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Architectural and Environmental Compositional Aspect for Technological Innovation in the Built Environment.

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Abstract

This paper focuses on the complex relationship between historical consolidate context and new building design projects, both from compositional and environmental points of view. In spite these two approaches often show contradictions in their nature, their integration is essential from the very early stages of the design process, both to improve and/or efficiently preserve the environmental and architectural quality of spaces. The aim of this work is to define a number of guidelines to support and inform the design process since its early stages, and eventually ensuring the quality of the built environment, both aesthetically and environmentally. To this end, the paper explores the use of climatic and microclimatic analysis as a tool to maximize the environmental and sustainability performance of future buildings. In particular, the work analyzes tools such as the site microclimatic matrix, as support to the climatic considerations about different technological choices for heating and cooling systems; and to the architectural/compositional approach definition.

Keywords: architecture, environment, microclimate, technology, innovation

1. Introduction

The building sector, excluding industrial buildings, is responsible for almost 40% of total primary energy consumption in developed countries [1]. This percentage includes energy demand for space heating and cooling, hot water production, lighting, cooking and other appliances. In addition, considering the global warming effect of a persistent trend of green-gas emission, the energy consumption for space cooling is rising in several countries [2&3]. Within this framework, a passive approach to building design and construction, i.e., taking envelop rather than HVAC system as the main indoor environmental control technology, is essential for reducing energy consumption in the building sector. This approach can contribute to curb the global warming trend related to carbon emission from oil and gas-dependent space conditioning systems. Nowadays, technologies able to increase the efficiency of building and equipment are consolidated and incentivized in legislation, standards, and codes of practice. In addition, passive and hybrid solutions for reducing solar gains and mitigating internal gains in summer, and solutions for increasing solar gains in winter, are well known – even if, especially for cooling, not widespread – could decrease drastically, if more diffused, the energy need for heating and cooling a building. However, to reach much more stringent goals such as the one related to near-zero-energy-buildings (NZEB), as set by EPBD 2010/31/EU by 2020, or, even more, the future net-positive-energy-building (NPEB), a much stronger effort than currently done to integrate low environmental impact technologies to a sustainable architectural design approach needs to be exerted.
In spite the scientific progresses achieved in the studies of environmental systems and technologies, the debate about the aesthetic of sustainability seems to have fell behind the interest of professionals and academics. The projects categorized as ‘sustainable’ are often defined either according to the number and type of environmental systems and technologies utilised, as well as their efficiency, rather than their architectural design approach. The contemporary examples of ‘sustainable’ architecture show a number of different aesthetic approaches that designers seem to have undertaken. These approaches span from the more literal design solution of ‘environmentally aware’ buildings, in which the relation with the natural resources was conceived as a design tool; to the more technology oriented approaches, where technologies and environmental artificial systems became expression themselves of an architectural aesthetic. Examples of

these approach can be considered: 1) the Jacob House 2 by Frank Lloyd Wright, in Middleton, Wisconsin, United States, built between 1944-1948, in which the incidence of the solar light was literally utilised to shape the building and the floor plan; to the 2) the environmental houses largely produced in the 70s where technological features where heavily applied to the buildings without much design integration efforts; to 3) the more sophisticated example of high tech buildings such as the Centre du Pompidou by Renzo Piano, in Paris, France, built between 1971 – 1977. The architectural language of sustainability seems therefore to follow either the mimetic tendencies of relating to the environment in a literal manner; or to show the approach to sustainability by expressing the efficiency of the technological features put in place. Yet, today the path of integration seems not to be explored or discussed as much. This happens despite the vast availability of software and tools that can assist the design process, by integrating microclimatic analysis and environmental systems and technologies analysis. This paper will explain in the next sections how some of these tools could 1) offer support to the design process; 2) enhance the integration between design and environmental technological systems; and 3) contribute to the debate on the definition of an aesthetic of sustainability.

2. The preliminary design process

According to Nigra and Marfella [4] the delivery process of building projects can be subdivided in a number of theoretical areas such as: building opportunity generation; building scope formulation; building/project production; building erection; building functioning; and project definition and control. Each of these phases, - from conception to construction - is characterised by a number of instances in which the integration between design choices and technological systems can be critical to enhance the environmental and architectural performance of projects. Specifically, this paper will deal with the area of project production, focusing on the design process, as critical moment to explore the integration between architectural characteristics and technological features. Several researchers [5] explained that the earliest involvement of environmental awareness in the design process, the more cost, time, and quality effective this process appear to be. Moreover, Grosso [6&7] together with Chiesa [8] pointed out a number of critical aspects to consider during the phases of building design programming and building preliminary design, the design process. Beside the clients' need, the building scope and the building codes or regulation – characterising the building program – another important part of the preliminary design, the site analysis, represents a critical aspect of integration between environmental awareness and architectural design approach. The site characteristics, such as sun, wind, light, ground, water, surrounding buildings, and urban legislation, has the potential to dramatically inform building orientation, dimensions, interrelation, and localization, as well as informing the overall design approach. During the preliminary building design, technical and environmental requirements can contribute informing geometry, volumes, colours, construction systems selection, and assembly/erection type.
As the flow chart in Figure 1 shows, the building design program phase is centred to a loop between compatibility and performance assessment of choices related to the definition of virtual space units, which is a result of fulfilment of both functional and environmental requirements. These, in turn, depend on the client brief – determining design objectives, activities to be performed in the building, and relevant needs – as well as laws, standards, and regulation at various scales. On the side, but not less important, the site analysis – often not considered part of the building programming – represents an essential operation for the environmental compatibility assessment of building design choices.

