Conceptualizing energy performance-based design: a case of social housing

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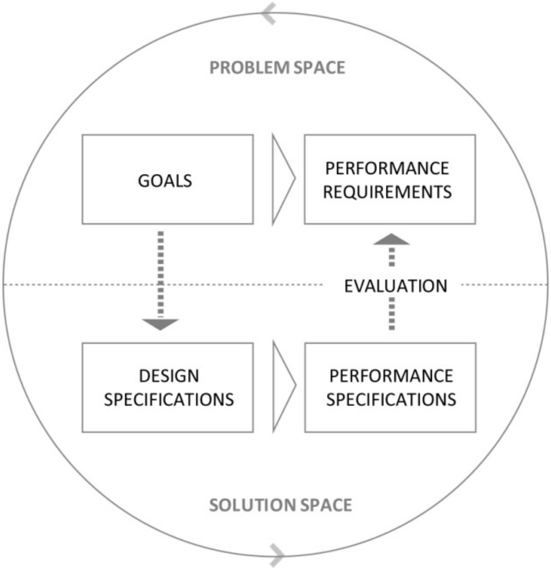
Abstract Over the past three decades, performance-based design has pursued the development of a methodology that anticipates the impact of a design solution in order to evaluate its performance. According to this methodology, designing can be considered as an iterative process of exploration, where desired performance requirements are defined –problem space–, design alternatives are proposed –solutions space–, and a process of evaluation is used to determine the confluence of the predicted solutions performance to the stated performance requirements, i.e. the solutions space can be refined through iterative simulations. Energy efficiency is one of the fundamental issues to evaluate the performance of buildings. This paper summarizes a research work which seeks to apply a performance-based design methodology to support the decision-making process in order to improve the energy performance of buildings. A case study of a social housing building recently built in Cerdanyola del Vallès, Barcelona, has been used to explore the application of performance-based design to make better informed decisions in the design process.

Fig. 1 Performance-based design model.



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Introduction: fundamentals of performance-based design

In the decade of 1960, a way of design thinking, known as Performance-based Design (PBD), started to be developed. The origin and development of this approach to design derives mainly from the disciplines on Systems Analysis and Operational Research, in particular from the application of analytic methods to the management of complex situations, especially in the military and industrial sectors. Through the use of mathematical models, and with the support of computers, PBD pursued the development of a methodology that simulates the effects of different design solutions, in order to improve the effectiveness of the decision-making process.

Different rational decision making sequences have been proposed in the past (Churchman, Ackoff, & Arnoff, 1957), (Sargeunt, 1965), defining a universal model for accomplishment-focused problem-solving: formulate the problem; develop alternatives by constructing a mathematical model to represent the system under study, and deriving a solution from the model; finally, evaluate the solution. Accordingly, design for performance can be described as a more detailed part of the foundational problem-solving model (Fig. 1): a set of future desired conditions or goals are defined in terms of performance requirements –problem space–; a set of design alternatives is specified in terms of performance specifications, by predicting its effects –solution space–; and a process of evaluation is used to determine the confluence of the predicted solutions performance to the stated performance requirements.

Fundamentally, the key feature of PBD is the explicit formulation of statements of performance requirements that will guide decisions, and the subsequent management of a process that guarantees their fulfillment. In this process, evaluation plays a central role: it is responsible for the basic iterative structure of the process (feedback), i.e. if a design solution does not fulfill the initial performance goals, it could be modified to achieve them, or the desired conditions should be revised. In other words, designing can be defined as a goal-oriented decision making activity, which aims to satisfy specific needs by exploring the options to reach the goals.

This approach to design, based on an adjustment process, has represented a shift with regard to the “traditional” design methodology –direct fulfillment of stakeholders functional needs into a design solution–, by which design decisions should be made through the simulation of the building performance. Thus, it was expected that “better” buildings would be designed, too (Markus, 1969).

PBD in architecture: representing and managing the design process

The PBD methodology can be applied in many diverse fields –software engineering, industrial engineering, strategic planning and management, or policy strategies–, whose nature of organization is essentially immaterial. However, when this idea of design is applied in the field of architecture, it has to be adapted to direct determining the configuration of a physical system (Ferguson, 1975), for example the building. The difficulty of designing complex artifacts, such as a building, implies that numerous decisions have to be made towards the building definition, from its inception to final use: a building being design should first to be conceived, it should be developed, detailed and, finally, have to be constructed and put in use. In other words, design in architecture has to be intended as a progression from the abstract to the concrete (Asimow, 1962), in which a great number of decisions need to be made, i.e. designing is an iterative problem-solving process (Asimow, 1962).

