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From construction site to design: The different accident prevention levels in the building industry

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ABSTRACT

The construction industry is responsible for one of the highest incidences of work-related accidents in Brazil, as well as in various other countries. In spite of the dissemination of prevention programs and the proposals for developing safety design for the construction industry, construction sites remain dangerous and unhealthy places. Recently, safety has been proposed to be considered from the development phase of the design (Construction Hazards Prevention through Design), but with little effectiveness in practice. In addition to these more recent proposals, we will demonstrate that the integration between safety and production can proceed through anticipations occurring at several levels of the construction phase, not only in the design phase. Through narratives emerged through techniques of activity analysis at the construction site, it was possible to highlight and categorize 25 cases with implications for the production process development. The results show that this integration between production and safety is possible through anticipations occurring at several levels of the construction phase, from the design analysis conducted by the construction engineer to the implementation. This will allow the development of design situations for implementing safe work situations. The contribution and originality of this paper are based upon the presentation of a model in three levels of anticipation of problems during the construction phase and its effects on improving production and safety.

1. Introduction

In order to improve its poor performance in safety, the predominant strategy of the construction industry has been the multiplication of prevention norms and programs (for example: OSHA Law & Regulations in the U.S.; the Program of the Conditions and Environment in the Construction Industry (PCMAT) demanded by NR-18, organized by the Ministry of Work and Employment (MTE) in Brazil; and the actions to improve safety and health in construction promoted by the European Agency for Safety and Health at Work (EU-OSHA)). More recently, such safety practices in the construction industry have been enriched by proposals of design development aiming at safety at construction sites through the implementation of the concept of Construction Hazards Prevention through Design (Gambatese et al., 2005; Toole, 2002; Weinstein et al., 2005; Behm, 2005; Toole and Gambatese, 2008). However, construction sites remain dangerous places, prone to accidents (Saurin et al., 2005; Weinstein et al., 2005; Suraji et al., 2001; Behm, 2005; Haslam et al., 2005). Behm (2005), for example, points out that the construction industry is still the most dangerous industry in the United States in terms of the total number of deaths.

Although the construction industry in Great Britain has presented modest decline in fatalities in the last years (rate from 4 per 100 thousand workers), when compared to other industries, the construction industry has been reported as responsible for 31% of deaths occurred at work in 2002/2003 (see Health and Safety Commission (HSC), 2003). This study shows that the number of fatal accidents dropped from 80 in 2001/2002 to 71 in 2002/2003. However, 46% (33 out of 71) of the total fatal accidents happened with construction industry workers due to falls from heights (see Health and Safety Commission (HSC), 2003, p. 14). Furthermore, the rate of accidents in construction in Great Britain increased from 356 per 100 thousand workers in 2001/2002 to 375

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per 100 thousand in 2002/2003 (HASLAM et al., 2005). This 5% increase represents a backset to frequency rates of five years before (HASLAM et al., 2005).

In Brazil, according to DATAPREV/CAT data, between 2003 and 2006, the number of typical construction accidents increased yearly, from 22,686 in 2003 (Anuário Brasileiro de Proteção, 2006, Tab. 6, p. 26) to 27,147 in 2006 (Anuário Brasileiro de Proteção, 2008, Tab. 6, p. 34). On the other hand, it is possible to see that such increase does not mean an increase in the rate of typical accidents per 100 thousand workers, but shows prevention stagnation: (1) In 2003, the total number of workers in Brazil was 29,544,927, and the total number of typical accidents was 325,577 (Anuário Brasileiro de Proteção, 2006, Tab. 1, p. 20). Thus, it can be estimated that in Brazil in 2003, the total number of typical accidents per 100 thousand workers was approximately 1102. As in 2003 civil construction had a total of 22,686 typical accidents, it can be estimated that the sector contributed with 6.97% of the total typical accidents. Such contribution meant approximately 77 typical accidents per 100 thousand workers. (2) In 2006, the total number of workers in Brazil was 35,155,249, and the total number of typical accidents was 403,264,577 (Anuário Brasileiro de Proteção, 2008, Tab. 1, p. 28). Thus, it can be estimated that in Brazil in 2006, the total number of typical accidents per 100 thousand workers was approximately 1147. As in 2006 civil construction had a total of 27,147 typical accidents, it can be estimated that the sector contributed with 6.73% of the total typical accidents. Such contribution meant approximately 77 typical accidents per 100 thousand workers.

Therefore, the maintenance of the typical accident rate, the increase in the number of these accidents and the maintenance of the high number of deaths in the construction industry seem to put into question the evolution and adaptation of the existing actions and proposals concerning the reality of the construction industry.

The predominant principle behind the prevention proposals and/or programs is that most accidents can be avoided if due attention is given to the norms. Such principle (traditional or classical safety paradigm) has in its root the so-called "domino theory" (Heinrich, 1959), in which accidents are equivalent to a linear sequence of "dominoes", and the third domino represents "unsafe acts" and "unsafe conditions". Mitropoulos et al. (2009) point out, for example, that the current approach to prevent accidents has as basis the violation of OSHA norms and it aims at prescribing and imposing the use of protections. The violation of such norms (defenses) is called "unsafe actions" and "unsafe behaviors" (Mitropoulos et al., 2009). However, the normative approaches do not consider the characteristics of the production process or those of the work teams that influence the behavior at work and may lead to mistakes and accidents (Mitropoulos et al., 2009).

Faced with the limitations of such proposals and principles, various works point to the necessity of studies that try to model the contribution of subjacent factors to the process generator of accidents in the construction industry. Atkinson (1999) suggests that the causes of faults in the construction are not as obvious as they may seem, and that violations are a natural human tendency to improve the work condition within the context presented. Thus, it is necessary to investigate the subjacent causes of the faults, and the analysis must address the whole construction design as a system (Atkinson, 1999). The analysis of the causes of accidents in the construction industry evolve and start to consider organizational and management aspects (Suraji et al., 2001; Saurin et al., 2005; Chua and Goh, 2004; Abdelhamid and Everett, 2000; Lee and Halpin, 2003); design aspects (Gambatese et al., 2005; Haslam et al., 2005; Toole and Gambatese, 2008; Behm, 2005; Wulff et al., 1999; Hale et al., 2007; Mohamed, 2002) and cognitive aspects (Saurin et al., 2008; Mitropoulos et al., 2009).

Still, specifically in relation to design aspects, the implementation of the workers' safety during the design phase presents limitations, as not everything can be anticipated, and accidents happen in conditions not foreseen during the design phase (Hasan et al., 2003; Behm, 2005). The results of a study that investigated the way designers evaluate ergonomic criteria, which are part of the design specifications, indicate that the design specifications are subject to organizational restrictions and that, therefore, the specification does not necessarily ensure its implementation (Wulff et al., 1999). The implementation of specifications of ergonomic criteria in designs is a process of negotiation which faces various logics (Wulff et al., 1999) before going from paper to reality.

The objective of this article is to show how the improvement of the production and safety performance is possible to be achieved by means of anticipation levels (analysis of designs, planning/scheduling of services and implementation) present in the construction phase. This model of anticipation levels materializes, in an original formulation, the principle of experience return, often stated, but still little operationalized in an effective way. Based on the observation of practical examples, it shows how the performance of production and safety can be improved through the expansion of competences, by means of exchange and feedback of experiences (collaborative efforts – see, for example, Karlsson et al., 2008; Weinstein et al., 2005), and through the formalization of the possible experience in these anticipation levels (Jackson Filho et al., 2012; Fonseca and Lima, 2007).

Thus, it is presented here an inversion of the time–influence curve formulated by Szymberski (1997, Fig. 1). On the curve of Fig. 2, it is indicated that, in the design schedule, the competences to influence production and safety performance increase the closer the Design Schedule is placed in relation to the construction phase. On the other hand, it is in the construction phase that the "breaking strength" (a term borrowed from Resistance of Materials) of these competences is found (specifically at the level of work management), which may result in negative consequences for production and safety.

