observing the set distances from the propriety line and roads according to the local urban plan. The outside living activity area is placed in front of the dwelling facing toward south and connected with the dwelling. A site entrance for pedestrian and vehicular is provided with an adjacent waste collection area.

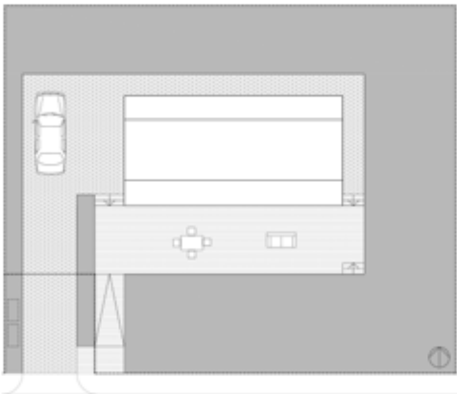

Figure 4. Site space system

The related DPs that satisfy the FRs listed above are:
DP1.1 = dwelling area
DP1.2 = paved area toward south
DP1.3 = service area composed of waste collecting area near the road and parking area
DP1.4 = pedestrian-vehicular site entrance on road side
DP1.5 = pedestrian-vehicular path

The evaluation of the Cs compliance is performed. The check of the DM is shown in Table 5.

Table **5** Second level **DM FR1**

	DP1.1	DP1.2	DP1.3	DP1.4	DP1.5
FR1.1	X	-	-	-	-
FR1.2	-	X	-	-	-
FR1.3	-	-	X	-	-
FR1.4	-	-	-	X	-
FR1.5	-	-	-	-	X

The resulting DM is diagonal: the Axiom one is satisfied.

The customers provide further specifications regarding their functional needs. It is requested: a pleasant living open space with kitchenette and a study area, a private area with bathroom and double bedroom, and a loggia. The main spaces should be sunny, well-lighted and ventilated.

The FR1.1 is decomposed further to a lower level FRs in order to provide specific areas for the user's activities. The lower level of FR1.1 is defined as follows:
FR1.1.1 = accommodate cooking-dinning-living activity
FR1.1.2 = accommodate study/work activity
FR1.1.3 = accommodate cleaning activity
FR1.1.4 = store service systems/things
FR1.1.5 = accommodate sleeping activity for a couple
FR1.1.6 = accommodate living activities outside in a sheltered place
FR1.1.7 = connect inside-outside
FR1.1.8 = connect inside activities

The design is subjected to constraints specified by the customers or imposed by the building regulation (Table 6).

Table **6 Third** level **Cs - FR1.1**

C1.1.1	locate living activities towards south *(customer need)*
C1.1.2	locate openings on the windward and leeward sides *(customer need)*
C1.1.3	provide a double-height living space with zenith light *(customer need)*
C1.1.4	guarantee average interior height of 2.70 m, area of 9 m2 for single bedroom, 14 m2 for double-bedroom and living room, width of 1.10 m for corridor *(building regulation)*
C1.1.5	total opening surface regarding each room (living room, kitchen and bedroom) should be at least 1/8 of the room area and even at least equal to 1 m2 *(building regulation)*
C1.1.6	guarantee circle maneuver space of 1.5 m (diam.) for motor disability people (living room and bathroom) *(building regulation)*
C1.1.7	guarantee at least door passage width of 0.80 m for motor disability people *(building regulation)*

According to them, each activity must provide adequate space that observes defined minimum dimensions (area and height); each space must be sized to be equipped with system networks and terminals, fixtures and furniture. Some spaces (access, living room and bathroom) must be planned to allow the accessibility of people with physical disabilities. Finally the definition of the space solution is bounded by aesthetic requirements also. A solution is defined according to the CAs and observing the set local rules and Cs (Figure 5).

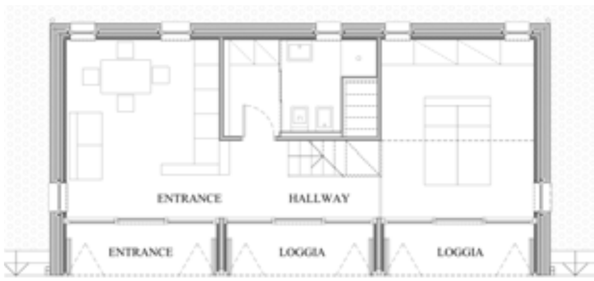

Figure 5. Building space system

The related DPs that satisfy the FRs listed above are:
DP1.1.1 = living-room on south with kitchenette
DP1.1.2 = study-room at mezzanine with a skylight
DP1.1.3 = bathroom
DP1.1.4 = storage room
DP1.1.5 = double bedroom
DP1.1.6 = loggia toward south
DP1.1.7 = entrance and openings
DP1.1.8 = hallway and staircase

The corresponding DM is shown in Table 7.

