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A Thorough Protocol to Study and Develop Constructive Systems of Façades

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Abstract

In the Department of Construction Science, we have developed and documented a specific model of systematized process in order to carry out activities of R&D&I oriented to a detailed design of constructive systems of innovative façades. This specific model will be used as a guide for the study, analysis, design and evaluation of the proposed solutions for façades.

This model of systematized process of research provides a general idea of the set of stages and activities in the processes of R&D&I, with a graphical map and a documentary structure that describes how all the process works, step by step, facilitating its comprehension and application. The protocol details the key procedures within the global process.

This protocol allows elaborating the programme of necessities derived from the conditionings, requirements and demands related to every specific façade, assisting with the definition of the technical characteristics of its parts and components to approach the conceptual and graphical design of constructive solutions, in successive stages.

This protocol provides the means to analyze and evaluate every particular design of façade and the process of R&D&I that has been followed, so that it allows to justify and demonstrate the fulfilment of the requirements and demands that concern every stage of the complete life cycle of façades, and to identify fields that could be improved in the R&D&I process, in order to apply corrective actions.

This protocol is complemented by some *Supporting Technical Documents*, where the scientific and technical criteria and the information from compulsory regulations that are necessary to take decisions in the design progress, are developed.

On the whole, it is a useful tool that allows rapid availability of knowledge and rigorous information related to the process of R&D&I, to the constructive systems of façades and to the activity of the diverse agents involved in the building process.

1 Introduction: description of the protocol for the study and development of constructive systems of façades.

In the Department of Construction Science, we have developed and documented a specific model of systematized process that establishes the methodology to carry out activities of R&D&I oriented to a detailed design of constructive systems of innovative façades. This specific model will be used as a guide for the study, analysis, design and evaluation of the proposed solutions for façades.

The numerous facts and circumstances relating to façades are closely interrelated and need to be considered systematically during the various phases of this process.

This model of comprehensive and systematic process has been called *Thorough Protocol for the study, analysis, design and evaluation of Constructive Systems of Façades,* its acronym is PROEX[1].

The PROEX gathers the following features:

- Provides a general idea of the set of stages and activities in the processes of R&D&I, with a graphical map and a documentary structure that describes how all the process works, step by step, facilitating its comprehension and application. The protocol details the key procedures within the global process.
- The PROEX allows elaborating the programme of necessities derived from the conditionings, requirements and exigencies related to every specific façade, assisting with the definition of the technical characteristics of its parts and components to approach the conceptual and graphical design of constructive solutions, in successive stages.
- The PROEX provides the means to analyze and evaluate every particular design of façade and the process of R&D&I that has been followed. It allows justifying and demonstrating the fulfilment of the requirements and demands that concern every stage of the complete life cycle of façades, and to identify fields that could be improved in the R&D&I process, in order to apply corrective actions.

The PROEX includes a number of *Supporting Technical Documents* required for its application, to help understand and interpret those aspects that need further clarification, taking into account the particularities of façades.

These *Supporting Technical Documents* develop conceptually the scientific and technical criteria and the information from mandatory regulations that are necessary to take decisions in the design process of a façade. This body of knowledge and data are updated according to the progress of general and own knowledge and to the demands of society.

The *Supporting Technical Documents* that have been developed are related to:

- The comfort conditions of building users.
- The actions and solicitations[2]
- The general and specific conditionings.
- The general and specific requirements.
- The development of exigencies.

[1] *Protocolo Extenso para el estudio, análisis, diseño y evaluación de sistemas constructivos de cerramientos de fachadas innovadores→PROEX*

[2] Solicitations refer to the combination of actions of various kinds that act together.

The PROEX and the *Supporting Technical Documents* include procedures for progressive control of the successive stages of the R&D&I activities and results.

2 Integration of factors and circumstances to be considered and assessed in the study, design, analysis and evaluation of constructive systems of façades

This model of systematized process, proposed to guide the research works, has been represented graphically for better understanding and use (Fig. 1).