From this perspective, the design process can be organized on the basis of two abstract structures: the one comprising a progression of various stages in time, i.e. briefing (inception and feasibility), design (outline proposal and scheme design), construction and operations (RIBA, 1965); the other, describing a cyclical design decision sequence, based on a series of systematic actions which are reiterated in each stage. From a diachronic point of view, designing is a process of progressive solutions refinements; from a synchronic one, each stage of the design process determines a certain design situation at a certain moment in time, i.e. a specific design context, in which specific design tasks or an activity have to be performed for a decision be made. Moreover, this description suggests that some design decisions should be made before others, until all the details that may affect them are known. In contraposition to this traditional hierarchical and sequential nature of the decision-making process (Asimow, 1962), (RIBA, 1965) (Archer, 1969), (Markus, 1969), this research proposes a methodology in which the decisions made in the more advanced phases can help to reconsider decisions that were previously made, by linking the information generated throughout the various phases of the design process (Fig. 2). In this way, information from the early design phase can be compared with information of the building in operation.

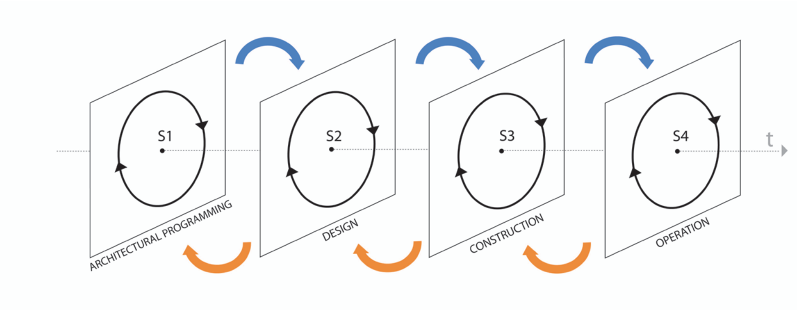

Fig. 2 The temporal and informational representation of the design process: feedback and feed-forward of information through the different phases.

From the informational point of view, the design process can be represented as a flow, in which the outputs –evaluation results– of a stage become inputs –constraints– for the next one, and vice versa. In this way, a bidirectional propagation of information and constraints increases the project's knowledge, especially at the beginning of the design process, when the design problem has to be defined, and consequently a solution suggested. The beginning of the design process is quite critic: despite the effort to define and structure the design problem by making explicit project goals through a performance language –architectural programming–, the stance of a "given problem", i.e. a well-defined set of goals and criteria, cannot be accepted in architecture (Simon, 1969), (Rittel & Webber, 1973). The initial architectural programming has to be considered as embedded in the design process, and not as an independent phase that precedes the design conception (Hershberger, 1999).

[1]This means that the initial stated goals, as well as the desired states can continuously change during a design process, as design solutions are proposed[2]. Therefore, the designing has to be intended as an iterative process of exploration –co-evolution (Cross & Dorst, 1998) – of both the design solution and, in parallel, of the understanding of the problem.

Case study: a case of social housing

A case study of a social housing building recently built in Cerdanyola del Vallès, Barcelona, has been used to explore the application of performance-based design to make better informed decisions in the design process. For this case study, the decision-making process followed by the

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[1] Architectural programming is commonly intended as the first stage of the design process in which the relevant values of the client, user(s) and architect are identified, important project goals are examined, facility needs are clarified (Duerk, 1993). Moreover, a change in the description of architectural programming can be appreciated from William Peña (Peña & Focke, 1969), which describes the "*problem seeking*" as an independent phase that preceded the design process, to Robert Hershberger (Hershberger, 1999), which considers the programming as phase completely integrated in the design process.

[2] Lawson pointed out that clients often seem to find easier to communicate their wishes by reacting to and criticizing a proposed design (Lawson, 1980).

design team has been analyzed and alternative processes based on the application of performance-based design methodology have been explored.[3] The existing residential building is a rectangular block that occupies the maximum area of the site allowed by local regulations (64x12m); its main façades are oriented to South and North. It is a five-story building –the underground is destined to car parking, the ground floor to commercial use, and the three upper floors to residential use (24 apartments) –, served by two vertical cores (stairs and lifts).

Demand side: design brief and architectural programming.