Table 7 Third level **DM - FR1.1**

	DP 1.1	DP 1.2	DP 1.3	DP 1.4	DP 1.5	DP 1.6	DP 1.7	DP 1.8
FR1.1	X	-	-	-	-	-	-	-
FR1.2	-	X	-	-	-	-	-	-
FR1.3	-	-	X	-	-	-	-	-
FR1.4	-	-	-	X	-	-	-	-
FR1.5	-	-	-	-	X	-	-	-
FR1.6	-	-	-	-	-	X	-	-
FR1.7	X	-	-	-	-	X	X	-
FR1.8	-	-	-	X	-	-	-	X

The resulting DM is triangular. This solution is acceptable as long as DP1.7 is defined after DP1.1 and DP1.6, and DP1.8 is set after DP1.4. An alternative solution with similar DPs is evaluated to reduce couplings (Figure 6).

Figure 6. Building space system - alternative

The corresponding DM is shown in Table 8.

Table 8 Third level **DM - FR1.1**

	DP 1.1	DP 1.2	DP 1.3	DP 1.4	DP 1.5	DP 1.6	DP 1.7	DP 1.8
FR1.1	X	-	-	-	-	-	-	-
FR1.2	-	X	-	-	-	-	-	-
FR1.3	-	-	X	-	-	-	-	-
FR1.4	-	-	-	X	-	-	-	-
FR1.5	-	-	-	-	X	-	-	-
FR1.6	-	-	-	-	-	X	-	-
FR1.7	-	-	-	-	-	-	X	-
FR1.8	-	-	-	X	-	-	-	X

Regarding the technology system, customers require high comfort, energy efficiency and independence and context integration using local typical materials and technologies.

According to the decomposition proposed by UNI [UNI, 1999], the FR2 is decomposed into a lower level FRs to provide conditions of safety, health and comfort and to supply resources. The lower level FR2 is defined:

FR2.1 = support loads and external actions
FR2.2 = separate inside from outside
FR2.3 = divide inside spaces
FR2.4 = divide outside spaces
FR2.5 = provide and distribute resources (energy and materials) to support user's living
FR2.6 = support inside client's living activities
FR2.7 = support outside client's living activities

The technology system is mostly constrained by the local building rules and CasaClima protocol (Table 9).

Table 9 First level **Cs - FR2**

C2.1	provide renewable energy equal to the building energy demand *(customer need)*
C2.2	be connected to urban energy supply *(customer need)*
C2.3	adopt local vegetation and typical features (pitched roof and well-oriented balcony) and materials (roof tiles, wall plaster) of local architecture *(customer need, building regulation)*
C2.4	guarantee a load-bearing structure able to resist to the provided loads and the peak ground acceleration due to a seismic action equal to 0.05 g *(building regulation)*
C2.5	guarantee envelope energy efficiency in winter smaller than 50 kWh/m2yr *(building regulation, CasaClima)*
C2.6	observe envelope energy efficiency in summer smaller than 30 kWh/m2yr *(building regulation)*
C2.7	guarantee overall energy efficiency in winter (EPw) smaller than 110 kWh/m2yr *(building regulation)* that is smaller than 20 kg CO2eq/ m2 yr *(CasaClima)*
C2.8	provide at least heating system, water-sanitary system, mechanical ventilation (in space without windows) and disposal system *(building regulation)*
C2.9	at least 1.2 kW photovoltaic energy system power if provided *(building regulation)*
C2.10	guarantee global average seasonal energy efficiency of plant greater than (75 + 3 log Pn)%, (Pn = rate output power) *(building regulation)*
C2.11	provide a rainwater gutter system connected to the urban disposal system *(building regulation)*
C2.12	observe ground water permeability index RIE equal to 4 *(building regulation)*
C2.13	use materials with environmental impact index smaller than 300 points *(CasaClima)*
C2.14	observe the formaldehyde limit of 0.05 ppm in the indoor air emitted by pasted wood products, the formaldehyde limit of 10 ppm, without heavy metals, organic compounds and risk warnings emitted by interior paints and the VOCs limit smaller than law limit *(CasaClima)*
C2.15	guarantee water impact index greater than 35% *(CasaClima)*

According to national and local building regulations, structural safety must be guaranteed and building shell and service systems must assure the high energy efficiency and internal minimum conditions for thermal, daylight, acoustic comfort and air exchange. Building service systems must generate the demanded energy by renewable sources. Moreover in order to build a sustainable building according to CasaClima Nature, additional restrictive bounds relative to water impact and low environmental impact of construction materials limit the design solution. Finally the definition of the solution is bounded by aesthetic requirements also.