3. Environmental aspects of the preliminary design

The environmental aspects of the preliminary design process are related to the assessment of all factors affecting the impacts of the building-to-be-designed on the physical context at various scales: spatial, i.e., global, regional, local, and indoor/outdoor as well as temporal, i.e., concerning both the day-by-day running of the building and its entire life cycle.
Environmental assessment implies different approaches and methods at different scales. However, at the preliminary design phases, two main types of analysis are, generally, considered: environmental building programming and site analysis. After a brief framework description, this paper will focus on the latter, with particular attention to site climate evaluation.

3.1 Environmental building programming

Environmental building programming follows a performance-based approach characterized by a process of analysis and assessment from user needs and activities to requirements, and from functions to virtual space definition, according to the compatibility (environmental) loop above described and shown in Fig. 1.
During this process various tools, such as diagrams, checklists and matrixes, can be applied. Examples of these applications are numerous, but generally they do not deal with environmental aspects [9;10&11].

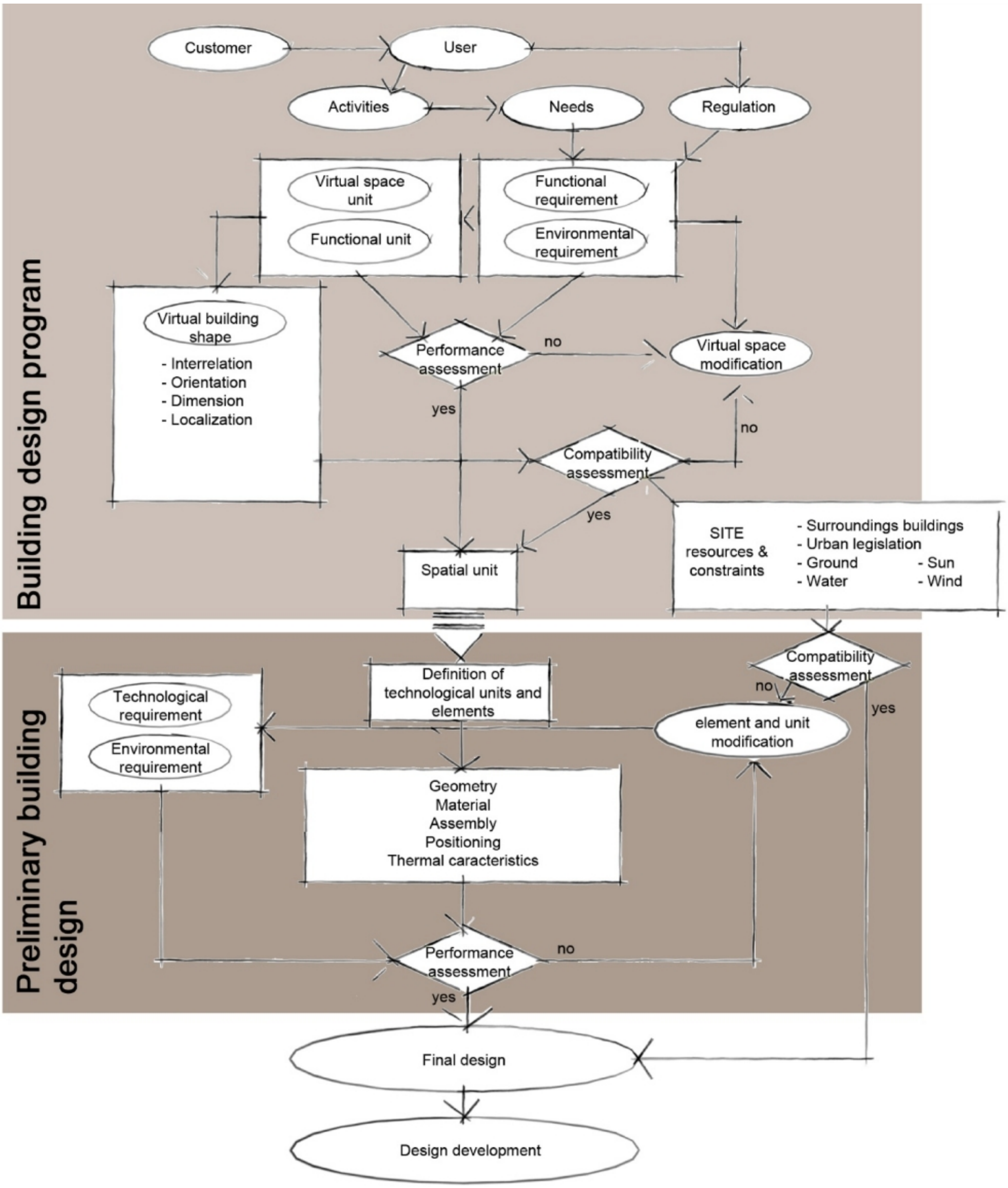

Fig. 1: Flow-chart of the preliminary design process based on a performance-driven approach (image modified from [6]).

