15 YEARS OF FAÇADE ENGINEERING DESIGN WITH CERAMIC TILES

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1. ABSTRACT

A little over fifteen years ago, Medeiros (1998) debated the importance of hiring and elaborating designs for implementing façade adhered cladding in a scenario of significant change in construction.

At the time, the Brazilian scenario was one of technological progress that allowed the fabrication of ceramic tiles of lower absorption and flexible polymeric mortars with great adherence potential, as multi-storey building structure design became increasingly slender using high performance concrete.

The lack of knowledge regarding the application of ceramic tile façade systems, associated with factors, such as the shortage of information on the construction site, caused many liabilities in buildings with façade ceramic rendering. The Brazilian standard NBR 13.755 (ABNT, 1996) was elaborated in order to attend to a present need at that period.

Even with the establishment of the regulation, the difficulties in executing façade adhered cladding remained, which made the agents involved attach more importance to the hiring of projects.

Throughout this period and with the growing experience regarding this type of adhered cladding system, much has been developed on the subject. The present article aims to present briefly how such progress was made, both in the light of design (criteria, parameters, material specification and constructive detailing) and of execution and control on the construction site, with reference to the main standard on the subject, mentioned above, which is under revision with a view to incorporating the knowledge developed and acquired in the last 15 years.

2. FAÇADE CERAMIC CLADDING AND THE BRAZILIAN MARKET

Although no specific data are available on the consumption of ceramic tiles applied on Brazilian building façades, the national ceramic production for cladding is second in the world ranking, according to data from ANFACER (Brazilian Association of Manufacturers of Ceramic Tiles, Sanitary Ware and Related Products).

Brazil is the largest world consumer of this sort of cladding. Therefore, it is possible to consider that the share referring to façade ceramic cladding is not irrelevant in the national scene. Table 1 details ceramic cladding production in the Brazilian context.

Year	Production (10^6 m^2)	Production Growth Rate	Construction Sector Growth Rate
2008	713.4		
2009	714.9	0.21%	7.50%
2010	753.5	5.40%	13.10%
2011	844.3	12.05%	8.30%
2012	865.9	2.56%	2.80%
2013	871.1	0.60%	4.70%
2014	903.3	3.70%	-2.60%
2015	969.3	7.31%	-4.70%

Table 1. *Comparison between ceramic cladding production and construction growth rate (SINDUSCON, 2015).*

In this regard, it is possible to observe an increasing demand in the use of ceramic cladding in the Brazilian context. This increase is associated with several aspects, some of which are listed below:

- Increase in urban population in the cities, which created the need for construction verticalization to better use urban land, and consequently an increase in the construction market;
- Modifications in the architectonic culture and aesthetic taste in the use of ceramic cladding façades;
- Bioclimatic characteristics. As a continental country, between tropics, subject to the incidence of heat and humidity and thermal variance, the appropriate use of ceramic cladding in a façade contributes significantly to reducing maintenance costs in the life cycle of a building;
- Technological development of material such as concrete, enabling a slender building project, with a better exploitation of the surroundings;
- The technology in the production of ceramic cladding with very appealing aesthetics and high performance – porcelain tiles resembling wood and natural stone, for example.

According to a data collection from designs developed in the last five years at Inovatec, over 60% of the buildings have a ceramic cladding on the façade.

3. TECHNICAL EVOLUTION IN FAÇADE ENGINEERING DESIGN WITH CERAMIC TILES IN BRAZIL

The design of façade ceramic cladding in Brazil was conceived in a scenario of recurring pathology cases and with the purpose of introducing efficient solutions – carefully studied previously to execution on the job site - that would contribute to the achievement of adequate performance.

On the 1990s, an analysis started of ceramic tile façade systems from a holistic perspective, taking into consideration all the factors of influence. The design elaboration with an integrated analysis of these factors applied to each building has enabled achievement of better cladding system performance.

The achievement of appropriate system performance is basically related to the correct:

- Analysis of the architectonic, structural and partitions designs for the building;
- Positioning of reinforcements and movement joints;
- Constructive detailing;
- Specification of materials and application methods for the different layers of the system, which must be all evaluated through applications on a small scale on cladding panels on the job site before starting the general application;
- Workmanship orientation on the job site.

When major factors such as these are taken into consideration, the fact becomes clearer that each building must have a specific design for the façade adhered cladding.

This type of design has two acting phases: the design phase itself and the execution follow-up phase. If the construction does not take ownership of the technical knowledge present in these two phases, it will be used inappropriately.

Figure 1 presents a proposal for the flowchart of façade ceramic cladding design, with the detailing of each of its phases. It is important to highlight that the design quality is tied to the standardization of an analysis method that must be used for each building in order to address all the important factors that can influence ceramic cladding performance.