The first step of the PBD methodology is the definition of the design problem, i.e. the explicit formulation of the stakeholder's expectations of the project in terms of performance requirements,[4] by which the success of the project can be measured. For this case study, among the typical long list of goals,[5] it was assumed that the client would like to encourage a responsible and efficient use of energy through the building, but other several goals have to be satisfied as well, as comfort or economy issues (Tab.1). Even if the energy efficiency is the main goal of the project, a multi-criteria decision making approach has been adopted during the design process.

DEMAND			SUPPLY
Issues	Goals	Performance Requirements	Performance Indicators
Comfort	Create the conditions for a the physiological comfort	Thermal comfort zone should be respected (indoor environmental conditions)	Time above/below Comfort (%)
Energy Efficiency	Encourage a responsible and efficient use of energy	Energy consumption should be reduced	Heating/Cooling Demand (kWh/m²/year)
Economy	Construction costs should be reduced	The initial budget should be respected	Construction cost (€)

Tab. 1 Architectural programming: definition of project's issues, goals and performance requirements or criteria; translation of performance requirements into performance indicators.

Supply side: generation and evaluation.

Once defined the project performance criteria, a set of performance indicators (PIs),[6] has been derived from them (Tab.1), with the objective to plan the information that has to be generated about the project to objectively evaluate it. At this point, in order to progress from the problem planning to the building definition, an initial abstract idea has been gradually fully formulated and concretized through the decisions made along the different stages of the design process.

The design process: conceptual, development and detailed phase.

The building has been considered as a system partitioned into discrete manageable "*chunks*" (Kalay, 1992) or levels –subsystems, assembly of components, and single components–, and structured on the basis of an abstract hierarchy, also known as top-down partitioning. In this way, the building has been approached at different scales, from general to detail level, and, accordingly with the methodology proposed in this paper, from detail to general level (Fig. 3). Both the

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[3] The real building is the result of design process in which the experience of the design team guided the design decisions; energy simulations have been used in the final phases of the design process, in order to verify decisions already made, rather than to support the decision-making process.

[4] Performance requirements (PRs), or criteria, are user requirements or desired results expressed in terms of the performance of the building (Augenbroe, 2011). In other words, they are statements about the measurable levels of the function that the building should provide for a goal to be met (Duerk, 1993).

[5] Aesthetic, functional or psychological issues are generally fundamentals issues in the design decisions-making process, but in this case it is supposed that they are less important than energy efficiency, economy and comfort issues. Therefore, they are only implicitly considered in the design process.

[6] Performance indicator (PI) is quantifiable indicator that adequately represents a particular performance requirement, for example PIs are used to quantify the performance requirements (Augenbroe, 2011).

overall system and the details have been considered by thinking on different levels of abstraction, in which the objects of design decision have been decomposed into sub-problems and recurrent predefined performance indicators taken into consideration. By adopting contemporarily a top-down and bottom-up strategy, the elements and subsystems at different levels have been gradually adjusted into fit with each other (Mitchell, Ligget, & Tan, 1992). In other words, lower-level decisions helped to reconsider decisions previously made at a higher level, in order to accomplish the project goals.

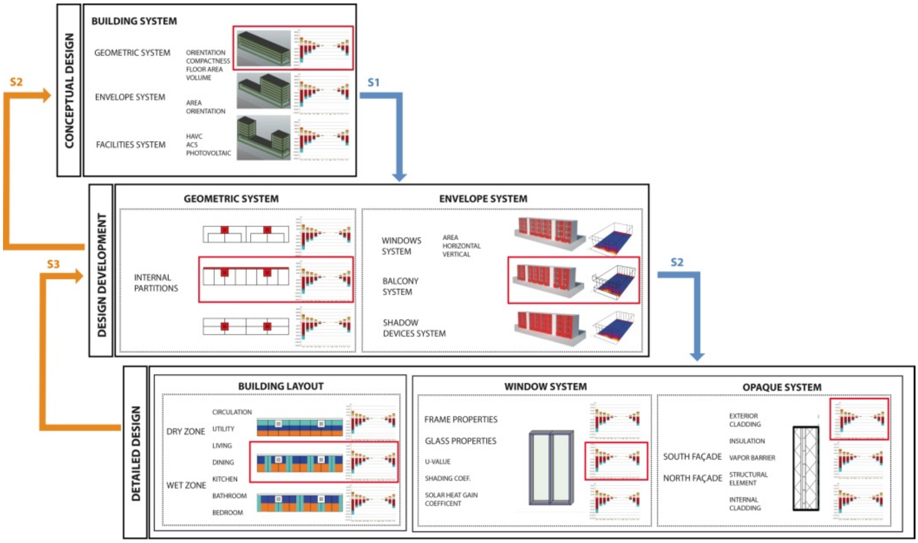

Fig. 3 The design process comprises a progression of various stages –i.e. design, development, detailed–, in which the building is considered at different scales, from general to detail, and vice versa.