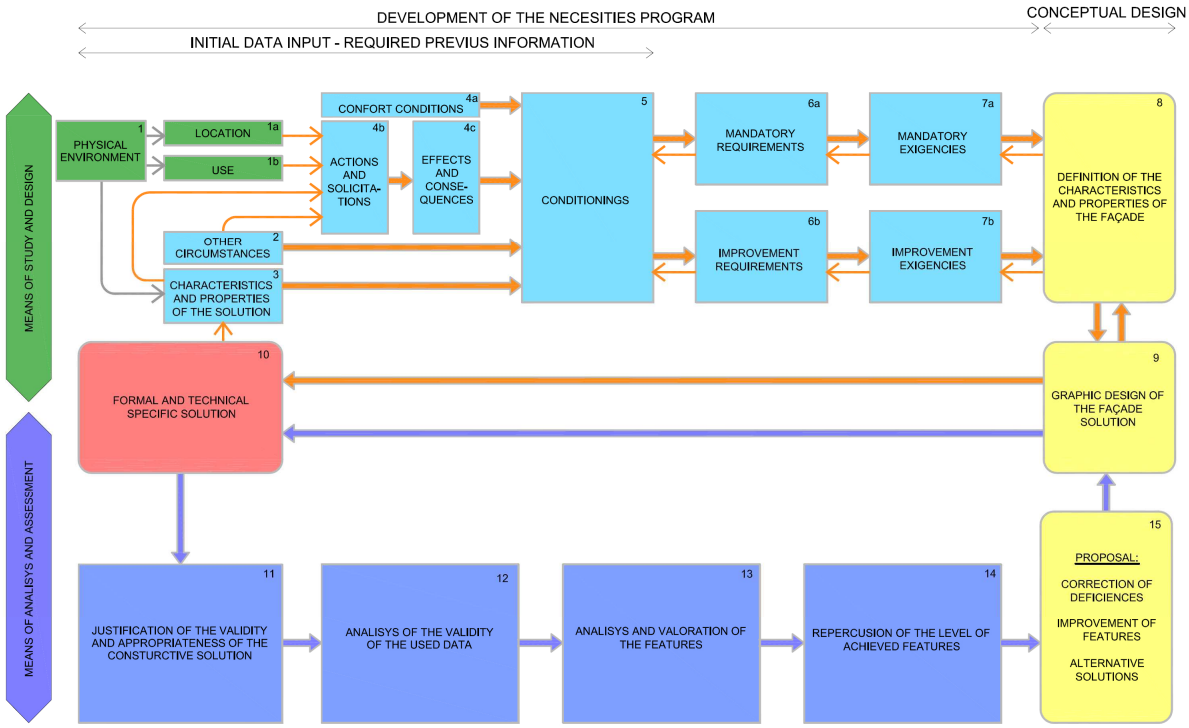

Figure 1: Integration of factors and circumstances to be considered and assessed in the study, design, analysis and evaluation of constructive systems of façades

All the factors and circumstances that should be taken into account are integrated and listed in a logical order, from the general aspects to the specific ones, structured and interrelated in successive levels.

The PROEX provides at each stage, the means for the study of each façade solution, (steps from 1 to 7), the means for the façade design, (steps 8, 9 and 15), and the means for the analysis and progressive evaluation of the validity and appropriateness of the specific façade solution (steps from 11 to 14).

The PROEX and the *Supporting Technical Documents* will also be helpful:

- As a guide to identify all the aspects that, in each particular case, may affect the façades in the phases of design, building and service.

- To define qualitative and quantitative exigencies of different kinds and according to them, the conditions that the façades should achieve to have the required performance.
- To choose each specific constructive solution of the façade and to assess its likely behavior or to prove or demonstrate compliance with the exigencies which affect it in each case.

The upper part of the graphic scheme corresponds to the means of study and design related to general and specific aspects of each façade solution.

The lower part corresponds to the means of analysis and evaluation of the specific design of façade that is being developed.

2.1 Stages 1, 2 and 3, initial data input, required previous information

The first step is the assessment of the physical environment related to the façades, distinguishing:

- The physical environment outside of buildings, depending mainly on their geographical location.
- The physical environment inside buildings, which depends mainly on its use and the characteristics of the building.
- And the physical internal environment of the façades, depending on the characteristics and properties of each particular solution, and on physical exterior and interior environment.