The conceptual model herein proposed aims at describing the management activity of the construction's production process (mainly of the construction engineer), which must integrate safety and production (quality, cost, deadlines, etc.) into the daily management of the construction's production process. The model is represented in different anticipation levels (analysis of design, planning/scheduling of services and implementation), which follow the different management stages of the construction's production process, and offers a holistic approach in order to improve

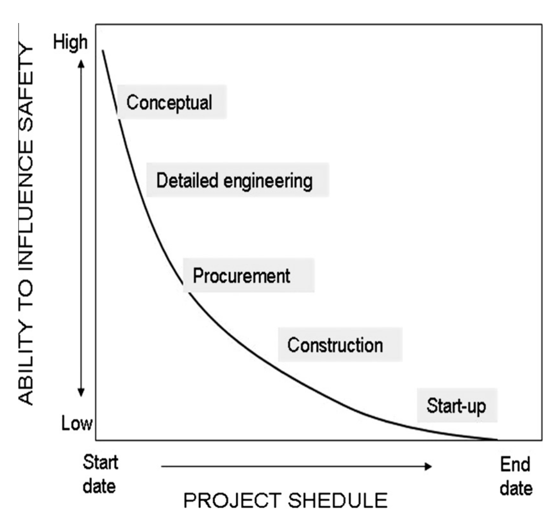


Fig. 1. Time/safety influence curve (Szymberski, 1997).

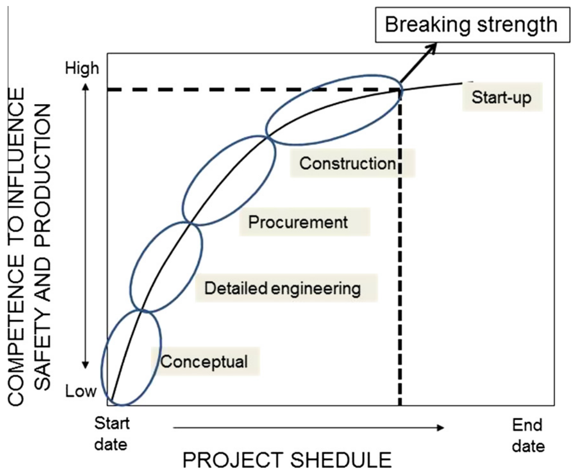


Fig. 2. Time/competence influencing the production and safety curve. Adapted from Szymberski (1997).

performance through the integration of production and safety. The results show how the constraints and responses experienced during the construction phase, in each one of the anticipation levels, may influence the improvement of production and safety. In practical terms, this model brings a meaningful contribution to integrate safety and production in a more effective way, based on the experience of the construction engineer, of the construction management team and of the execution actors (workers), overcoming some of the barriers between production and safety.

2. The limitations of anticipation and the necessity of integration between production and safety

The principle of designing considering the worker's safety is starting to be disseminated in the construction industry (Gambatese et al., 2005). It is believed that the prevention capacity is reduced when the consideration for safety is absent in the phases prior to the construction (Szymberski, 1997, p. 71). But "the production system, being the subject of the design, results from the integration of different types of knowledge and aims to perform one or several required functions" (Hasan et al., 2003, p. 156).

Facing the limitations of anticipation, one will find that the production process in the construction industry is still poorly planned in terms of design and implementation (Mohamed, 2002). In the dynamics of work systems, such as construction sites, many degrees of freedom are left out for the adaptive modification of procedures (Saurin et al., 2005). Adaptations to solve problems not foreseen in the design phase are a very important source of risks (Hasan et al., 2003).

Behm (2005) reports cases that show how conditions not foreseen in phases prior to the construction may be related to accidents. One of the cases is of a crane operator who was assigned to remove a roof near an external wall. When the section of the roof was removed, the external wall, which had not been designed to be free from the roof, fell over the crane and smashed the worker. The analysis of this accident led to the development of safety recommendations during the execution of services in the following designs. Before the demolition and removal of any structure, there must be an engineering research accomplished by a competent person to determine the state of the structure, evaluate the possibility of unintended collapse and predict a plan of potential risks (Behm, 2005).

Another case presented by Behm (2005) is about two workers who went to an industrial construction in order to repair the electrical equipment located on the roof of the building. Part of the roof had been made of a series of wavy fiberglass panels, not designed to support people's weight on top, but indistinguishable from those designed for such purpose. Thus, during the work, the workers fell through the fiberglass panels. It is possible to conclude here that the design did not allow the workers to recognize the danger, so they were unable to foresee temporary safety measures, or to use a different approach for the work. A different design would have taken into account the construction and maintenance work on the roof, specifying an adequate surface for such activities (Behm, 2005). These two cases not only point out the need to consider the situation of safe work in the design phase, but also to show the importance of experience exchange (the integration between production and safety) prior to the construction phase, with special attention to the knowledge deriving from the construction phase for the prevention of accidents.

The importance of the knowledge deriving from the construction phase is also highlighted by Toole (2002), in a study with a sample of companies in Pennsylvania, to determine if there is a common agreement about responsibilities among architects and engineers (A/Es), i.e. design professionals, general contractors (GCs) and subcontractors about safe work situation at construction sites. When analyzing the results about the capacity of each sector (A/ES, GCs and subcontractors) to control the causes of accidents, the author observes that the subcontractors, having more knowledge on construction, are evaluated as having the greatest capacity to control the causes of accidents.

Constructability is a principle that aims to integrate design and construction, and that encourages to take into consideration the construction's ways and procedures during the preliminary phase of design and planning/scheduling (Szymberski, 1997; Anderson et al., 2000; Ardit et al., 2002). The first objective of constructability is to make the execution of services easier and more profitable in the construction phase (Szymberski, 1997), but it also offers the opportunity to consider the situation of safe work in the phases prior to the construction phase (Szymberski, 1997; Weinstein et al., 2005), that is, the integration between production and safety in the phases prior to the construction phase. Supported by the concept of constructability, prevention through the design goes forward, striving from the initial phases of the design to ensure easiness along the construction. At the same time, it aims to assure the workers' safety, and to keep the construction within the budget, the chronogram and quality goals. Gambatese et al. (2005, p. 1030) point out that "recognizing the importance of the design to construction safety, the American Society of Civil Engineers (ASCE) states in its policy on construction site safety (Policy Statement Number 350) that engineers shall have responsibility for recognizing that safety and constructability are important considerations when preparing construction plans and specifications".

Due to the importance of knowledge of the construction phase in the design phase to improve safety performance (Toole, 2002; Weinstein et al., 2005; Behm, 2005; Toole and Gambatese, 2008; Chua and Goh, 2004; Szymberski, 1997), another suggested change is the development of a collaborative system (Weinstein et al., 2005). "Design changes noted by trade contractors were often implemented in the design and more frequently deemed a success in improving construction worker safety. Their involvement in the process is beneficial not only during programming, but also during detailed design" (Weinstein et al., 2005, p. 1133).

In short, the principle of prevention through the design is developed supported on the concept of constructability and participative processes, considering safe work situation from the design phase. But there is a gap between the statement of the principle of prevention through the design and its concretion into analytical models and action tools (the act of construction). It is important to remember that not all the problems can be anticipated, and many emerge in the construction phase. "There are some consequences of technology that cannot reasonably be predicted at the design phase, particularly in new technologies, using new materials and scientific principles" (Hale et al., 2007, p. 310). Thus, it is necessary to recognize the limitations of the anticipation of events (Hollnagel, 2008), for there are situations that cannot be predicted in the design phase (Behm, 2005). "To presume that implementation of the design for the construction safety concept would automatically reduce construction industry fatalities is incorrect; the concept itself is not a panacea" (Behm, 2005, p. 609).