The main actions to be carried out in the environmental building programming phase are the following:

- reception of the client brief including building design objectives and users' needs;
- reception of laws, standards and regulations related to the building type to be designed;
- list and classification of activities and relevant environmental requirements;
- analysis of input/output flows related to the activities affecting the environment, both outdoor and indoor;
- list and classification of functions related to the activities;
- definition of virtual space units as spatial representations of aggregated functions;
- definition of dimensional (order of magnitude) and environmental requirements of virtual space units;

- aggregation of virtual space units according to their reciprocal linkage characteristics and constraints in compliance to the defined environmental requirements;
- alternative configurations of virtual space virtual layout.

A virtual space does not have physical boundaries but just potential links within itself, with other spatial units, and with the external context. These potential links are related to various aspects: dimensions, context, geometry, communication, physics phenomena (airflow, daylight, solar radiation). The environmental building programming focuses on some of these aspects, the ones which have an impact on resources and emissions as mentioned above.

3.2 Site-climate analysis

The site analysis phase of a preliminary design process concerns various aspects, such as urban context, transportation, landscape, social issues, town-planning tools, land use, economic value, environmental impacts. Within the latter, the site-climate analysis is aimed at evaluating the potential vocation of a specific site to locate an activity, or a virtual space, or a building, with regard to thermal comfort as a function of climate factors such as solar radiation and wind flow [7&12]. The site-climate analysis uses a site microclimate matrix (SMM) as a tool allowing for optimising the location of outdoor activities, space units, of aggregation of them, i.e., buildings, in relation to thermal comfort and energy flow. The elaboration method behind it was introduced by two American scientists [12] and modified by Grosso [7]. It allows designers to locate properly, according to a sustainable and bioclimatic approach, the different activities/functions/space units defined in the building programming phase as described above. An SMM can also be used to study the optimal layout of buildings in urban design by evaluating the influence on potential exposure/protection related to solar radiation and wind either for new assets or in a specific existing context.
An SMM is elaborated as a graphic overlay of output from the analyses of solar shading and airflow dynamics on a lot resulting on a four variable zoning derived from the combination of shaded/non-shaded and windy/sheltered zones (Fig. 2). This zoning is called "matrix" because it is discretized by a normal grid, whose cells are characterized by one of the four variables. Each variable is then associated to a potential comfort level (see Table 1) in order to assess its vocation as a recipient of activities.
The SMM is built on a virtual plane, which is generally set at the ground level, even if it is possible to produce different matrixes by changing height or to create a three-dimensional matrix of the project site. This choice depends on the specific needs, remembering, however, that three-dimensional analyses require a higher investment in terms of time, cost and complexity, and could require three-dimensional CFD software for airflow studies. It is advisable to proceed with analysis on the vertical facades of building under design, or retrofitting, in order to evaluate the mutual influences between different buildings and obstacles.