2.2 Stage 4a: comfort conditions

The next step is estimating the comfort conditions of the users of buildings.

The concept comfort refers to the set of environmental characteristics of the indoor spaces that are required to ensure that users feel a sense of biological and psychological well-being, according to the kind of developed activity.

In the *Supporting Technical Document* related to comfort conditions, the various compulsory regulations and the reference basic documentation, have been studied in detail. This document gathers the physical and biological fundamentals related to the sense of hygrothermal comfort.

2.3 Stage 4b and 4c: actions, solicitations and their effects and consequences

In the next phase of the process, the potentially destructive actions that will affect the building are assessed, as well as the internal forces derived from the actions, and their effects and consequences.

The concept of action refers to actions carried out on a particular building or its construction elements and components during their entire existence, both in normal situations, according to their conditions of use, and in extraordinary situations. They are due to physical, mechanical, chemical, electrochemical, and biological agents.

It is important to design the façade systems so that they have the durability needed to keep their initial performance over time, assessing the effects and consequences that the simultaneous combination of different actions can have.

The evaluation of the actions and solicitations is based on the analysis of the physical environments, considering the specific location of the building, its use, and the interactions among the parts and components of the façade, and of these with the rest of the building, as a result of the features of each façade solution.

2.4 Stage 5, conditionings

Taking into account the characteristics of the physical environment, the actions and solicitations, the comfort conditions and other specific circumstances related to the façades, we study the conditionings arising from this.

The concept *conditioning* refers to those aspects of very diverse nature and degree of influence, depending on which the ultimate result of an activity may achieve the intended purpose. This concept can be applied to different fields: R&D&I activities, projects and processes of construction of a whole building or some of its parts or components (for example the constructive systems of façades), etc.

These conditionings should be taken into account early in the process of developing the solution and latter to make an assessment of the achieved results.

We propose a list of the various types of conditionings, which is a guide to identify and define those that explicitly or implicitly are required in each specific case [1, 2]

2.5 Stage 6, requirements

Based on the various families of conditionings, the requirements to be achieved by the solutions made with the new construction systems are defined. Using a set of main objectives, the different requirements are defined, each of which in turn results in a set of specific exigencies that should be fulfilled to demonstrate that every requirement considered is satisfied.

In this stage we distinguish between mandatory and voluntary requirements and objectives:

- The *Mandatory Requirements* are defined and specified in laws and regulations of various kinds depending on the intended use of the building. They are directly derived from the application of CPD 89/106/EEC [3] –essential requirements– and the Spanish LOE [4] –basic requirements–.
- Other requirements have a voluntary nature and the aim of improving the minimum level of features that is derived from the mandatory requirements. These voluntary requirements can have several purposes: economic objectives, prestigious, competitiveness, etc. These can be called therefore *Improvement Requirements.*

2.6 Stage 7, exigencies

In this stage the definition and quantification of the exigencies, in the form of specific conditions of different nature that should meet the constructive systems, is done to ensure that buildings meet the main objectives of each of the requirements.

These exigencies are sorted into different families and, like the requirements, are separated into *Mandatory and Improvement Exigencies*. The former are defined and specified by mandatory regulations (eg. In Spain, they arise from the implementation of the Technical Building Code [5]). The *Improvement Exigencies* come from the *Improvement Requirements*, which have been incorporated as targets of the promoter or the researchers that develop a new construction product.

2.7 Stages 8, 9 and 10: definition of the characteristics and properties of the façade; graphic design of the façade solution; formal and technical specific solution.

All this information can produce a detailed program of the specific necessities of façade constructive systems and define their technical specifications. This allows continuing with the conceptual and graphic design.

The characteristics and properties that should have the new constructive systems are defined based on the necessities program in order to fulfill the requirements to be met by buildings.

Progressively in successive approximations, the conceptual and graphic design is set to reach a sufficient level of definition to consider it as a first formal and technical solution.

Once this first level of definition is reached, the means of analysis and evaluation provided in the PROEX are applied to check the validity and appropriateness of the work.