Thinking further ahead the design phase, Attar et al. (2009) when using the concurrent engineering (CE) approach, show that design parameters can be adjusted during the construction phase, contributing to the reduction of time and cost scales. This makes it reasonable to consider that each problem (specifically of safe work situation) can also be solved during the management phase of the construction's production process, but before the execution of services, specifically in the work management level.

Thus, it is necessary to propose conceptual models that make it possible to understand how anticipation works, and how it is put into action in the construction phase, which leads us to the objective of this article: the model of anticipation levels that occur in three moments of the construction phase: design analysis, service planning/scheduling and implementation.

3. Method: an interactive approach

The purpose of this study is not to find numerical indicators, but to achieve understanding of the complex interactions that characterize the various problems which may arise during a construction's production process. Traditional approaches used in the investigations in the construction industry have led to limited advances towards the understanding of phenomena within this specialized industrial sector (Phelps and Horman, 2010). Such limitations may be overcome through specific ethnographic studies, that is, studies based on the detailed observation, in the long term, of construction sites (Phelps and Horman, 2010). In his study about the process of design in engineering companies, Bucciarelli (1996) already pointed out that there would be no pioneering in dealing with the practices of an engineering design company as a subculture, as many anthropologists and sociologists already do when studying "Organizational Culture".

Therefore, to overcome the limitations of the traditional approaches in the construction industry, Phelps and Horman (2010, p. 64) teach: "Ethnographic theory-building methods provide significant opportunities for the construction research community to address issues that in the past have been neglected due to methodological limitations. The major areas include: (1) understanding of social processes; (2) understanding the interaction between social and technical processes; (3) providing a direct link between academia and industry; and (4) linking related research areas into overarching paradigms".

Thus, aiming to overcome the limitations of the traditional approaches by means of detailed observation of a construction's production process, the results were obtained in two construction companies of a big Brazilian city, portraying the current stage of the civil construction in this country, specifically in the edification sector, which is mainly characterized by the use of concrete technology with masonry wall.

The two construction companies observed here are called A and B. In construction company A we analyzed two construction sites: the AI construction site, with 16 units of family dwelling, 9 floors and 4,316.93 m^2 of built-up area; and the AII construction site, with 36 family dwelling units, 18 floors and 8,650.95 m^2 of built-up area. In construction company B, just one construction site, BI, with 37,596.24 m^2 of built-up area and 18,348.09 m^2 of lot area, with 9 floors of commercial offices.

The data collection process occurred by participant observation, initially following the AI construction site in March, 2009. Subsequently, in July 2009, the observations were extended to the AII construction site, when the A construction company was still completing the AI construction site and was starting the implementation phase of the AII construction site. One year after beginning the observations in the A construction company (January, 2010), observations were begun also at a B construction company.

With the A construction company, the observations have were made over a two years, at two construction sites (AI and AII). With the B construction company, at the BI construction site, the observations were made over a period of approximately 6 months. At this construction site it was possible to study up until the finalization of the structure phase.

At the beginning of the observations of the A construction company, it was found that the construction engineer was the center of coordination for the production process and the decisions made at the construction site. When a problem needed to be solved, the construction engineer was sought by actors of the management team of the construction's process (master builder, foreman, etc.). This same procedure was also found at the B construction company.

At each construction site, the observations during the first three months were made systematically, three times per week, eight hours per day. After discovering that the majority of problems occurred in the morning, observations were then concentrated on that period. Depending on the context of the activities of the day, observations were made of a whole day of activities at the construction site. Also, due to be impossibility of being able to observe all activities that were carried out, when we missed a problem, we later interviewed the people involved – a way to reconstruct the continuity of events (BUCCIARELLI, 1996). Thus, a case is determined for a narrative that begins with the identification of a problem on the construction site and follows through until the solution is found, but this analysis can refer to decisions taken more distant in time and space, by going to the initial phase of the project.

Therefore, the cases were selected based on their importance for the construction engineer, his team of construction managers and/or the execution actors (workers). According to Yin (2003), a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly defined. One of its features is that it must be centered on a situation or particular event whose importance comes from what it reveals about the phenomenon under investigation.

Following these criteria, during the observations at the construction sites, by means of narratives emerged through the technique of activity analysis, it was possible to identify 25 cases (Table 1). According to Yin (2003), the traditional prejudice in relation to the case study strategy lies in the fact that it provides little fundament for scientific generalization. According to the author, the question is how one can generalize from a single case. Yin (2003) points out that, in fact, scientific facts are rarely based on single experiments, but generally on a multiple set of experiments that repeat the same phenomenon under different conditions. Analyzing multiple cases (troubleshooting stories) within several cases (construction sites AI, AII and BI) is a way to increase the power of generalization of the strategy case studies.

The search for these meaningful cases, for the understanding of the complex interactions that characterize many of the problems that may arise during the construction's production process, had as a starting point the AI construction engineer's verbalization about the need to notice the problems before they become unalterable: "When a problem arises at the site, the first step: to notice

Table 1
The cases.

Identifier	The cases	Construction firm	Construction
AI-1	The case of the fire box	A	I
AI-2	The case of the frame of the main entrance door and of the apartments' baseboards		
AI-3	The case of the excess on the pillar of the WC		
AI-4	The case of the detailing of the meeting between different materials on the building's façade		
AI-5	The case of the plaster ceiling on the third floor		
AI-6	The case of the barbecue grills in the penthouse apartments		
AI-7	The case of ceramic laying in the kitchens		
AI-8	The case of the pillar located in one of the elevator shafts		
AI-9	The case of the dimensions of the granite pieces of the façade		
AI-10	The case of concreting of slabs and beams		
AI-11	The case of the façade scaffold and the granite laying services on the façade		
AI-12	The case of the sanitary installation and the beam in one of the apartments' WC		
AII-1	The case of the confrontation of architectural and fire designs	A	II
AII-2	The case of the problem with beam 25		
AII-3	The case of service scheduling for the execution of the first garage slab		
AII-4	The case of stormwater runoff from the garage		
AII-5	The case of the minimum radius for the opening of the emergency door and the stairs landing		
AII-6	The case of plotting the construction in the lot		
AII-7	The case of the blocks excavation		
AII-8	The case of the detail of the niche over the countertop of the apartments' kitchen sink		
AII-9	The case of the two-sided staircase		
BI-1	The case of the earth retaining wall	B	I
BI-2	The case of the garage ramp		
BI-3	The case of the blocks excavation		
BI-4	The case of earth movement and the building structure services		

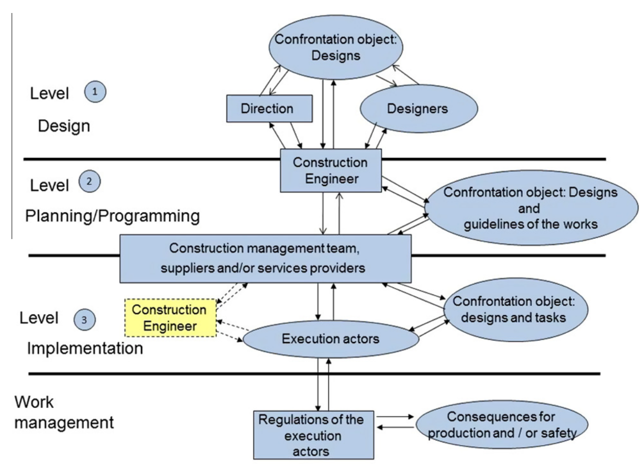
the problem before it becomes an eternal problem" (AI construction engineer). According to him, your task normally would be to manage material, manpower and designs. But, as this normalcy does not exist, he spends a great part of his day solving problems: "Normal construction engineering activity is to manage material, manpower and designs. But, what happens? Ninety percent of my day I spend solving problems" (AI construction engineer). Therefore, a case is a problem (event) that significantly affects the normal course of the production process, with important effects on the quality and functionality of the construction environment, whose solutions involve decisions made at construction sites during actual construction. Of course, not all problems solved by the construction engineer could be considered, so the cases studied were only those whose history could be reconstituted from the initial event observed directly by the researcher up until the implementation of the solution was found.