A design solution is proposed that satisfy the specified FRs and imposed Cs (Figure 7).

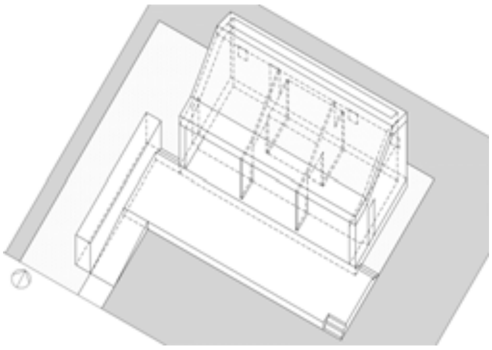

Figure 7. Technology system

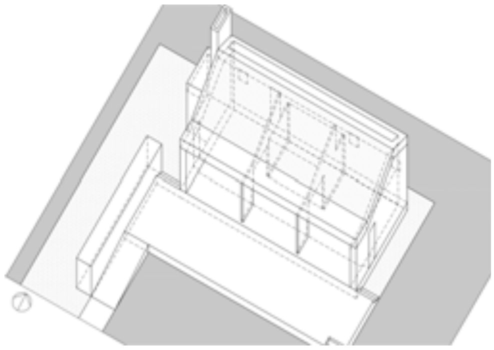

Figure 8. Technology system - alternative

The corresponding DPs are defined as follows:

DP2.1 = load-bearing structure in wood beams
DP2.2 = high energy efficient building shell with big openings toward south
DP2.3 = interior walls
DP2.4 = hedge of local bush and perimeter fence
DP2.5 = service systems with solar and photovoltaic energy systems integrated on the roof
DP2.6 = interior furniture and finishing with low indoor emissions
DP2.7 = outside finishing with high ground water permeability and vegetation

The DM is shown in Table 10.

Table 10 Third level **DM - FR2**

	DP 2.1	DP 2.2	DP 2.3	DP 2.4	DP 2.5	DP 2.6	DP 2.7
FR2.1	X	-	-	-	-	-	-
FR2.2	X	X	-	-	-	-	-
FR2.3	-	-	X	-	-	-	-
FR2.4	-	-	-	X	-	-	-
FR2.5	-	X	-	-	X	-	-
FR2.6	-	-	-	-	-	X	-
FR2.7	-	-	-	-	-	-	X

Some couplings are noticed: the continuous load-bearing structure contributes also the separation from inside-outside; the roof dimensions influence the functions of proving solar energy because the solar energy system is integrated in the roof. The solution is acceptable if DP2.2 is defined after DP2.1, and DP2.5 is set after DP2.2. In order to reduce the coupling between the supply of the demanded energy by renewable energy sources and the available shell area for the integration of the energy system, an alternative solution is evaluated.

This solution (Figure 8) is based on biomass energy source and solar hot water source; a further space for the biomass storage on the site and a roof surface for the solar energy panels are required.

The DP2.5 is changed and is expressed as follow:

DP2.5 = service systems with biomass energy source and solar hot water panels

The resulting DM is similar to Table 10, but in this case the coupling is simpler: only the hot water supply by renewable energy source is bound by the roof. This means that the energy supply is just influences by the roof slope.

Regarding the shell, customers require closures able to generate comfortable and energy efficient spaces. Moreover building appearance should contribute to the context integration using local materials and techniques.

According to the decomposition proposed by UNI [UNI, 1981], the FR2.2 is decomposed into a lower level FRs to provide safe, healthy and comfortable conditions. The lower level FR2.2 is defined as follow:

FR2.2.1 = divide spaces from outside vertically
FR2.2.2 = divide spaces from ground
FR2.2.3 = divide spaces from outside horizontally

The design of the envelope is mostly constrained by the building rules and CasaClima protocol (Table 11).