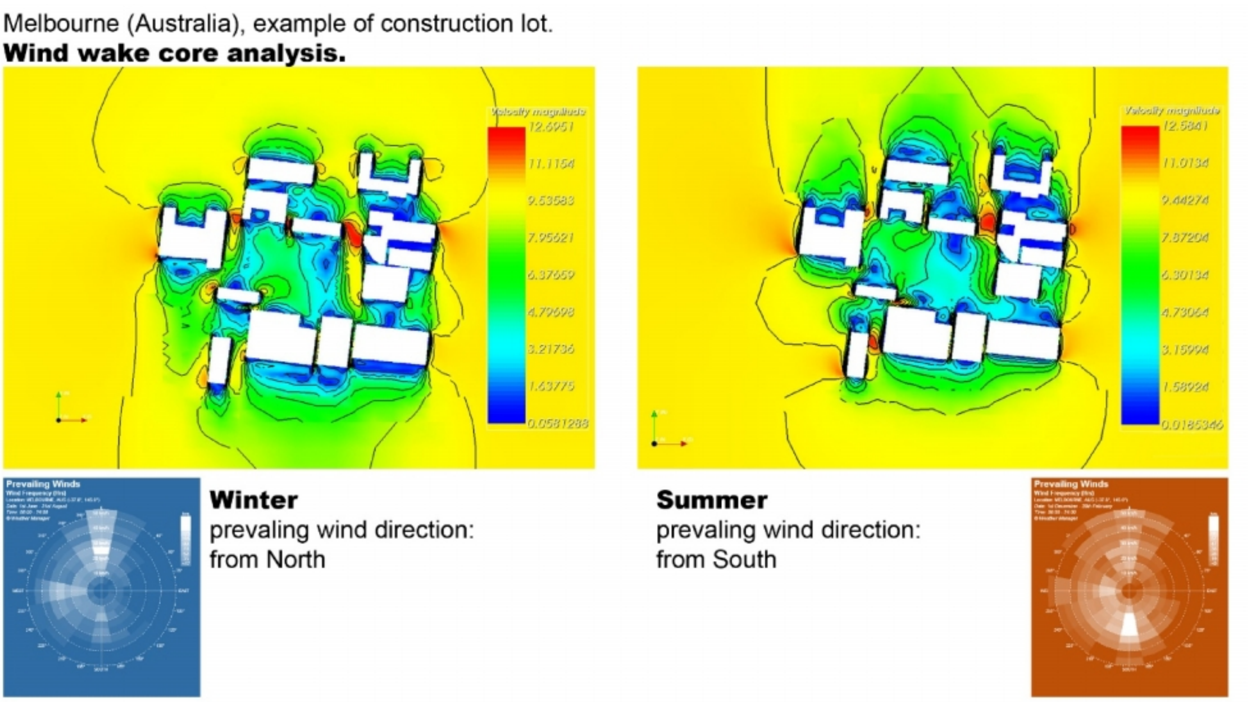

Fig. 2: Example of wind wake core analysis on winter and summer (point 4) for a construction lot in Melbourne, Australia. The airflow analyses were conducted by using the software KARALIT CFD.

Theoretically, an SMM changes over time following the yearly, daily, and hourly apparent sky position of the sun and the seasonal (or monthly, daily, hourly) prevailing wind direction, on the considered site. However, a SMM, being used as a design parameter, is elaborated at reference extreme climate conditions as expressed during solstices, in the morning and afternoon, and relevant seasonal prevailing wind directions. As an example, the reference dates are, in the Boreal hemisphere: 21 December at 10:00 and 14:00, and 21 June at 8:00 and 16:00. However, it is possible to choose different timing based on the hottest and the coldest days of the year, estimated by using the typical meteorological year (TMY) of the locality or using as general reference July 21st and January 21st at 9:00, 12:00 and 15:00 [12]. When the calculation of shading is conducted by using specific software, it is important to paid attention to the correct time definition (local Meridian, reference Meridian, solar hours).

The following steps shall be performed to elaborate an SMM:

1. definition of the site context and constraints due to surrounding built and natural obstacles;
2. discretization of the analysed lot by a normal grid with cell's dimensions depending on design scale (for example, 5x5 m);
3. analysis of solar paths and relevant shading dynamics in different reference days and hours;
4. seasonal analysis of wind wake cores (see Figure 2) (or different temporal analysis, for example day-night breezes);
5. overlapping of the results from the above analyses (steps 3 and 4) on the grid defined in step 2 in order to classify each cell by a 2x2 matrix of climate conditions (sunny-windy; sunny-calm; shaded-windy; shaded-calm); this process is repeated for all considered hours and days (see Figure 3);
6. assigning a score to the four classes identified according to the activities to be located for each matrix developed in step 5 (see Table 1);
7. construction of four time-referenced SMM for each type of activities/functions/space units.

In Figure 2 wind wake core seasonal analyses on a specific plot localized in Melbourne, Australia, are reported. The prevalent chosen wind directions are from North in winter (from hills to sea) and from South in summer (from sea to land), even if an analogous change in directions occurs daily due to a day-night breeze regime. These analyses were carried out using the CFD software Karalit [13]. Existent building context reduces the wind velocity at the ground floor in the East side of the construction lot, characterized by a low potentiality for natural ventilation. At the same time, on the same side, nearer to building, a Venturi effect is evident, with consequent increases in the wind velocities. The predisposition of tree barriers with different height could represent an effective solution for curbing this potential discomfort situation.

Wind analyses could be conducted in different ways: using a CFD software, which needs specific aerodynamics knowledge and is time-consuming and costly; by wind tunnel simulation, which requires a physical model, specific knowledge and a dedicated laboratory facility; or by a simplified method based on the statistical correlation of wind tunnel test data on modular solids with varying geometrical dimension and wind incidence angle such as the one elaborated by Grosso [7] on the basis of a previous research [14].

The score assigned to each cell of an SMM, as indicated in the above step 6, is based on a classification of potential outdoor comfort conditions related to types of activities and their relevant metabolic rate, that can be assess on a qualitative scale (Table 1) or using quantitative values.

Activities		**Season**	**Relation between site microclimate matrix and comfort conditions**			
			shaded-calm	**shaded-wind**	**sun-calm**	**sun-wind**
Low metabolic rate	Stay; walking around	Winter	Unfavourable	Worst	Optimal	Good
		(cold wind)	Good	Worst	Optimal	Unfavourable
		Summer	Optimal	Good	Worst	Unfavourable
		(high RH)	Unfavourable	Optimal	Worst	Good
Medium metabolic rate	Walking fast; slow running	Winter	Unfavourable	Worst	Good	Optimal
		(cold wind)	Good	Worst	Optimal	Unfavourable
		Summer	Good	Optimal	Worst	Unfavourable
		(high RH)	Unfavourable	Optimal	Worst	Good
High metabolic rate	Run fast; gym activities	Winter	Worst	Unfavourable	Good	Optimal
		(cold wind)	Good	Worst	Optimal	Unfavourable
		Summer	Good	Optimal	Worst	Unfavourable
		(high RH)	Unfavourable	Optimal	Worst	Good

Tab. 1: A classification of outdoor thermal comfort conditions in relation to the macroclimate matrix variables for different types of activities.