2.8 Stage 11, justification of the constructive solution

In this stage of the PROEX, the control procedures to justify and demonstrate the validity and appropriateness of the constructive resolution, and the compliance with the exigencies and requirements are applied successively.

2.9 Stage 12, analysis of the validity of the used data

In this part, the analysis of the used data is done by:

- The analysis and assessment of the comfort conditions and the actions and solicitations that have been chosen.
- The analysis of the definition and specification of the mandatory and improvement exigencies.
- And the analysis of the definition and specification of the characteristics and technical properties of the solution.

2.10 Stage 13, repercussion of the achieved performance level

The next step is to make the assessment of the reached performance level, evaluating:

- The response from the specific façade to actions, solicitations, and conditionings.
- The level of suitability that has been achieved.

2.11 Stage 14, repercussion of the achieved features

Subsequently, we estimate the impact of the assessment of the reached level of features, on the durability, comfort, consumption, costs of construction and exploitation, obsolescence and depreciation, the behavior of the façade and its relationship with the rest of the building, etc.

2.12 Stage 15, proposal

Based on the results, we propose:

- Correcting the deficiencies.

- Feature improvements.
- Possible alternative solutions.

Initially, in the process of developing constructive systems of façades, we do not make a full implementation of the contents of the PROEX. Its implementation is progressive depending on the degree of specificity that will be reached on the technical solution.

The systematic implementation of this model allows a rigorous monitoring of the process status and ensures control and quality of the used information and the obtained results.

3 Conclusions on the implementation of the PROEX

The PROEX consists of a set of interrelated stages that are combined orderly in a more or less flexible way and forming a sequence of successive actions in a logical order, to guide R&D&I activities in the field of innovative façades. The combination of all these stages form a complete functional unit, more or less complex depending on the size and complexity of the R&D&I activities, which constitute a specific methodology.

Applying this protocol and taking into account the requirements defined in each of the stages, we get results that allow obtaining reliable and demonstrable advances and meeting the expected objectives and purposes.

The PROEX and the *Supporting Technical Documents* have been used to study the façades of three buildings, with the aim to check their usability and practical usefulness [6, 7, 8]. This implementation has been partial because the buildings are already built and in use.

The complete verification PROEX requires its application to other cases: the analysis of an existing constructive system of façade, the design of a façade for a particular building and the development of new constructive systems of innovative façades. These will be subject for further investigations and will allow expanding and updating the contents, and revising the method of application. The PROEX and the *Supporting Technical Documents* are very flexible tools that are easily adapted to the stage at which each case is studied (project, construction, service).

The *Supporting Technical Documents* and the study of the façades of each selected building have been developed simultaneously. This way we have completed the contents of those *Documents* with issues that have arisen during the studies of buildings and the studies themselves have been improved, because the *Supporting Technical Documents* and the PROEX contain issues that otherwise would have gone unnoticed.

The PROEX has helped to structure the study of the three buildings. We have compiled the specific data related to the physical environment outside of the building that are closely related to the location and the climate and we have studied the constructive characteristics of each façade. In addition, we have considered the use of the different spaces along the building that influence the physical environment inside the building. Both physical environments are closely related to the actions and solicitations that will act on the façades and to the comfort conditions of the users of the building.

We have checked that the *Supporting Technical Documents* related to *Actions and solicitations* and to *General and Specific Conditionings* are the most useful for this partial implementation of the PROEX.

The implementation of the PROEX to a specific case has allowed valuing the constructive solutions adopted in the façades, their features, their interaction with other constructive elements and checking their strengths and weaknesses. We have proposed for each case, a number of improvements that allow

addressing the weaknesses that can be motivated by aspects that either were not taken into account, or were not assessed properly during the design process of the buildings and their façades.

The PROEX and the *Supporting Technical Documents* are very useful resources that allow obtaining reliable information. They constitute a guide that allows integrating and considering systematically the various factors and circumstances that can influence the performance of the façades and that otherwise could be ignored.

This partial implementation of the methodology and resources defined in this set of documents shows that they will also be helpful to provide reliable steps in future R&D&I activities to develop innovative façades.

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