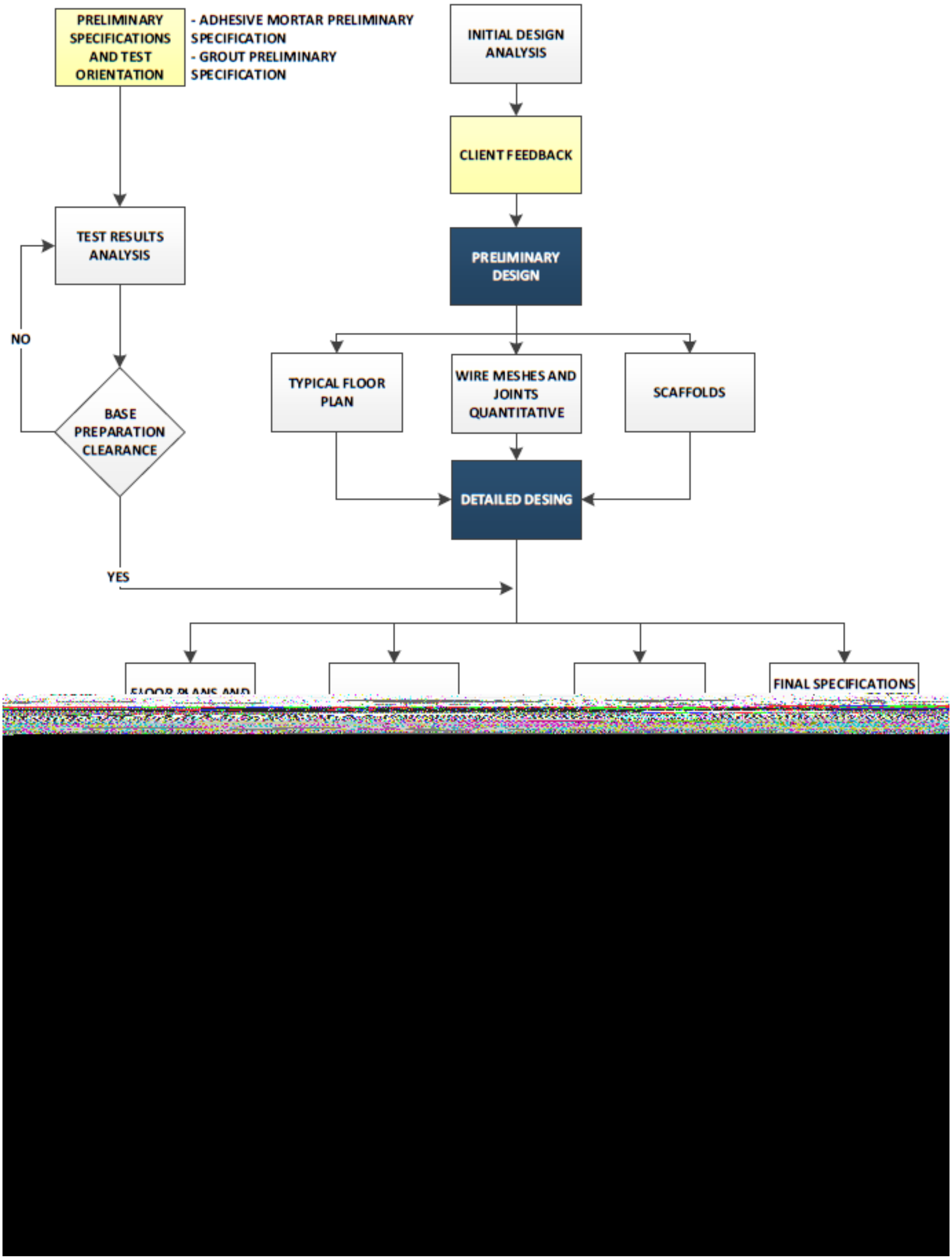

Figure 1. *Flowchart of façade design with ceramic tiles (INOVATEC, 2015).*

The development of this flowchart was based on designing experience and it aims to internally organize the design production steps, as well as guide the client through the whole process – products to be delivered, tests preparation phase and technical follow-up of the construction in the phases of cladding execution. In this article, the major content of each of the products elaborated by the designer is also discussed.

3.1. ANALYSIS OF THE ARCHITECTONIC, STRUCTURAL AND PARTITIONS DESIGN

The design process begins with the analysis of the architectonic, structural and partitions design of the buildings, preferably in the pre-execution phase. This analysis consists of the verification of items such as the lower alignment of beams, upper alignment of the window frames and graphic positioning of movement joints.

The foreseen fixing methods between masonry and structure are also analysed. If necessary, a specific request, such as the execution of a flange slab for masonry, due to the excessive movement of the seal and consequent incidence of cracking in the cladding system, can be made.