As an example of a quantitative assessment, a score could be, for a high metabolic outdoor activity, such as running: in winter, 1 for shaded-calm, 2 for shaded-windy, 4 for sunny-calm, 5 for sunny-windy; in summer, 1 for sunny-calm, 2 for sunny-windy, 4 for shaded-calm, 5 for shaded-windy.

3.3 Architectural/compositional implications

The SMM presented above was used as a base for a design research atelier conducted in the Master of Architecture (Sustainability) of the Polytechnic University of Turin. The call of the atelier was to develop a design proposal for a new university building in Melbourne, following the existing brief for the new Architecture Building and planning faculty at The Melbourne University.
In this atelier, the microclimatic analysis was applied to a number of stages of the design process, to inform the decision-making process on a compositional level.
As showed in figure 3 and 4, the microclimatic analysis produced a reading of the site that showed the areas of calm (wind and sun) over different time of the year. By analyzing the site characteristics, a design proposal was defined optimizing the volumetric definition of the building, in order to defined accesses; shape the volumes; define the internal layout and spatial allocation of functions; and determine the microclimatic characteristics of each façade defined in the project (figure 4). This latter allowed the design of a façade in which pattern, shading systems, and glazing features where equally balanced according to the solar incidence and surfaces exposures (figure 6).

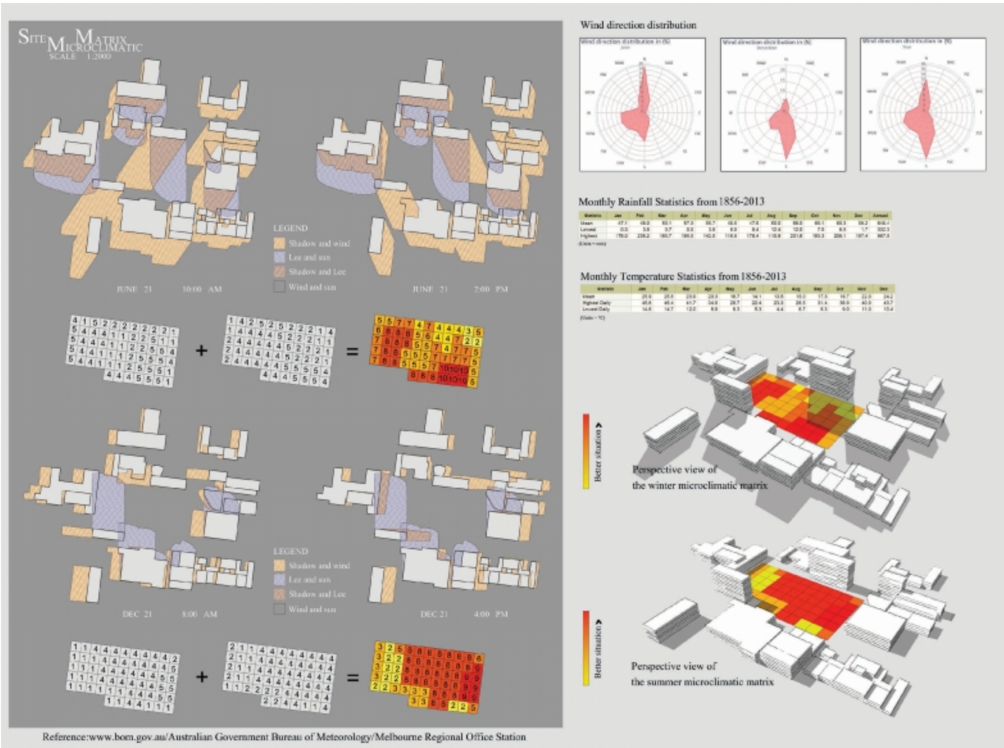

Fig. 3: Example of calculation of a site microclimate matrix as base for a volumetric study (study by Mamak P.Tootkaboni, Danial Mohabat Doost, and Xiaochen Song).

The definition of the volumetric organization allowed the definition and the further analysis of the facades in the design proposed. Figure 5 shows and example of solar exposure analysis in which the facade was 'mapped' according to incidence of the sun on each its part. This analysis allowed modifications and further decisions on the shading devices design as well as of the perforation patterns of the façade envelope (figure 6).

Further analysis was also utilised to determine the performance and specifications of the main façade components defined in the project proposal. Specifically, glazing characteristics, shading devices, and ventilated façade rain screen were selected ad-hoc for each façade, according the exposure and characteristics, elaborated in the micro-climatic analysis.