Conceptual phase: building main subsystems.

According to the hierarchy described above, the general aspects of the building –orientation, shape, envelope area, total floor area and volume, etc. –, have been object of design decisions at the conceptual design stage, some of which have been limited by the project constraints (local regulation and building program). A parametric model has been built to represent and simulate the building energy performance. Accordingly, the building has been considered as a system composed of various subsystems (geometry, envelope, and facilities system), whose interaction substantially influences the building performance. By varying the parameters of the systems that make the building (height, length, envelope area, etc.), various design alternatives have been generated. For each parametric variation, energy simulations have been performed in order to evaluate the effect of the different design alternatives on the diverse aspects of building performance established by performance indicators (time above/below comfort, heating/cooling demand and construction cost)[7].

By simulating different design alternatives (Fig. 4a), several rules of thumbs have been confirmed in the specific context of the project, for example, by increasing the compactness of the building a thermal imbalance is produced (heat losses are not compensated by heat gains, and vice versa), which contributes to the increasing of the heating/cooling demand (Fig. 4b). Thus the

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[7] Beyond the information that has to be generated about the project, PIs define design strategies; for example, in order to reduce energy consumption, only heating /cooling demand is considered in the project. This means that the strategy of the project is to focus on design passive strategies, in which only building’s geometric and envelope characteristic are considered as design variables, while facilities system are not contemplated.

option with a small value of compactness has been preferred, also for being the most economic. In terms of comfort, not significant differences have been observed by varying the compactness of the building, although it could be appreciated that a substantial difference between the time above/below comfort zone (18-26°C) is produced in each design option (Fig. 4c); as the time below comfort zone predominates, the initial energy performance requirement have been refined to focus on minimizing only heating demand. On the other hand, by changing the orientation of the building, significant variations in the heating/cooling demand are produced; by increasing the openings of windows on the South façade, heating/cooling demand is increased, too (Fig. 4d). The calculation informed that a consistent heat loss is produced through the opening area in the South façade, thus next step was to minimize it.

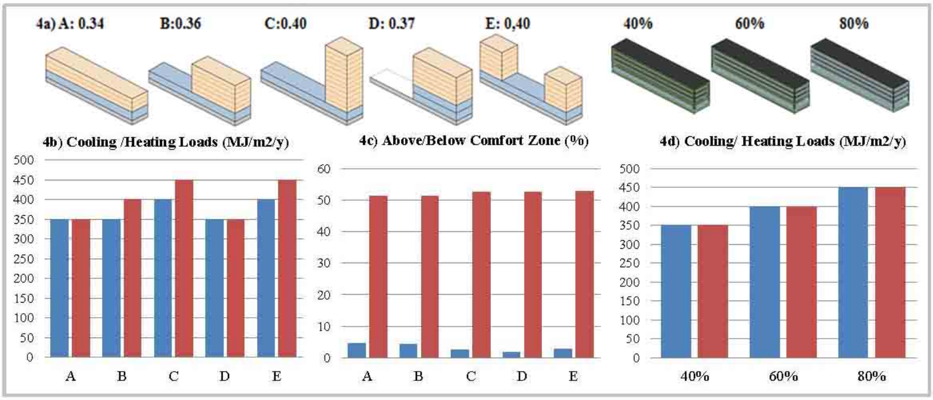

Fig. 4 (a) Different design alternatives obtained by varying the compactness of the building; (b) Effects of the different design alternatives on cooling/heating demand; (c) Effects of the different design alternatives on comfort; (d) Effects of different percentage of opening area on heating/cooling demand (Simulation tools: Autodesk Vasari-Ecotect)

In conclusion, some initial goals have been refined –feedback–; as well as, some decisions have been made through a trade-off between design variables. A candidate solution has been selected, with similar characteristics to those of the existing building (compactness, orientation, etc.); these characteristics have then been considered then as constraints in the successive step of the design process –feed-forward–.

Development phase: aggregation of building’s components.