At this stage, the best constructive solutions for the different architectonic elements in the façade and the ceramic pre-specification, which can be inadequate for such use, are also discussed. Many details are set and even altered due to the correct technical guidance at this moment.

Hiring a façade cladding design in a more advanced phase of the architectonic and structural designs, or even when the building is already under construction, can result in a more restrictive contribution. The acceptance of requests, such as beam dimension adjustments, addition of support to harmonize cantilever shifts or the alteration of the ceramic tile, becomes difficult, even with accurate technical argumentation. The non-acceptance of these suggestions is usually related to the impacts on the construction deadline and budget, as they had not been foreseen.

Studies show (MATTOS, 2010) that the more time is spent planning a construction, the lower is the execution cost, since the necessary alterations have to be predicted in the project, to avoid project revisions and adjustments in construction, as these are unforeseen costs.

3.2. GRAPHIC POSITIONING OF REINFORCEMENTS AND MOVEMENT JOINTS

The accurate positioning of reinforcements and movement joints is an extremely important activity in order to extend the lifespan of the ceramic rendering and avoid pathological manifestations.

Ceramic tile rendering must be considered as a system made up of different layers of materials that present different properties. Therefore, in order to understand its behaviour, it is necessary to observe not only the performance of each layer separately, but also the system as one single body, from the inner layer (framework or masonry) to the outer layer (ceramic tile and joints).

The specification of reinforcements and movement joints is based on the structure's behaviour analysis, considering its connections to the partitions, differential deformities and the consequent tensions imposed on the cladding system. Figure 2 presents an example of a tool that can be used by the designer for structural behaviour analysis, a floor plan with the structure isodeformation curves.

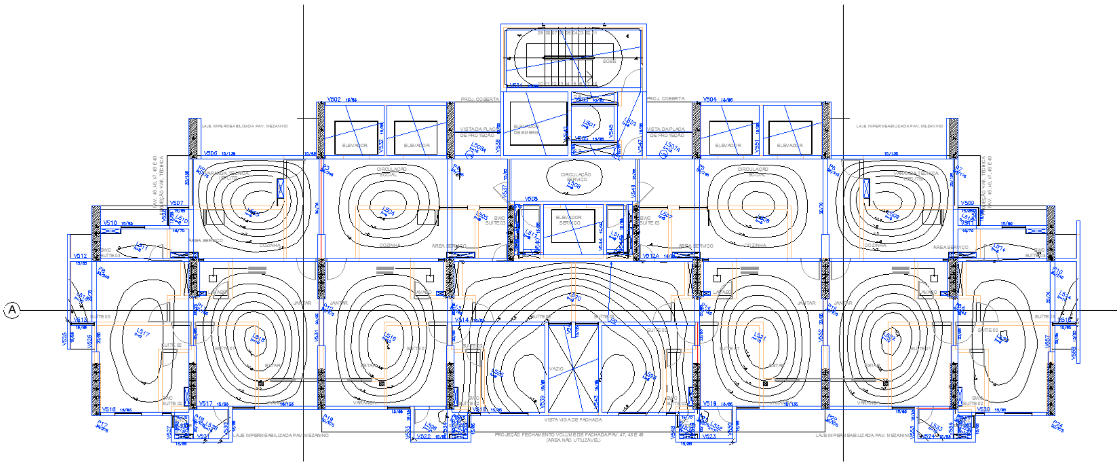

Figure 2. *Floor plan with structure isodeformation curves for a building in Brazil (GBM, 2014).*

With a view to countering the cracking in ceramic façade cladding that results from tensions in the interfaces between the substrates, the designer can work with the two most relevant solutions:

- Reinforcements – these are usually configured by the use of hot-dip-galvanized electro welded metal meshes implemented in the stucco layer, which has presented the best performance on dissipating tensions and not letting the system crack. The masonry in a cantilever, for example, requires a differentiated reinforcement, so that the masonry is able to move and does not crack either itself or the cladding that is adhered to it.
- Movement joints – these serve to define smaller panels of rendering, minimizing the unwished effects of global movements/deformation. The geometry of the joint cavity and its seal must be dully calculated to fulfil its purpose, absorbing the foreseen deformation and avoiding infiltration.

On the floor plan presented below it is possible to verify the graphic positioning of these solutions in the cladding design.

Figure 3. *Floor plan with graphic positioning of wire meshes and movement joints (INOVATEC, 2014).*

The proposed graphic language also shows in which storey each reinforcement or movement joint must be implemented. Figure 4 details a type of key that can be used to indicate this.