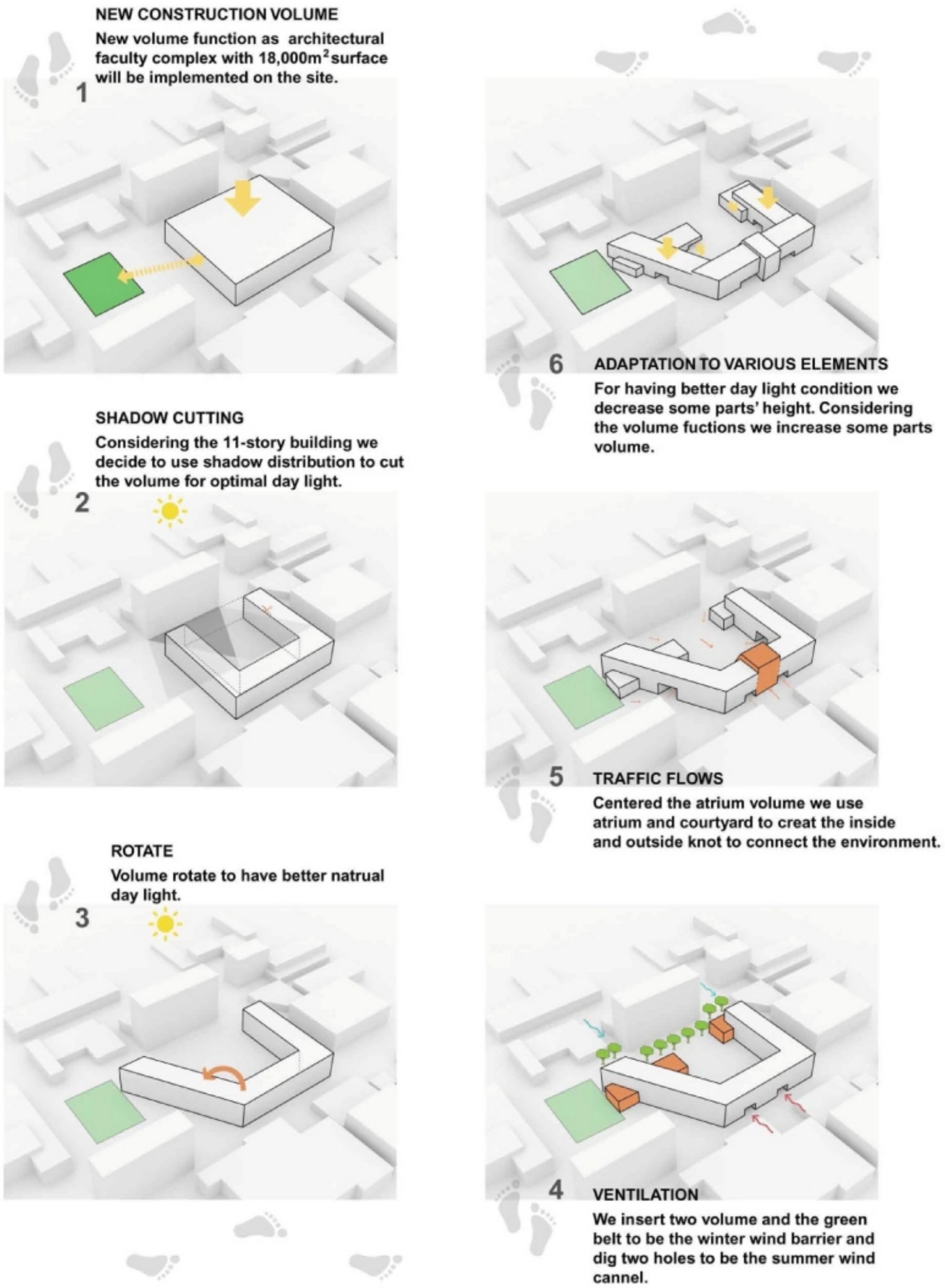

Fig. 4: Example of design process in which the volumetric organization was defined to maximize the characteristics of the site, previously explored by the microclimatic analysis (study by Mamak P.Tootkaboni, Danial Mohabat Doost, and Xiaochen Song).

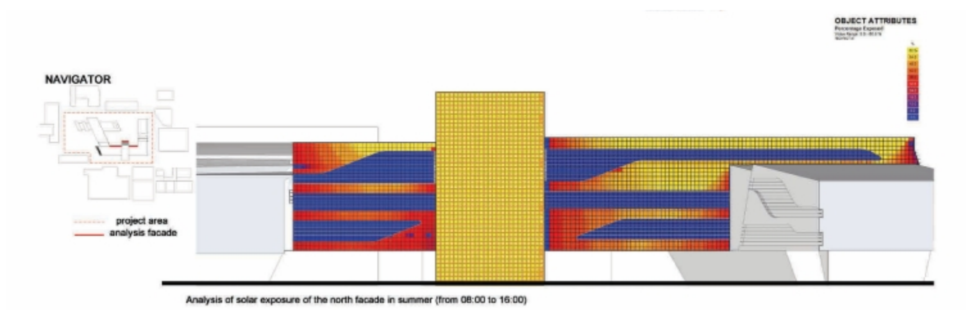

Fig. 5: Example of solar exposure analysis on the design proposed for the site (study by Mamak P.Tootkaboni, Danial Mohabat Doost, and Xiaochen Song).