Thus, in the selection of the meaningful cases, based on the verbalization of the actors of the construction's production process (construction engineer, his team of construction management and/or actors of service execution), an attempt was made to follow Yin's teaching (2003) that each step must be carefully selected so as to: (a) predict similar results (literal replication), or (b) produce contrasting results just for the sake of predictable reasons (theoretical replication).

To find the results, after the selection of the meaningful cases, all material (narratives, interviews, verbalizations, etc.) were recorded and later transcribed. After the meaningful cases were thematically coded (type of problems and origin of problems) it was possible to build the model of anticipation levels (Scheme 1) and knowing how the constraints and responses experienced during the construction phase were confronted.

4. Presentation and analysis of results and construction of the model

For a better understanding of the cases, based on the narratives emerged from field observations, a short report of each one of the 25 selected cases will be presented hereafter.



Scheme 1. Model of anticipation levels.

4.1. Presentation of cases

4.1.1. AI construction

Case AI-1 – In the case of the fire box located in the standard floor hall, the fire design places the fire box in the same place where the architectural project had designed a frame for the ventilation duct. The construction engineer notices the problem when monitoring the beginning of the walls brick laying service. Together with the actors of his management team of the construction's production process (master builder and the foreman of installations), the construction engineer searches for a solution to the problem and finds an alternative: a space between the ventilation ducts where the pipes could run. The solution found is discussed with the designer of the fire-fighting installations and he authorizes the execution of the modification. Thus, the solution developed by the construction engineer and the actors of his management team of the construction's production process, to the problem derived by the incompatibility between designs, minimizes the problems generated for the production (delay and rework in the execution of services and rework for the designer).

Case AI-2 – In the case of the frame of the main entrance door and of the apartments' baseboards, lack of detailing in the architectural design about the meeting of the marble door surrounds of the social front door with the marble baseboard of the apartments generates difficulties in the execution of services. The baseboard is 2 cm thick, whereas the surrounds are 1 cm. The construction engineer notices the problem when monitoring the beginning of the finishing work on the first standard floor. The solution to the problem, which was chamfering the baseboard in the meeting with the door surrounds, was developed in loco by the construction engineer and the actors of his construction management team (head mason and head carpenter in charge) and workers who execute the service. However, the need to chamfer the marble baseboard during the execution of services generates improvisation (adaptations) at the work site with the use of cutting hand tools by the workers. Therefore, by giving the workers sole responsibility for the elaboration of a workstation with the available materials, the situation of safe work gets jeopardized. Thus, the solution to the problem derived from the lack of detailing in the design causes problems for the production (delay, rework and difficulty in the execution of the service), and for safety (accident risks and health risks).

Case AI-3 – In the case of the excess on the pillar of the WC on one of the standard floors, the structural design does not observe the limits in the dimensions of one of the pillars established in the architectural design. The construction engineer notices the problem when inspecting the work progress, and finds that the pillar is 15 cm outside the wall. Such excess, according to the construction engineer, is incompatible with the architectural design and the construction standard. The construction engineer and the actors of his construction management team of the construction's production process (master builder and foremen) elaborate a solution to the problem so as to avoid the demolition of the excess of the pillars. When passing the problem on to the construction firm and to the structure designer, the construction engineer also presents the way the problem could be solved without the need of demolishing the excess of the pillar. However, the construction firm's Direction and the structure designer decide for the demolition of the excess of the pillar. For the execution of the services, the structure designer elaborates the modification executive design. Once the work of demolition of the excess of the pillar starts, it is in the work management that the execution actors solve the problem concerning the working conditions for the use of the electric demolition hammers, and the safe work situation gets jeopardized. This will be seen ahead with more details. Thereby, the solution adopted by the construction firm to the problem originated by incompatibility between designs causes problems for the production (delay in the production, rework for the designer and difficulties in the work execution) and for safety (risks of accident and health risks).

Case AI-4 – In the case of the detailing of the meeting between different materials on the building façade, lack of detailing in the architectural project for the meeting of ceramic with granite causes difficulty in the service execution. The masonry foreman notices the problem and passes it on to the construction engineer as he monitors the work implementation. The construction engineer solves the problem designing an aluminum angle at the meeting point. According to him, the solution was found based on experiences in previous works. In this case, as the problem caused by the lack of detailing is immediately solved by the construction engineer based on his experience, the problem for the production (delay in work execution) is minimized.

Case AI-5 – In the case of the plaster ceiling of the third floor, while inspecting the work progress, the construction engineer notices some pendency in some services necessary to start the assembly of the plaster ceiling on the 3rd floor. For the construction engineer, failure to realize the interrelation of services (plastering the walls to a level above that of the plaster ceiling before the beginning of the plaster ceiling service) by his management team of the construction's production process (master builder, foremen, etc.) is causing pending issues from previous services. In this case, the deficiency in the execution management of interrelated services causes problems for the production (delay in the beginning of services for the execution of the plaster ceiling on the third floor).

Case AI-6 – In the case of the barbecue grills in the penthouse apartments, while inspecting the work progress, the construction engineer verifies that the execution service of the grill is stagnant. He says: "Either it is a lack of workers or it is the material that has not arrived yet." When checking the orders at the warehouse, he notices deficiency in the supply management of the requested materials from the supply sector. Some granite pieces, necessary for the assembly of the grills, had not been provided yet. Thus, the lack of material interferes in the scheduling of the service execution and causes problems for the production (delay in the conclusion of the grill assembly).

Case AI-7 – In the case of ceramic laying in the kitchens, when monitoring the service implementation, the construction engineer notices that the ceramic laying is not in accordance with what had been planned and designed. During the observations, it was possible to identify that the problem occurs due to a deficiency in the execution management of the services in charge of subcontractors, and not a matter of the workers' "wanting to invent", as the construction engineer says. The planning and the tile layout for ceramic laying were elaborated by the construction engineer together with the construction master builder and masonry foremen in the kitchen of one of the apartments. After that, the master builder and/or the masonry foremen pass the planning and the tile layout on to the subcontractors' workers. However, without proper monitoring and orientation, when the subcontractors' workers had doubts during the execution of services, they performed the services as they understood them to be right. On the other hand, the tile layout which is correct for the subcontractors' workers is not in accordance with the one which was planned and designed by the construction engineer. Therefore, the issue of noncompliance with what had been planned and designed in some kitchens generates problems for the production (rework and delay in the execution of the service).

Case AI-8 – In the case of the pillar located in the shaft of one of the elevators, the structural design does not follow the measures established in the architectural design for the elevator shafts. The thickness of one of the pillars is greater than that of the wall, which reduces the clearance dimension necessary for the installation of the designed elevator model. When analyzing the design and scheduling/planning the services in the construction phase, the construction engineer and the technicians of the company that supplies and assembles the elevators detect the problem. Later, the construction engineer says that he remembered an elevator model used in another construction that could be used with no need of making alterations to the building's structure. He passes the information on to the technicians of the company that supplies and assembles the elevators, and they confirm the possibility of altering the elevator model with no loss in its cargo capacity (number of people). The new model's only difference is in the way the door opens. In this case, the solution to the problem generated by incompatibility between designs generates a problem for the production (delay in assembling the elevator due to the need to change the model that was already at the site). But according to the construction engineer, the adopted solution minimizes the problem for the production and safety as it could have been necessary to demolish the excess in the pillar dimension and reinforce the structure.