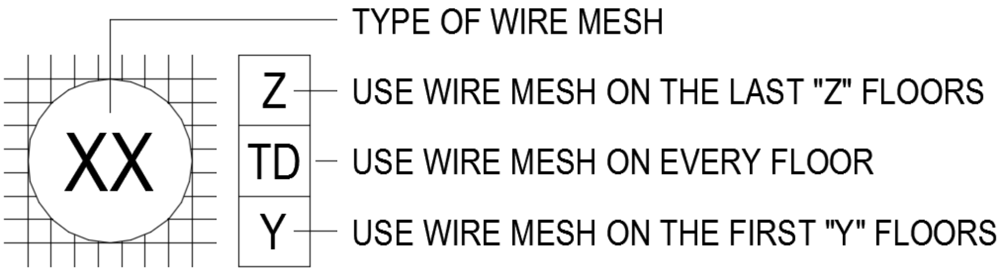

Figure 4. *Key used in designs for definition of the wire mesh positioning on the different building floors (INOVATEC, 2015).*

The same reinforcements and movement joints are also indicated in elevations, as shown in Figure 5. It is possible to verify the use of wire meshes in the sections with cantilever beams, or in the beams designated by the structural project with larger deformities.

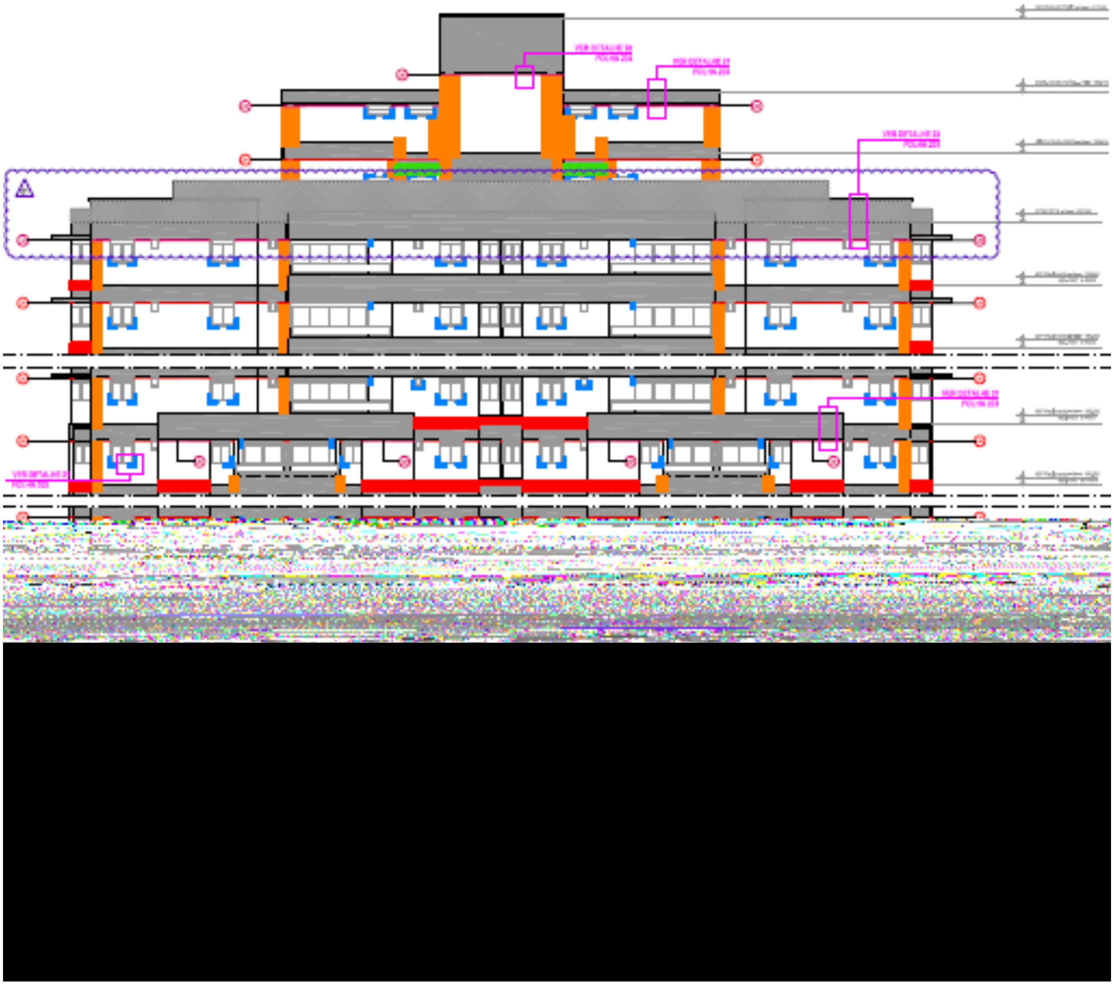

Figure 5. *Elevation with graphic positioning of wire meshes and movement joints (INOVATEC, 2014).*

The definition of where to apply this sort of solutions is of major importance for the cladding performance and it must be made before its execution.