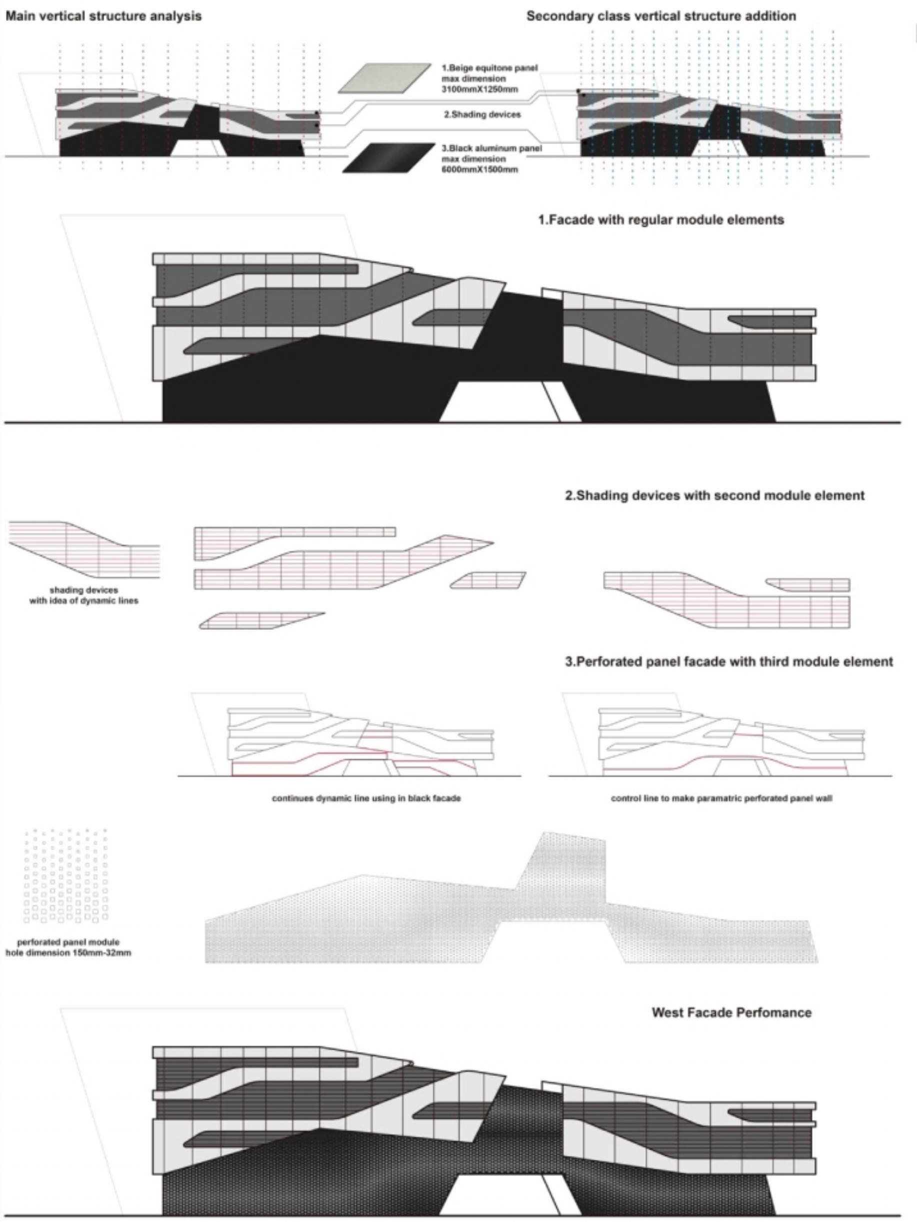

Fig. 6: Example of design process to establish modules, patterns and shading devices in a façade design proposed according to the solar analysis on the façade, based on the micro-climatic analysis (study by Mamak P.Tootkaboni, Danial Mohabat Doost, and Xiaochen Song).

4. Discussion

The use of a SMM showed a number of aspects that can enrich the design process, such as the ability of 1) providing design alternatives; 2) the assistance in the definition of technologies and specifications; 3) the contribution to the selection to the more appropriate construction systems; 4) ensuring quality throughout time,

1. The ability of providing design alternatives could be referred to the ability of exploring different options of volumetric configuration and location within the site; the definition of people flows and accesses in relation to the building orientation and volume; the use (or re-use) of the land; the inclusion (or use) of natural elements found on site as architectural features; and the possibility of using the site characteristics as main concept for the overall design approach. Moreover, the microclimatic analysis can also inform elements of façade design such as the relation between open and close elements; shading configuration and location; colours and patterns diffusion, volumetric configuration of elements; orientation and type of façade elements.
2. The use of a SMM can also assist in the definition of technologies and specification, by informing on the relation between performance required and positions within the building; defining the need of

specific technical requirements and therefore offering guidelines on required elements; and highlighting the opportunity to design ad-hoc/innovative elements or details.

3. The awareness of the microclimatic configuration of a site could assist in the selection of the more appropriate construction systems, by offering an accurate analysis of areas of the future building that could be design or treated with the use of different construction systems. This aspect could also contribute in saving in cost and time by applying the use of construction systems only where required. Moreover, the results of a microclimatic analysis could as well inform the design of innovative construction systems.
4. The ability of designing buildings that embed the site-specific conditions can also contribute to achieve better conditions throughout the life span of the building itself. Not only architectural features, but also more effective choices in terms of construction systems, and technologies can contribute to a degree of sustainability over time.