As established in the precedent phase, the main goal of the development phase has been the reduction of heating demand by taking into account also costs and comfort issues. To this purpose, once the compactness and orientation of the building was defined, the object of the design decision has been to improve the design of different building aggregated component: building’s internal partition (area of internal mass), and the relation between opening area and opaque area of the envelope system (opening ratio). Even if the area of internal mass does not contribute significantly to construction costs and building energy demand, the results of energy simulation informed of an appreciable reduction of heating demand produced by the design option 2 (Fig. 5b), probably thanks to the improvement in natural cross-ventilation, which simultaneously improved the indoor comfort, too. Moreover, by simulating different percentages of area of the southern windows, the calculation informed that a consistent reduction of heating demand is produced by 40-45% ratio options, due to a balance between solar gains and heat loss through the envelope (Fig. 5c). This information has been used to design South façade of the building: the relation between the design alternatives of the windows (horizontal or vertical) and the shadow devices (balcony and railings), has been considered to maximize solar radiation during winter and minimize solar radiation during summer (overheating control), in order to increase the opening area. This study led to decide between two design alternatives: the first, a vertical window and a balcony with the maximum dimension permitted for the local regulation, and without railing (glass railing); the second, the reconsideration of the previous decision of the building compactness, in relation to the recess of the window from the wall.

In conclusion, it is not necessary that the windows area should be strongly minimized –feedback–, the building heating demand has been reduced by improving other design characteristic of the building envelope, as well as it could be further reduced by improving the building envelope thermal properties –feed-forward–.

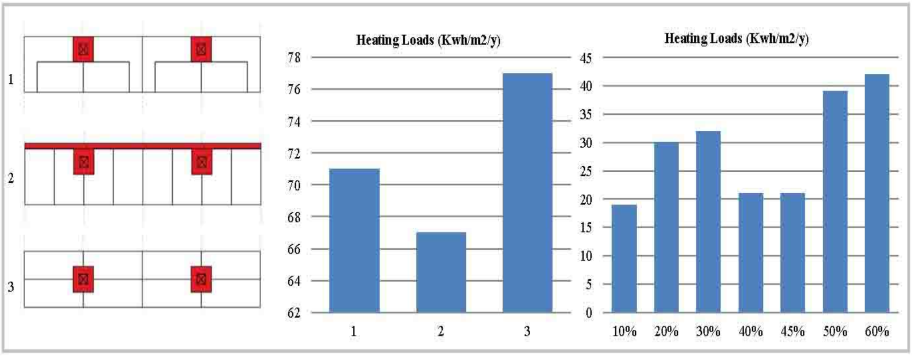

Fig.5 (a) Different design alternatives of building layout; (b) Effects of the different design alternatives on cooling/heating demand; (c) Effects of different opening ratios on heating/cooling demand (Simulation tool: Autodesk ECOTECT)

Detailed phase: building components.

As defined in the precedent phase, the main goal of this phase is the reduction of heating demand by changing the characteristics of the building envelope, as for example the thermal transmittance of the windows. By comparing the results of energy simulation between two options –simple glazing window (U-value: 6 W/m² K) and double-glazing window (U-value: 2.4W/m² K)–, the calculation informed that the heating demand can be reduced in the second option, without compromising the indoor comfort; by adopting a double-glazed window, the energy saving may be 40%,[8] whereby additional constructions costs can be justified (trade-off between design goals). This information has been used to reconsider the openings ratio decided in the precedent phase –feedback–, which could be further increased, as well as the compactness of the building; these characteristics of the building has been changed for improving some other design related aspects, like lighting, privacy and external views.

Conclusions

The objective of this paper was to present a performance-based design methodology with the purpose to make better informed decisions that would contribute to improve the energy performance of buildings. Fundamentally, the proposed methodology lies on two feedback levels: the first one, in which design intentions can be subjected to modification through an instant feedback on building performance (simulation); the second, by which better informed decisions can be made by looking back and reconsidering, through the new generated information,

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[8] By considering an electricity based cost of 0,165€/kWh, 45% openings area (10m² for each apartment) and a difference of 10°C, the first option (U-value:6W/m²K, apartment heating demand:21Kwh/m²y, comfort: 33.6%) consumption for heat loss is 2.3€/day, while in the second option (U-value:2.4W/m²K, apartment heating demand:19Kwh/m²y, comfort: 33,3 %) is 0,95€/day for each apartment. During six months, the first option consumption costs is 427,8 €, while in the second option is 176,7€ for each apartment. This means that the second option produces an energy saving of 40%, by which the additional construction costs can be amortized over 10years (a double-glazing windows cost is approximately the double of the single-glazed window).

decisions previously made at the earlier phases. The application of this methodology to a case study highlighted how developing and evaluating proposals and alternatives is a way of experiential learning in a design process, which can help to promote an energy-conscious decision-making process throughout all phase of the design process, but especially in the earlier phases, when critical decisions about energy performance of the building have to be made, but designers typically lack the necessary information.

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