3.3. CONSTRUCTIVE DETAILS

The graphic solutions presented in item 2.2 are not enough to provide complete information on the job site. It can solve the matter of where to implement reinforcements and movement joints but not the how to. To fulfil these needs a cladding design must rely on execution details elaborated in a larger scale.

The detailing of other specific architectonic elements must also be created, it being essential to guide both the execution team and the client through the necessary treatments in the cladding system.

In this regard, the detail brochure is divided into two basic types of details: execution and specific. The execution details are those implemented several times in the tower, as seen in Figure 6.

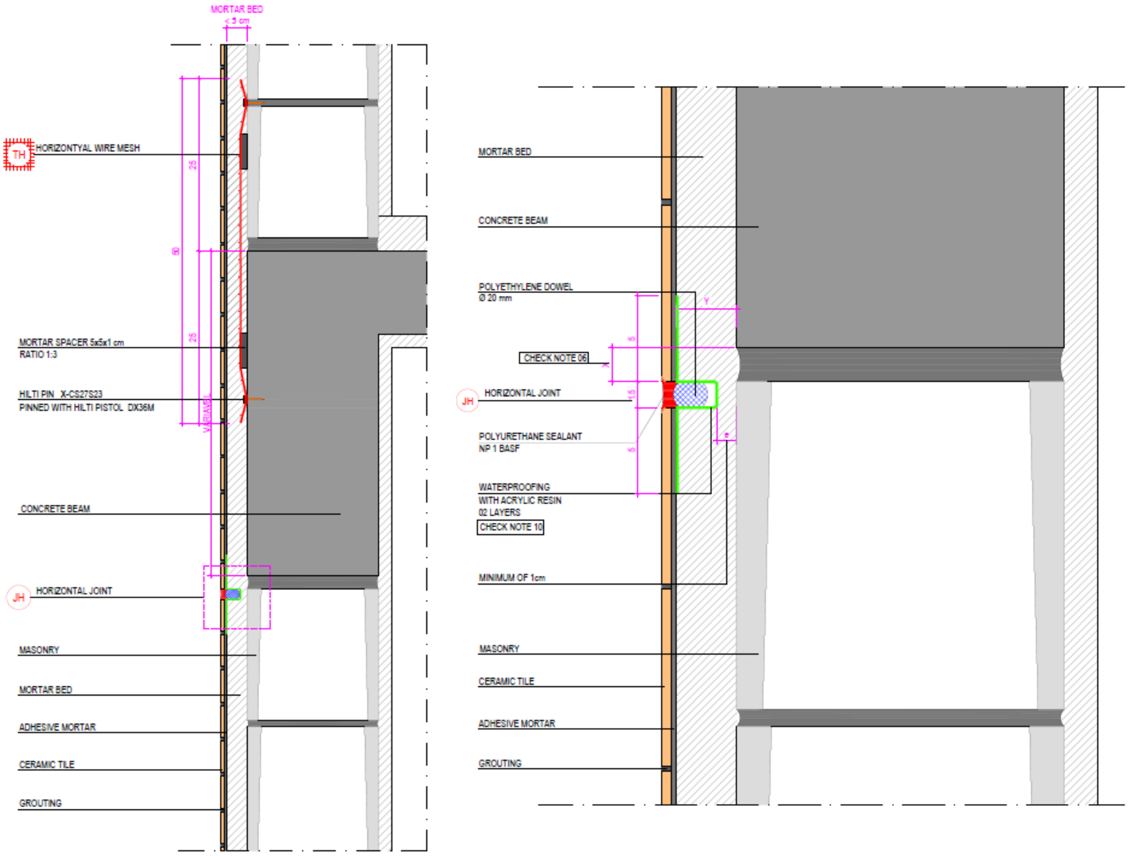

Figure 6. *Wire mesh fixation and horizontal movement joint details (INOVATEC, 2015).*

As the ceramic cladding project aims to propose solutions for each project's specific location, in which the incidence of a pathological manifestation is possible, it is very important to elaborate the details on a scale where all system's layers are clearly identified, such as: structure, masonry, mortar bed, adhesive mortar, waterproofing membrane and sealants as shown in Figure 7.