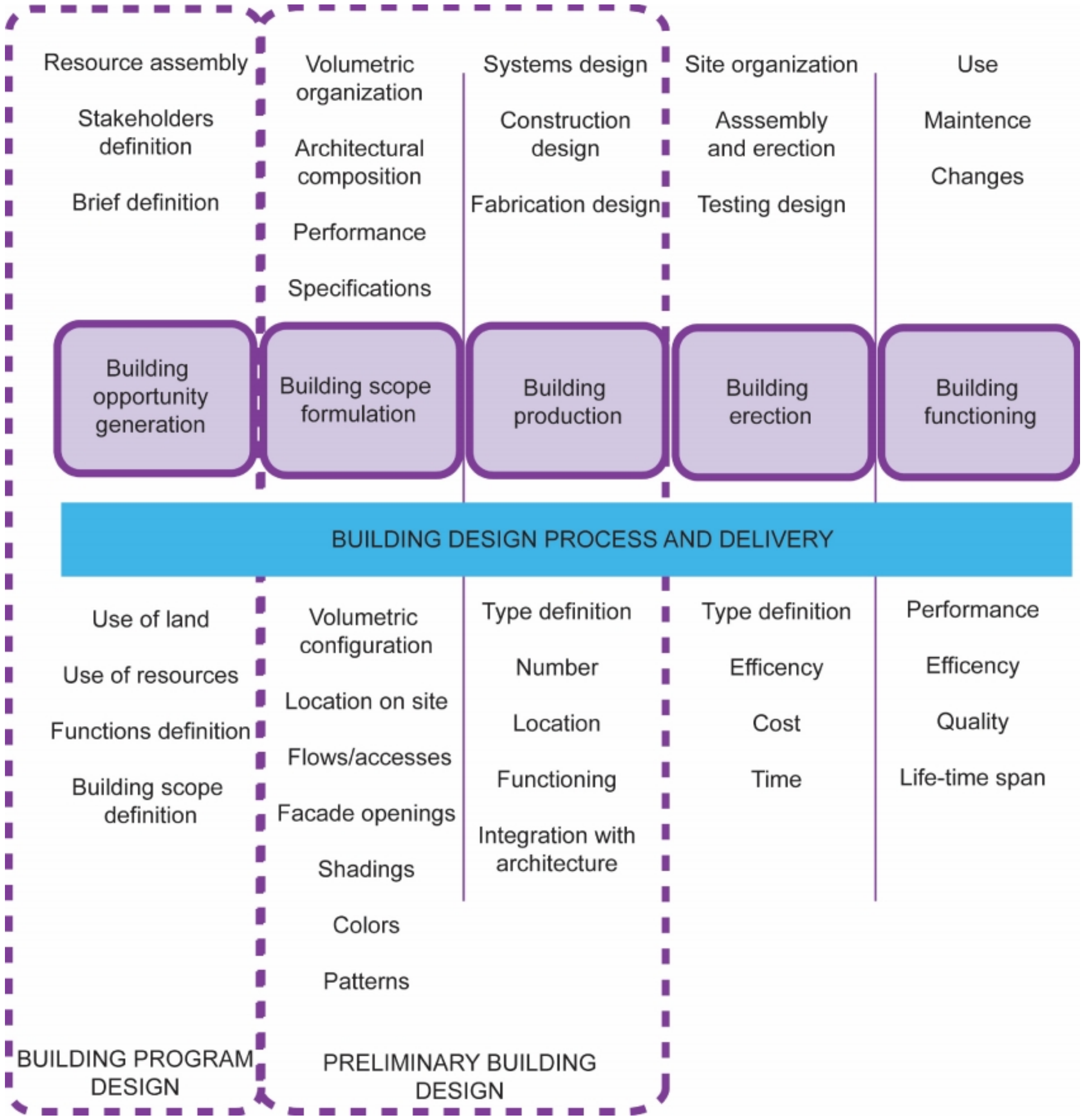

Fig. 7: The image shows the design parameters that can be informed by the use of microclimatic analysis for each phase of the design process and delivery. Above the blue band the design process is summarized in its phases and characteristics. Below the blue band the design parameters that be enrich/integrated by the use of the micro-climatic analysis are listed for each phase of the design process.

Figure 7 summarizes a number of parameters that can be modified and informed by the use of microclimatic analysis throughout the design process and delivery. In the image the design process is described in all its phases and related to all the design parameters that can be utilised in each of its phases. The ability of relating the use of a site-climate analysis, design phases and design parameters represents a design methodology that can be applied through all the phases of projects delivery. This methodology could assist in both considering technical parameters, and optimizing design solutions, without impinging on the creativity side of the design process, which instead informed on a number of potential design alternatives. Moreover, this methodology could assist the development of specific requirement schedules for each technical element, and support the testing of the quality of design choices and their optimization.

5. Conclusions

Environmental building programming and site-climate analysis can provide designers and architect with the ability of open an informed discussion on the role of design within the sustainability approach to buildings. Having a number of design alternatives directly informed by the environmental context could contribute defining a new architectural language that consider all the approaches that have been taken so far in the history of architecture until now, and implementing them toward an integrated language between design and technology. This language could potentially produce a variety of buildings that, not only try to limit energy consumption and resources depletion, but that are able to express the identity of those buildings. At the same time an environmental and technological approach to design, by using the performance-driven approach since the preliminary design phase, is essential for considering these issues in the design process evaluating different compositional solutions and suggesting possible optimization procedures.

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