Case AI-9 – In the case of the dimension of the granite pieces for the façade, the construction engineer designs a tile layout for the granite of the façade trying to establish the granite measures in accordance with the measures taken after leveling the substrate in which the granite will be fixed. But it is in the work management that the variations inherent to the execution of services (out of plumb, misaligned, etc.) are noticed, when they cause the need to make adjustments to the granite piece dimension (cuts in the granite pieces) during the execution of the laying work by the worker. To perform the task, the workers have the sole responsibility for setting up a workstation to cut the pieces with the materials they have available. In this way, improvisations (adaptations) are inevitable and the status of safe work is jeopardized. Consequently, it generates problems for the production (difficulties in the execution, rework in cutting the pieces and delays) and for safety (risk of accidents).

Case AI-10 – In the case of concreting slabs and beams, when analyzing the design and scheduling/planning the services in the construction phase, the construction engineer requests from the construction firm's Direction hiring the services of a shotcrete pump. However, as the construction market is hot and there is high demand for shotcrete pumps, there are difficulties in the availability of pumps on the dates when concreting is scheduled and, with the high demand, one has to pay a high price to hire this service. Thus, due to the high price, the construction firm's Direction decides to concrete the beams and slabs by transporting concrete in wheel barrels. Such decision, as expressed by the safety technician, brings negative consequences for safety (health risks and risks of accidents as a result of the workers' fatigue) and the production (delays in the execution of other services and difficulty in the execution). This occurs because, when privileging the cost of hiring a shotcrete pump, according to the construction engineer and the safety technician, in addition to the need of extra attention concerning the status of safe work as a result of the workers' fatigue, the construction engineer also has to stop all the site's activities on concreting day to have all the workers transporting concrete.

Case AI-11 – In the case of the façade scaffold and the granite laying services on the façade, at the beginning of the construction, the construction engineer and the actors in his construction management team (master builder and foremen) elaborate the assembly project of the façade scaffold. But the way in which the scaffold is placed on the façade's projection curve, which begins next to the place where granite is being laid, generates difficulties for the granite laying work. The bracing against movement at the opposite part of the scaffold installed perpendicularly to the other, at the point where the space where the granite is being laid meets the beginning of the curve projection, interferes with the worker's locomotion on the scaffold when he needs to access certain points of the granite laying. So, it is in work management that the workers notice and face the difficulties imposed by the working condition (difficulty in displacements and in the access to certain laying points) and improvise (adapt) forms of access. Thus, the situation of safe work gets jeopardized. Therefore, this situation generates problems for the production (difficulty in the execution and work delays) and safety (risk of accidents).

Case AI-12 – In the case of the of the sanitary installation and of the beam in one of the apartments' WC, the structural design, when designing the beam in the middle of the bathrooms space, creates interference in the pathway of the pipes that connect the sanitary appliances to the downpipe. When monitoring the beginning of the work, the construction engineer learns about the problem, which has been noticed by the foreman and the workers who install the pipes. In order to solve the problem, the construction engineer increases the ceiling's recess, thus allowing the pipes to pass under the beam, though it leads to a little loss in the ceiling height. Thus, the problem for the production (delay in the work execution) is minimized.

4.1.2. About construction AII

Case AII-1 – When confronting the architectural and the fire designs, when analyzing the designs before the beginning of the construction, the construction engineer finds some incompatibilities between them and passes them on to the architect for correction. When the incompatibility problem between designs is anticipated before the beginning of the construction, the problems for the production are only in the design (rework by the designers to achieve compatibility between the projects), that is, they do not reach the service execution phase.

Case AII-2 – In the case of the problem of beam 25, the construction engineer detects the incompatibility problem when he analyzes the structural design and schedules/plans the services in the construction phase. For the construction engineer, the fact that the structural design includes a beam in the middle of the balcony slab is an uncommon situation. This abnormality, which is far from the more traditional and simple ways (at the end of the balcony slab), will make difficult the execution of future services of fitting the plaster ceiling. Thus, based on his experience, when mentally designing the services of the plaster ceiling, the construction engineer resorts to the architectural design and verifies that, unlike the structural design, in the architectural design the beam had been designed at the end of the balcony slab. The construction engineer passes the problem on to the structural designer, who corrects the problem. In this case, the anticipation of the problem by the construction engineer, based on his experience in past constructions, allows for the correction of the problem before the execution of the services, and the problem for the production will be only in the design (rework of project alteration by the structural designer).

Case AII-3 – In the case of scheduling the services for the execution of the first slab garage, the fact that the telephone design does not consider the ventilation duct places the pipes of the telephone design and the projection of the ventilation duct in the same position. The construction engineer notices the problem when, together with the master builder, he analyzes the design and programs/plans the services in the construction phase. The construction engineer solves the problem by designing the telephone pipes pathway beside the ventilation duct. He consults the designer about the problem and the solution, and the designer authorizes the alteration. Thus, the solution to the problem, elaborated by the construction engineer, does not generate problems for the execution of services, and the problem for the production is only in the design (rework for the design of a new pathway for the telephone pipes).

Case AII-4 – In the case of stormwater runoff from the garage, the construction engineer notices the problem when, together with the master builder, he analyzes the design and programs/plans the services in the construction phase. For the construction engineer, the design for the stormwater runoff in the garage levels, with drains and pipes, does not properly meet the reality of use as the sand coming from the cars clogs the drains and pipes. According to reports from the construction engineer, from his experience in previous constructions, the clogging of drains and pipes by sand coming from the cars had already made him replace, after the construction phase, the drains and pipes by channels with iron grates. In this way, the solution to the problem, based on the construction engineer's experience, will not generate a rework problem after the end of the construction phase, and the problem for the production is only in the design (rework for the design of a new project using channels and iron grates).

Case AII-5 – In the case of the minimum radius for the opening of the emergency door and the stairs landing, the structural designer, failing to observe that in the architectural design the landing on the standard floor was different from the ground floor, designs the stairs with one more step, thus reducing the minimum radius in the landing necessary for opening the emergency door (according to Fire Fighting Norms). The construction engineer notices the problem when monitoring the beginning of the work of brick laying in the stairs hall. To solve the problem, the construction engineer fills the exceeding step with concrete, thus expanding the landing and reaching the minimum radius demanded by the Norm, and minimizing the impacts the problem could have caused once the stairs had already been concreted. In this case, the incompatibility between the designs generates problems for the production (rework and delays in the service execution), which are minimized by the solution elaborated at the construction site by the construction engineer.

Case AII-6 – In the case of plotting the construction in the lot, the structural design does not follow the architectural design in relation to the position of the axel of the first row pillars on one of the sides of the building. On this side there was no perpendicularity between the streets, and the structural designer, failing to observe the architectural design, designs the axel of the first row pillars parallel to the street curb. When monitoring the implementation of the service, the construction engineer learns about the problem, which had been noticed by the master builder during the positioning of the site. Once the existence of the problem is confirmed, the construction engineer passes it on to the structural designer to correct the positioning design. To correct the design, the positioning service is paralyzed. This problem, therefore, generates problems for the production (delay for the beginning of the construction works and rework for the structural designer).

Case AII-7 – The case of the block excavation serves to make evident the moment when, monitoring the beginning of the service, the master builder and the workers get together in the analysis of the work situation to determine the best way to execute the service. In this case, at implementation level, the workers count on the participation of the master builder for the elaboration of the work plan and, instead of a handwinch (as in case BI-3 of the block excavations in construction BI), the work plan elaborated by the foreman uses intermediate platforms, influencing the situation of safe work and the production performance (more details will be discussed further ahead). Therefore, by putting into practice the foreman's experience before and during the works, one can prevent lending the workers sole responsibility for the working conditions, and improve production and safety performance.