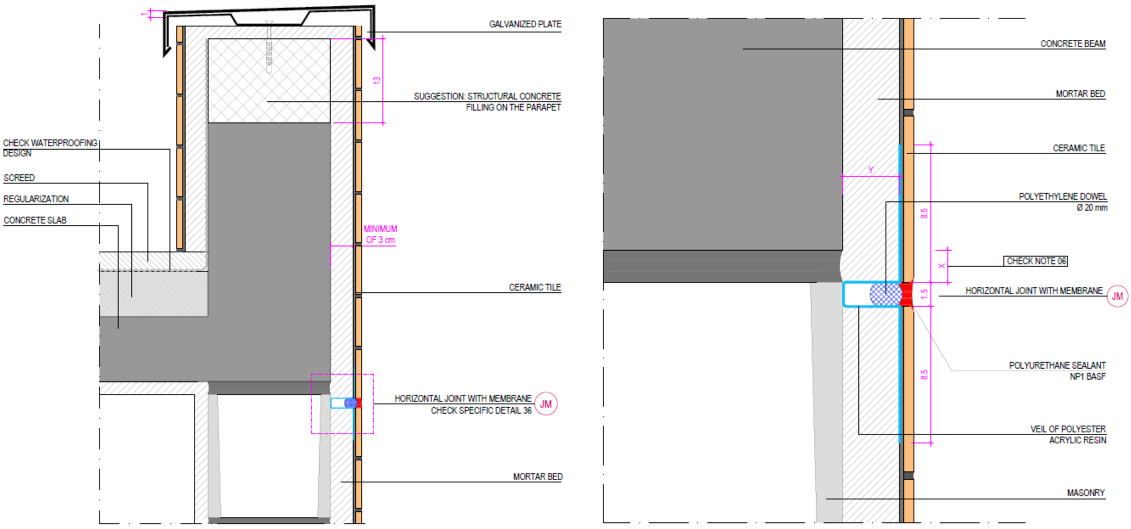

Figure 7. *Treatment of the platband coating and movement joint with membrane detail (INOVATEC, 2015).*

The detail brochure also proposes the positioning of the equipment used most for vertical moving in Brazil for the façade cladding execution, a suspended working platform called a "balancim". This proposition helps with the installation of this equipment and with the execution planning of the cladding system.

It is important for the designer to make a study of the ceramic layout by proposing a modulation to be followed in order to optimize the use of the ceramic tiles, minimizing cuts and the consequent waste. This proposition is usually made by defining the minimum grouting width, dimension of the necessary ceramic tile cuts, minimal leaning in the windowsills and the junction of ceramics and window frames as shown in Figures 8 and 9.