Table 11 Second level **Cs - FR2.2**

C2.2.1	adopt typical materials of local architecture: roof tiles, wall plaster and timber *(customer need)*
C2.2.2	guarantee static transmittance of each building component smaller than 0,8 W/m2K *(CasaClima)*
C2.2.3	observe dynamic transmittance smaller than 0.10 W/m2K and phase shift greater that 12h for vertical opaque closure and horizontal opaque closures *(building regulation)*
C2.2.4	provide external shadings on windows *(building regulation)*
C2.2.5	rainwater must be moved away from the building *(building regulation)*
C2.2.6	the number of air changes per hour should be less than 0.6 h-1 when the indoor ambience is subjected to a pressure of 50 Pa above the atmosphere *(CasaClima)*
C2.2.7	any interstitial condensation should result lower than the law limit according to the material type *(building regulation)*
C2.2.8	internal superficial temperature on building joints should be bigger than 17°C *(CasaClima)*
C2.2.9	average daylight factor in the main spaces should be bigger than 2% *(building regulation - CasaClima)*
C2.2.10	guarantee envelope acoustic insulation bigger than 40 dB *(building regulation)*
C2.2.11	exterior walls must be plastered *(building regulation)*
C2.2.12	use materials with environmental impact index smaller than 300 points *(CasaClima)*

A design solution is proposed that satisfy the specified FRs and imposed Cs (Figure 9).

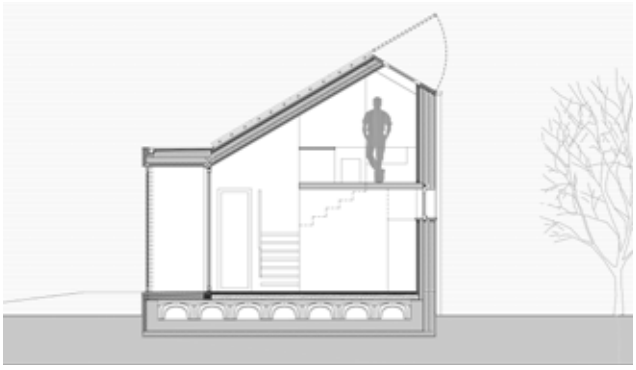

Figure 9. Building shell

The corresponding DPs are defined as follow:
DP2.2.1 = opaque and transparent vertical closures
DP2.2.2 = floor on the ground
DP2.2.3 = pitched roof and skylight
The check of the DM is shown in Table 12.

Table 12 Second level **DM - FR2.2**

	DP2.2.1	DP2.2.2	DP2.2.3
FR2.2.1	X	-	-
FR2.2.2	-	X	-
FR2.2.3	-	-	X

On the base of the DM, the design is defined uncoupled. In case of traditional technology solutions, this DM results commonly.

3 DISCUSSION AND CONCLUSIONS

In general, architectural design approach emphasizes intuition and experience during the co-evolving and iterative concept generation. Architects tend to identify a rough concept quickly based on a limited set of design objectives. Then the initially defined problems are constantly reformulated, co-evolving together during the design process until the relevant issues of the specific task and the related design solution are defined. This kind of serial and iterative approach makes sustainable building design a complex design problem due to the numerous requirements and constraints that architects must consider in the early stage of the design process. In this stage, decisive design decisions regarding performances, appearance and also sustainability are to be made. In order to improve the conceptual design generation in the sustainable building design, AD approach is proposed and the conceptual design development of a sustainable building case study is reviewed. In this case study, a minimum set of independent FRs is defined based on all requirements including sustainable issues. Performing the AD approach through decomposing the initially defined functional requirements in a systematic manner requires extensive amount of technical and regulatory information during the design process. At the same time, searching for the corresponding design solution to satisfy the specified requirements requires a decision base how to make good decisions at the early stage of design. This study shows the potentialities of applying AD to the architectural design to support the full inclusion of all the requirements and architect's decision-making activity for the development of sustainable solutions starting from the initial phase of the process. This research intends to propose this kind of framework for a design support in a BIM tool in order to improve the decision-making activity in the initial phases of the design process. The application of the AD approach allows performing the control of process and solution quality. In the next future, the research intends to evaluate and compare alternative solutions.

In engineering design, solution concepts are synthesized only after rigorous and exhaustive analysis of user requirements and other basic features of the problem while architecture stresses the importance of generating solution concepts early in the design process, drawing upon presuppositions. As the complexity of architectural design is increasing due to the need for addressing more environmental and energy requirements along with social-economic considerations, an approach able to integrate both perspectives could be effective. In this way, this paper describes the effort to apply AD to the conceptual design of sustainable buildings for designing buildings in which form, function and efficiency are consistent combined according to the stakeholder needs and the existing context.

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