Case AII-8 – In the case of the detail of the niche over the countertop of the apartments' kitchen sink, when inspecting the service progress, the construction engineer notices that the head worker is having difficulty in interpreting the detail in the design and in executing the service. Then, this situation generates problems for the production (difficulty in the execution and delay). So, the construction engineer explains and orients the worker (in loco) about how the detail should be.

Case AII-9 – In the case of the two-sided staircase, the subcontractor's carpenter is helped by the master builder who, when inspecting the service progress, notices that the worker has difficulty in interpreting and executing what was designed. The stairs are different from those usually executed (where only the floor part is in the shape of steps), as the lower face (ceiling) is also in the shape of steps. Thus, as the worker has no experience with this type of stairs, the situation generates problems for the production (difficulty in the execution and delay). Putting his experience into practice in the solution of the problem, the master builder explains to the carpenter how to do it, and they think together about the best way to execute the stairs.

4.1.3. About construction BI

Case BI-1 – In the case of the earth retaining wall, simultaneity between the execution of the design of the building's foundation and the execution of the retaining wall services generates rework during the execution of the foundations. When monitoring the beginning of the foundation services, the construction engineer notices, at certain points, intercessions between the wall base and the foundations. For the construction engineer, this simultaneity makes the planning of the service execution inadequate, and makes it necessary to demolish the base of the wall where there are intercessions. According to the construction engineer, the problem could have been avoided if, at the intercession points, the foundation services had been executed before the wall base. Thus, due to the peculiarity of the interrelation of services, simultaneity between the elaboration of the designs and the execution of certain services generates problems for the production (rework and delay in the execution of services) and for safety (risk of accidents and health risks). To break the concrete of the earth retaining wall base with the electric demolition hammers, the workers, besides wearing masks and ear protectors due to the health risks that the work causes, are also subjected to vibrations (exposure to vibrations can be physically harmful or cause disorders in the nervous system). However, no type of follow up or elaboration of procedures or articulation with the workers is verified on the part of the managers of the construction's production process (specifically the safety actors) for the control of risks from the electric demolition hammer vibration during the service execution.

Case BI-2 – In the case of the garage ramp, the construction engineer realizes the problem when monitoring the beginning of the formwork service in the garage ramp. Failing to observe the minimum height for the circulation of certain vehicles (SUVs and trucks, for example) usually recommended for vehicle ramps in commercial buildings, the architectural design generates incompatibility between design and use. The construction engineer stops the work and passes the problem on to the designer. As there is space between the lot limit and the garage's entry point where the height is lower than necessary, the solution to the problem, elaborated by the designer, is to lengthen the ramp so as to reduce its inclination and increase the height where the problem lies. In this way, the incompatibility between design and use generates problems for the production (delay in service execution and rework for the designer).

Case BI-3 – In the case of block excavation, it is at work management that the workers solve the problem of failure in the design and/or of orientation for the execution of the work platform. In this case, as the workers have sole responsibility for the execution of the work platform, they build it with the materials they have available at the construction site, that is, improvising or making adaptations. The situation of the structure of the work platform calls the attention of the safety technician, who notifies the construction engineer. During the interview with the construction engineer on the subject, it is noticeable that his perception of risk is on the workers' behavior and on some norms that should be followed (placement of guardrails, of a baseboard to prevent material from falling, etc.). He does not refer to the elaboration of a design for the structure of the work platform. He also claims that the situation comes to his attention only after he is notified by the safety sector. In this case, as there is no report of complaints concerning the production, the situation is considered to generate problems only for safety (risk of accidents).

Case BI-4 – In the case of the earth movement and the building structure services, it is at work management that the execution actors notice and solve the problem. In this case, at certain moments, the machines that make the earth movement and the workers that make the structure share the same space. Deficiency in the management of service execution, that is, of the conflicts concerning the services performed at the same time in a restricted area, contributes with the emergence of regulatory actions by the workers of collective and individual synchronization between the works being executed. In this case, workers' complaints are frequent regarding production problems (delay and difficulty in the service execution) as well as safety problems (risks of accidents with the machines that make the earth movement).

4.2. Correlating the cases, the types of problems and the origins of the problems

Based on the reports above, in order to provide a better visualization of the types and origins of the problems, with the exception of case AII-7 that does not generate problems for the production or safety, we present: (a) in Table 2, the cases that generate problems for the production, the types and origins of the problems; (b) in Table 3, the cases that generate problems for safety, the types and origins of the problems.

When analyzing Tables 2 and 3, it is also possible to find that the cases of deficiency in work management (Table 3) present problems originating from previous factors.

4.3. Model of anticipation levels

The presentation and report of cases also make possible the conduction towards a path of analysis and construction of the model of anticipation levels. During field observations, the AI construction engineer reports that, in order to manage the construction process of a building and notice the problems, his main support tools are the designs, the budgets and the planning. He says: "The design is the starting point. It is based on the design that I can estimate the amount of material and work necessary, as well as the services to be implemented. So you get the given design and calculate the amount of work to be done" (AI construction engineer).

Table 3
Cases that generate problems for safety, problem types and origin.

Cases	Problem types	Origin of problems
AI-2	Risk of accident; Health risk	Deficiency in work management
AI-3	Risk of accident; Health risk	
AI-9	Risk of accident	
AI-10	Risk of accident; Health risk	
AI-11	Risk of accident	
BI-1	Risk of accident; Health risk	
BI-3	Risk of accident	
BI-4	Risk of accident	

Therefore, as the design is the starting point for the construction engineer to manage a building's construction process, it is possible to prioritize the perception time of problems and their respective anticipation levels at the construction phase (Table 4). In this case, in an attempt to systematize the perception of problems in the anticipation levels of the construction phase, in Table 4 only 21 cases are reported. In item 4, it is possible to verify that cases AI-9, AI-11, BI-3 and BI-4 are only perceived during the action, at the work management level, that is, after the anticipation levels.

(a) Level 1 (design) – it corresponds to the time at the construction phase when the construction engineer analyses the designs (executive and complementary), before the beginning of the construction.
(b) Level 2 (service planning/scheduling) – it corresponds to the time at the construction phase when the construction engineer and his construction and/or suppliers and/or service providers management team analyze the designs and plan/schedule the services, before moving on to the implementation level.
(c) Level 3 (implementation) – it corresponds to the time at the construction phase when the construction and/or suppliers and/or service providers management team and the execution actors (from the construction firm or subcontractors),

Table 2
Cases that generate problems for production, problem types and origin.

Cases	Types of problems	Origin of problems
AI-1	Delay; Rework	Incompatibility between projects
AI-3	Delay; Rework; Difficulty in execution	
AI-8	Delay	
AI-12	Delay	
AII-1	Rework	
AII-2	Rework	
AII-3	Rework	
AII-5	Delay; Rework	
AII-6	Delay; Rework	
AII-4	Rework	Incompatibility between design and use
BI-2	Delay; Rework	
AI-2	Delay; Rework; Difficulty in execution	Failure in project detailing
AI-4	Delay	
BI-1	Delay; Rework	Simultaneity between execution and project
AI-7	Delay; Rework	Deficiency in the management of service execution
AI-5	Delay	
BI-3	Difficulty in execution	
BI-4	Delay; Difficulty in execution	
AI-11	Delay; Difficulty in execution	
AII-8	Delay; Difficulty in execution	Difficulty in the interpretation and execution of what was designed
AII-9	Delay; Difficulty in execution	
AI-9	Delay; Rework; Difficulty in execution	Inherent unpredictability of the dimension of what was designed
AI-6	Delay	Deficiency in supply management
AI-10	Delay; Difficulty in execution	Unsuitable constructive technology

Table 4
Cases, perception times and anticipation levels.