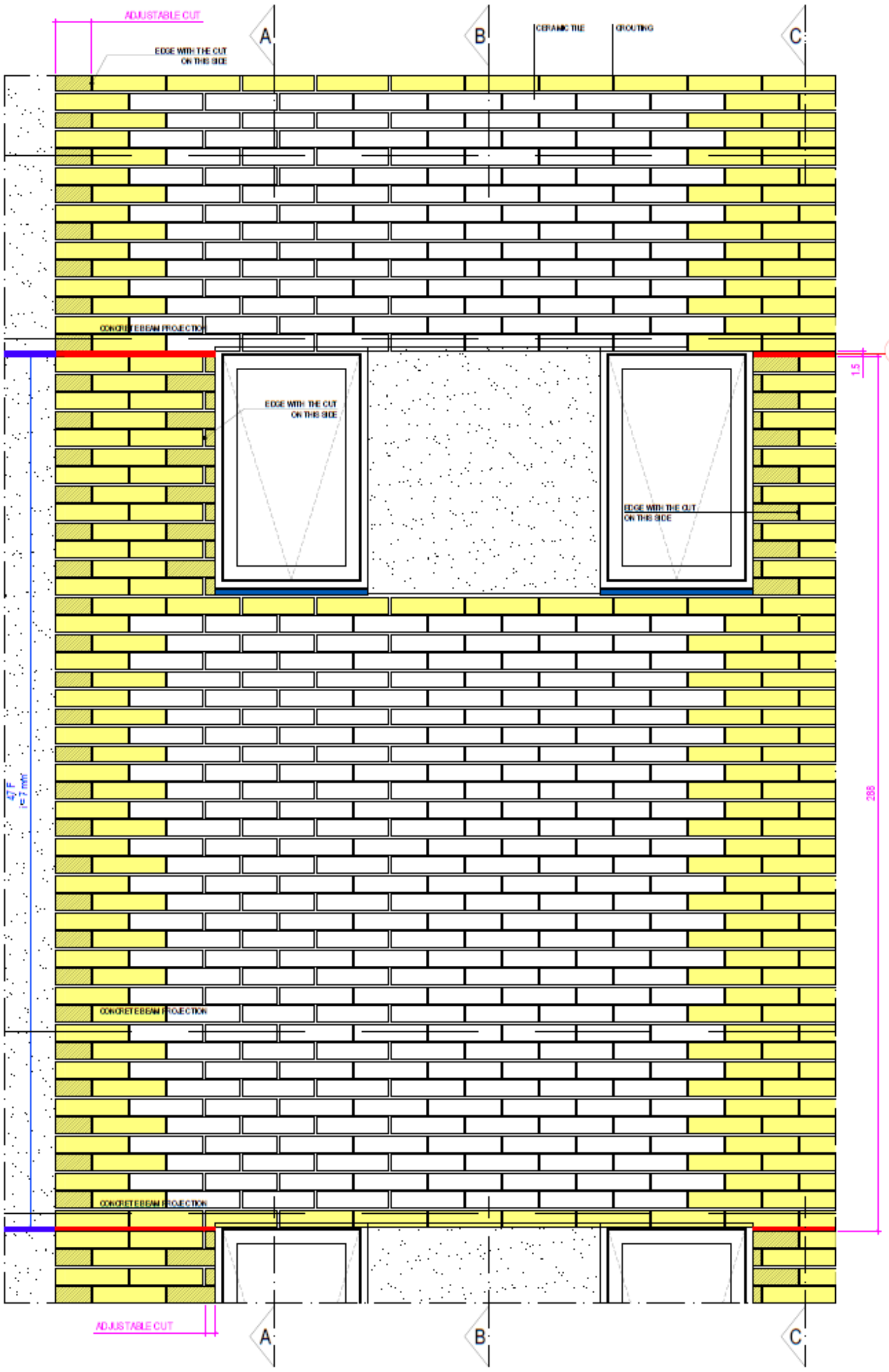

Figure 8. *Frontal view of ceramic tile modulation (INOVATEC, 2015).*

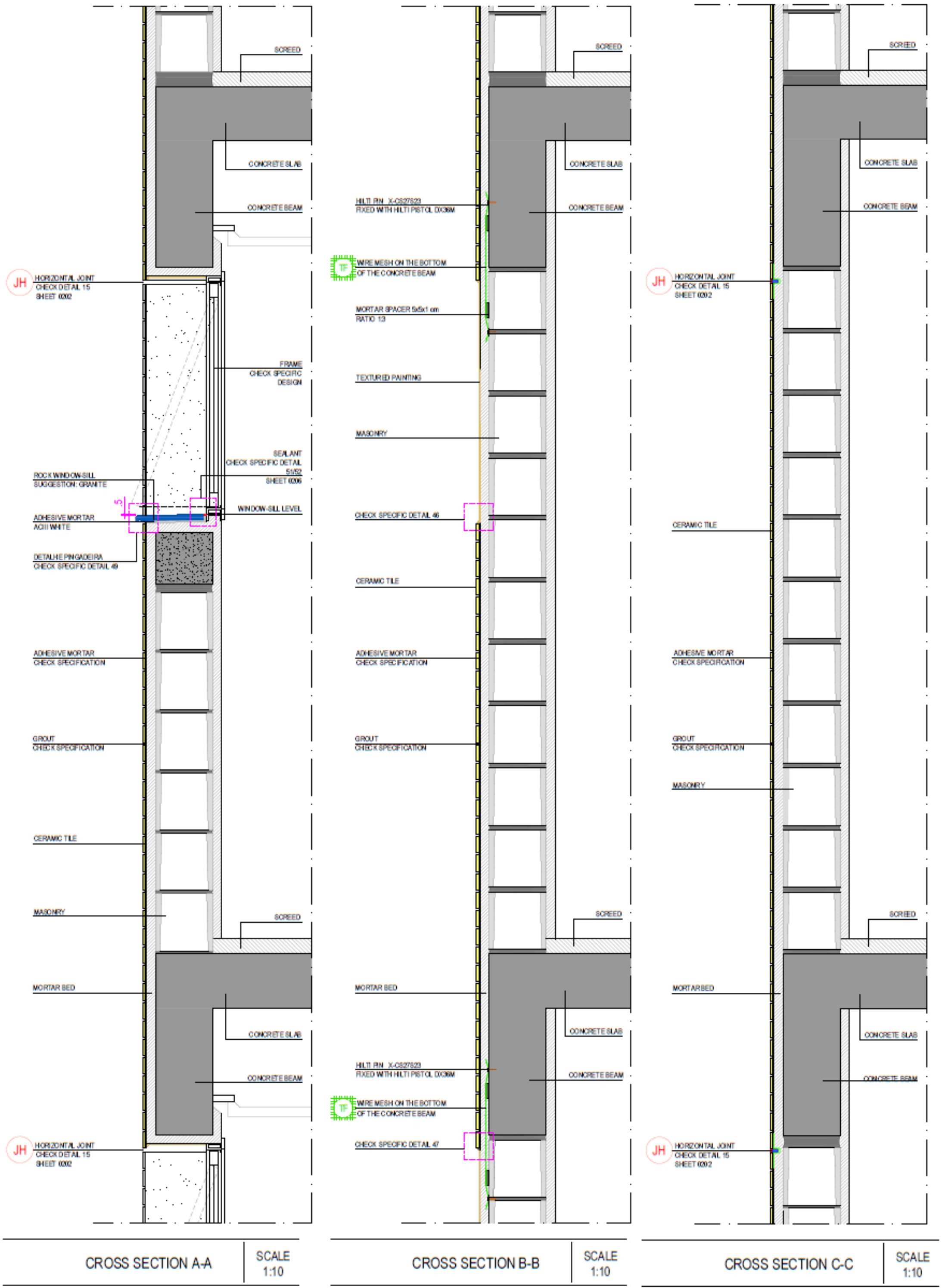

***Figure 9.** Cross sections with proposition of solutions based on a ceramic layout study (INOVATEC, 2015).*

3.4. SPECIFICATION AND SELECTION OF MATERIALS AND APPLICATION METHODS

The specification of all materials that are part of the cladding system is the designer's responsibility. When the material specification is based on an analysis of the various above-mentioned factors, the risks are minimized, avoiding mistakes such as the combination of low performance materials in critical situations. For example: adhesive mortar type AC II + ceramic tile with high hygroscopic expansion + slender building.

However, to minimize risks and avoid surprises, both materials and application methods must be evaluated at the construction site in real implementation