Identifier	Perception time	Anticipation levels
AII-1	Analyzing the designs before starting the construction	Level 1(design)
AII-2 AII-3 AII-4 AI-8 AI-10	Analyzing the designs and service planning/scheduling at the construction phase	Level 2 (service planning/scheduling)
AI-1 AI-2 AI-12 AII-5 AII-7 BI-1 BI-2	Monitoring the start of the service	Level 3 (implementation)
AI-4 AI-7 AII-6	Monitoring the implementation of the service	
AI-3 AI-5 AI-6 AII-8 AII-9	Inspecting the progress of the service	

with or without the participation of the construction engineer, analyze the designs and the tasks for the execution of the services as established at level 2.

But the results also show that, if the cascade effect of the 3 (three) anticipation levels do not work properly, the regulations of the execution actors (workers) during the execution (work management) are the last resort for the solution of problems, and they may or not generate consequences for the production and safety.

Based on this analysis, it is possible to build a path for the contribution of all participants in a construction's production process, which we have named model of anticipation levels (Scheme 1).

5. Discussing and validating the model

The results show that the management of the construction's production process unfolds in a continuous way, going beyond the discrete nature of managing what had been previously determined based on the designs, on the planning and the budget. It is framed by a series of time windows corresponding to the several stages of the construction phase.

The coherence established among the many moments of perception of problems at the construction phase is a sequence of actions concerning the same type of caution (as expressed by the construction engineer: "to perceive the problems before they become an eternal problem"), in accordance with written prescriptions and/or established rules, whose application is under the construction engineer's control.

5.1. Analyzing the trajectory of the general case: the case of excess in the WC pillar in construction AI

In order to discuss and validate the model, framed by a series of time windows corresponding to the several stages of the construction phase, initially we chose a general case that pervades all the problem time windows and allows for similar results to be found in other construction sites.

Analyzing Table 2, it is possible to find that 15 cases (AI-1, AI-3, AI-8, AI-12, AII-1, AII-2, AII-3, AII-5, AII-6, AII-4, BI-2, AI-2, AI-4, BI-1 and AI-9), of the 23 cases that generate problems for the production, are related to problems in the design, that is, 65.22% of the cases that generate problems for the production have their origin in problems in the design.

In Table 3, as previously pointed out, it is possible to verify that, in all the 8 cases with problems for safety, the problems have their origin in factors previous to the level of work management, that is, 100.00%. Among these cases, 4 have origin in problems in the design, therefore, 50.00%. Incompatibility between designs is the root of the problems in 9 (60.00%) of the 15 cases related to problems in the design.

The case of excess in the WC pillar of construction AI (AI-3) is a problem related to the design, whose root is the incompatibility between designs (Table 2). In Table 3, it is still possible to verify that the case of excess in the WC pillar of construction AI (AI-3) is also one of the cases that generate problems for safety.

Therefore, the analysis of case AI-3 makes it possible to evidence and understand the trajectory of the constraints and the responses that occur at the anticipation levels within a construction's production process, and to predict similar results in other construction sites.

Initially, the problem of the excess in the pillar was not realized at level 1 by the architect responsible for compatibility, nor by the AI construction engineer or the construction firm's Direction. At level 2, the construction engineer also does not notice the problem at the planning/scheduling level. The problem of excess in the pillar is only perceived at level 3, implementation, during the inspection of service progress by the construction engineer, who noticed that the pillar exceeded the wall in 15 cm, which was aesthetically incompatible with the architectonic design, besides, according to him, giving a sensation of reduction of the WC.

The construction engineer and his team look for a solution to the problem. The solution found is to align the masonry with the pillar and move 15 cm in the other walls, which would result in a 15 cm reduction in the closet dimension (Fig. 3). However, acknowledging his limitations, the construction engineer transmits the problem and his solution to the construction firm's Direction.

The solution of the construction engineer and his team is not accepted by the construction firm's Direction who, together with the structural designer, chooses to demolish the excess in the pillar (Fig. 4).

Since the work starts by demolishing the excess in the pillar, the analysis shows that failure in considering how the work will be performed, at the three anticipation levels, means that the strate-

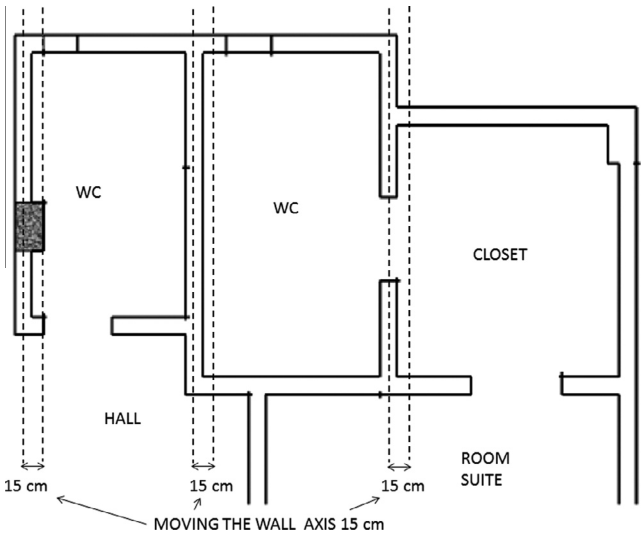


Fig. 3. Solution by the construction engineer and his team.

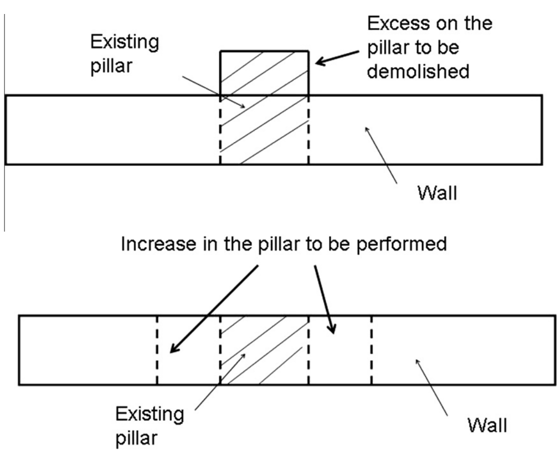


Fig. 4. Solution by the firm's Direction and the designer.

gies for the service execution will occur at work management level through individual or collective regulations of the execution actors (Scheme 2).

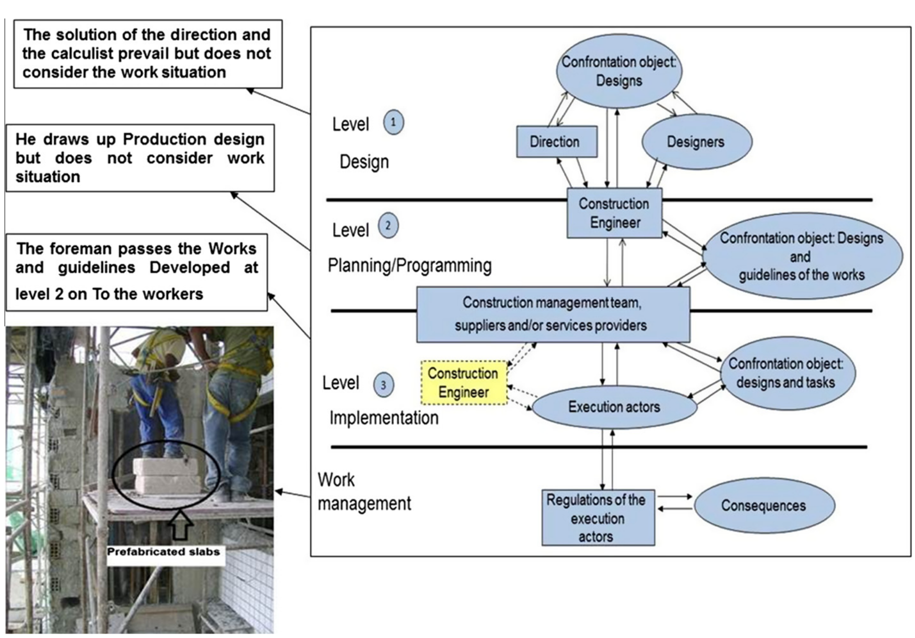
During the demolition of the excess in the pillar, so as to be able to use the electric demolition hammers, the workers need to develop work methods in order to deal with the difficulties found and make the service easier. As they do not have much space inside the WC to work with the electric demolition hammers due to the existing supports (Fig. 5), they have to work outside the building, using an external scaffold. However, the work platform is not high enough. So they had to improvise: they used prefabricated slabs found at the site, and put them onto the work platform of the external scaffold to reach the desired height (Scheme 2).

It becomes clear that failure in considering how the work should be performed, especially in relation to the situation of safe work, at the three anticipation levels, turns the work management the last regulation resort. When the workers are left with the sole responsibility for the situation of safe work, the competence levels, which could be expanded by the participation of the other actors of the construction's production, are weakened, and the workers get more exposed to risks of accidents, in addition to a reduction in productivity.

In this case, at level 1, an alteration design is elaborated, but the conditions for performing the work are not anticipated. At level 2, service planning/scheduling is developed by the construction engineer and the actors of his construction management team, but the working conditions are also not anticipated or discussed. At level 3, the plan and the tasks for the execution of services are discussed, but without duly anticipation or guidelines of the working conditions, specifically in relation to the situation of safe work. In this way, at work management, the individual or collective regulations of the execution actors are the last resort for the viability of the working conditions and the situation of safe work for service execution.

5.2. Validating an effective intervention that expands the competences at work management level

After the analysis of the general case, validation of the model as an effective intervention, which expands the competences and prevents individual and collective regulations of the execution actors



Scheme 2. Anticipation levels and working conditions.

Fig. 5. Supports in the WC.

Fig. 6. Excavation of blocks in construction BI.

from being the last resort or viability of the working conditions for the execution of services, is based on case AII-7. This case shows how the exchange and feedback of experiences before the work management level result in improvement of performance of the construction's production process and of the situation of safe work.

In case AII-7, it is possible to verify that the excavation of large blocks is done differently from what is seen in construction BI, case BI-3 (a commonly used method in a variety of constructions). In case BI-3, the excavations are done by means of a type of hand-winch on wooden work platforms (Fig. 6). This wooden platform is built by the workers with materials available at the site, without

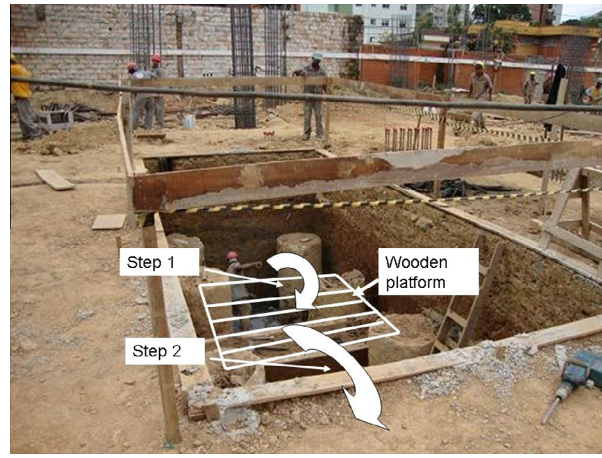


Fig. 7. Excavation of blocks in construction AII.

the participation of the construction engineer and/or his team of management of the construction's production process. However, in case AII-7, the excavation of blocks shows, at the implementation level, the attention paid by the master builder during the planning of the work to be performed. Facing the work situation to excavate large blocks, he uses a work plan with intermediate platforms. As the master builder explains: "The solution is as follows: when you have a hole too deep for the workers to throw out the material, you divide the hole, excavate on one side and throw the material to a wooden platform at a higher level (step 1). The worker on the higher wooden platform will throw out the material (step 2)" (Fig. 7). When interviewed about the plan for the excavation of blocks, the construction engineer reports that this plan has been developed by himself and the master builder in previous constructions: "It comes from experience and is largely used in mining". It is noteworthy that the master builder and the construction engineer had been working together for 15 years. On the other hand, we verified that this practice is not explicit or widespread at the construction firm.

In practical terms, the example describes how the constraints and the responses experienced by means of experience exchange and feedback, at anticipation levels of the construction phase, allow for improvements in the production and safety as they expand the competences at these anticipation levels and, later, at the work management level.

6. Conclusion

In this article, we suggest a model of anticipation with a cascade effect, capable of adjusting the design, the production planning and scheduling during the construction phase, and of improving production and safety performance.

The results allow the establishment of relations between the anticipation levels in the construction phase and the improvement of production and safety performance. Likewise, they are consistent with the importance of the experiences of the actors involved in the construction's production process. The key issue of the proposed model is to promote exchange, return and sharing of experiences (collaborative effort) among the anticipation levels in the construction phase, organized in such a way that they feed one another.

In this system, the construction engineer takes a fundamental mediation role between the design phases and the changeable realities in the construction phase. He not only transmits information to the designers, but also, together with his management team of the construction process, contributes for the expansion of competences, for the anticipation of problems at the project, planning/scheduling and implementation levels, and reduces the possibilities that the workers' competences, at the work management level, be the last and only resort for the solution of problems and the breaking point of these competences. As seen in case AII-7, in previous constructions, the construction engineer and the master builder anticipated the problems of the working conditions for the excavation of blocks and, based on their experiences, they elaborated a work plan with intermediate platforms. Thus, in construction AII, the experience exchange and feedback before the level of work management expand the competences and prevent individual and collective regulations of the execution actors from being the last and only resort for the viability of the working conditions and the situation of safe work for service execution.

Therefore, the study reveals that the construction's specificities increase the uncertainties that emerge from the prescriptive tools (designs and schedules), and the problems are solved in the construction's "heat of the moment". Case AI-3 shows the trajectory of these problems. Case AII-7 positively demonstrates how effective experience exchange and feedback are to improving production and safety performance.

Although these results are mainly focused on the construction engineering activity, their contribution also extends to the design phases, avoiding the retrospective biases that obstruct effective improvements. Some cases already had happened in other construction sites, showing that problems could be avoided in the project phases when applying experience at the construction site. The "executers" (construction engineer, construction management team, execution actors and others) should therefore participate in the project phase. This will allow expanding the capacity of anticipation and increase the effectiveness of the project regarding safety and production.

Designs and planning/scheduling, evidently, can and should be improved, as this is one of the conditions for the improvement of production and safety performance. However, we propose that adjustments to the designs and to planning/scheduling also take place during the construction phase, and that they should not be the sole responsibility of designers and engineers closed in their offices. Such adjustments should be based on the experience of the actors involved in the construction phase (especially the workers), who also offer creative solutions and make the project and planning/scheduling closer to real, specifically in relation to the situation of safe work.

So, as a continuation of this research, actions that can be taken in an aim to solve these problems, we are suggested:

- analyzing and to understanding the construction engineering activity when managing projects and the remaining elements of the production process of building (material, labor, equipment, suppliers and others);
- understanding the design process of an architectural "object" through examination of the course of action of designers in the situation, in order to identify key moments to use feedback from life experience at construction sites;
- identifying which characteristics of practical knowledge from each designer (architects and engineers) involved in the design process that can influence constructability of the project;
- developing procedures for feedback of experience and participation of executers in the project phase, favoring the constructability of the project and strengthening specific criteria for design of safe work situations in future projects.

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