conditions, by executing cladding test panels. The performance of the solutions being tested is analysed through the results of bonding tensile strength of the different layers (mortar primer, mortar bed and ceramic tile applied with adhesive mortar).

The analysis is based on the criteria provided by the regulation and on the designer's experience, it being the designer who takes the decision of approving or not each solution tested.

3.5. PLANNING THE EXECUTION AND ORIENTING THE WORKMANSHIP ON THE JOB SITE

In addition, as a part of the design process, the workmanship team is oriented with regard to the cladding execution sequence and application methods. Figure 9 indicates a cladding execution sequence, defining ascents and descents of the suspended working platform.

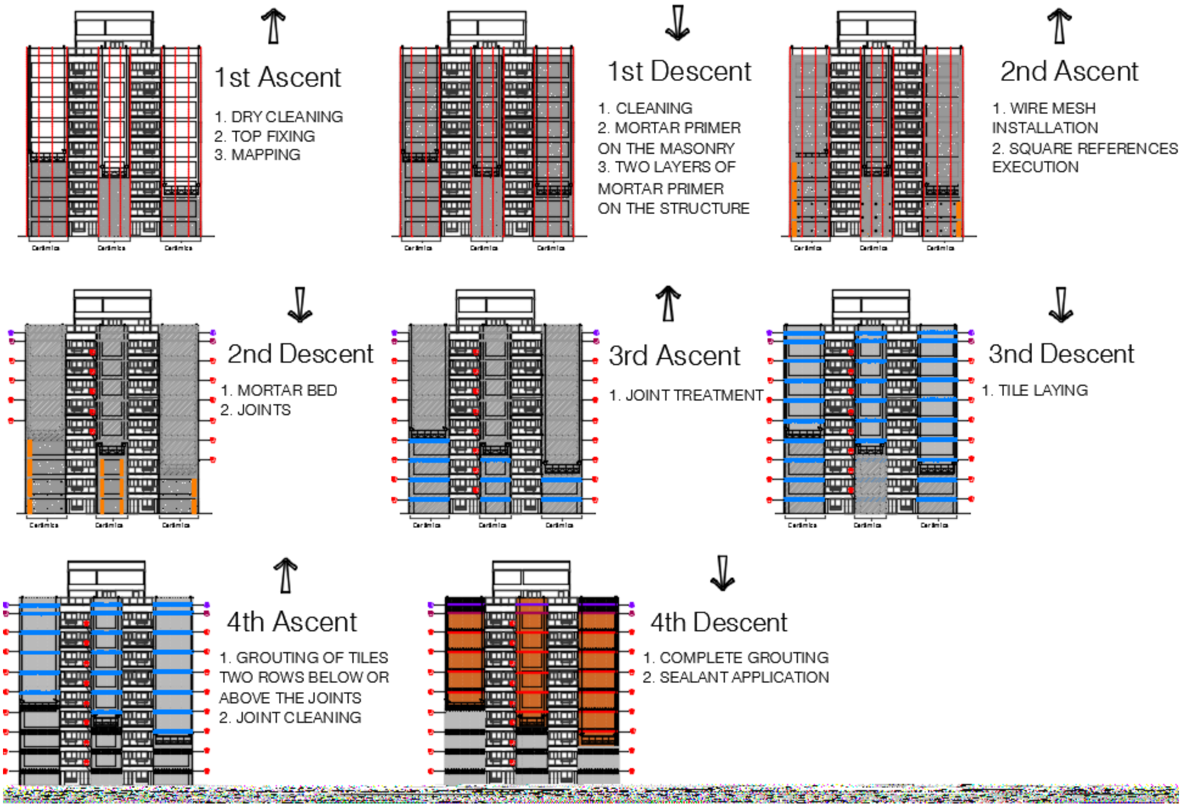

Figure 10. *Proposed sequence of execution of a ceramic tile façade system (INOVATEC, 2015).*