



Protection of interrupted concrete structure to prevent degradation: a case study

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Abstract

In interrupted concrete structures is fundamentally relevant to adopt protective measures, which purpose is minimizing degradation to ensure project life cycle, in addition to subserve a future construction resumption. In this context, this paper presents a case study of prestressed and reinforced concrete structures, located in Foz do Iguacu, Paraná, Brazil, whose execution was interrupted in 2014. At that time, the constructions were in superstructure execution phase. With an area of 155,000 m² and investment of \$ 31 million, the constructions belong to Brazilian Federal Government and are destined to Federal University of Latin-American Integration (Unila) installations. It was observed that performed protection works were mainly related to exposed reinforcement protection, waterproof and protection of structures in contact with soil, and drainage services execution. The protection costs were approximately 1.4% of investment value, following the Sitter's "Law of fives". Thus, the technical and economic importance of protective measures adoption in concrete structures that had their works interrupted is noted, so that the case study serves as a model for other buildings in same situation.

Keywords Protection systems · Durability · Service life · Preventive maintenance (PM) · Cost

1 Introduction

The development of new construction processes, building materials and technologies has encouraged the construction of more economical buildings. However, the high competitiveness in the construction sector and the need to reduce production costs have negatively influenced the quality of

buildings constructed in Brazil in recent years. It is common to find buildings with high level of degradation than expected, quality and durability problems due to execution failures and pathological manifestations that affect aesthetics, usability, safety and service life [1].

Durability is "essentially a retrospective view on the performance of a structure" [2]. It is an ability of a concrete structure, not only a constitution material property, being "given" from project design to maintenance of a concrete structure, involving the correct materials selection [3]. Durability problems can be present in finished and interrupted concrete structures. An interrupted or unfinished structure is defined as a construction that has been temporarily or indefinitely paralyzed due to financial, judicial or environmental problems. According to a survey conducted by the National Institute for Business Recovery (INRE), in 2016, there were 5.200 interrupted constructions in Brazil, which 50% of them were public, 30% were public-private and only 20% being completely private [4].

During the 2000s and extending to middle of 2014, Brazil experienced a wave of economic development, evidenced by positive variations in Brazilian Gross National Product (GNR) (except in 2009, because of US economic crisis) [5]. In the same period, between 2003 and 2014, 18 new federal

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universities were created, and the release of programs such as “Growth Acceleration Program” were launched, which includes social, urban, logistics and energy infrastructure, promoting the growth of public constructions in the period [6, 7].

All growth process that Brazil was going through was reversed in 2014 due to a heavy economic crisis, causing a 0.5% growth in Gross National Product (GNR) that year, and a 3.77% and 3.60% reduction in 2015 and 2016, respectively [8]. Moreover, in 2014, the “Lava Jato” operation was released by Federal Police [9], which was responsible for money laundering dismantling, discovering of active and passive corruption schemes and identification of overpriced contracts in public buildings. Due to ongoing investigation and overbilling discoveries, many public constructions were paralyzed, whereas a parcel of responsible construction companies were involved in the investigation [10, 11]. In addition to these issues, constructions such as Federal University of Latin American Integration (UNILA) were paralyzed due to contract breach of winning bidding consortium, which alleged problems in projects that prevented execution in the stipulated price.

In general, these interrupted or paralyzed constructions are subjected of favorable environmental conditions for building materials deterioration over time, being necessary to make protective and preventive maintenance actions to facilitate their resumption, ensuring the design service life (DSL), whose theme is the object of this study.

2 Degradation × maintenance

The appearance of pathological manifestations is inherent in the constructive process. Buildings are not identical to others due to the occurrence of variations in construction processes and their circumstances, such as weather variations that could affect concrete curing or some material substitution for an apparently identical one [12]. Such factors directly affect the durability and service life of concrete structures and/or their parts [13, 14].

Durability of concrete structures is a theme that has been gaining importance over the last decades due to concern related to structures premature degradation, mainly caused by the corrosion in reinforced concrete structures [15]. Köliö et al. [16] point out that during the DSL, a structure must confront external actions, such as weather, which should be durable enough to avoid repairs costs outside maintenance plan. In a study carried out in 52 Spanish provinces, the *Spanish group of hormigón* (GEHO) found that among the different pathological manifestations observed, reinforcement corrosion had the third highest occurrence rate. In total, 844 cases were raised, and corrosion was present in

15% of manifestations [17]. In addition, structures present in marine environment have higher potential of reinforced corrosion than other environments, due to high chloride diffusion incidence, verified in Bayuaji et al. [18], Possan et al. [19] and Shekarchi [20] studies.

One of the problems related to corrosion is cementitious materials carbonation. This phenomenon is responsible for causing reinforcement despassivation and, consequently, degradation and reduction of reinforced concrete structures service life [21–23]. In this sense, the concrete immersed reinforcement needs preservation against carbonation, which decreases structure’s pH due to reaction of carbon dioxide (CO₂) with hydroxides contained in cementitious concrete matrix, providing the reinforcement corrosion [24, 25]. Besides, chlorides and sulfates exposure, atmospheric pollution, freezing and thawing, and alkali-aggregate reaction also cause concrete and/or reinforcement deterioration [26].

Corrosion caused by carbonation can be minimized by inhibiting products whose use principles are a thin film formation on the steel surface or the corrosive agent’s immobilization to prevent reinforcement degradation [23]. An application of anti-carbonation coatings (elastomeric and thick), water repellent and chemical resistant coatings are some other possible solutions to act as a barrier against the aggressive agent [27, 28] and can be used as protective measures.

In reinforced concrete structures, steel protection begins in the design with materials selection (stainless steel, for example), continuing in execution (guarantee of the cover thickness, water/cement ratio control, concrete curing, etc.) and continues during the service life with maintenance, repair or recovery actions [26]. More attention should be paid to the proper management of infrastructures that essentially depend on public funding, and to the development of engineering solutions that provide confidence in the future infrastructure provision [29]. Main pathological problems present in concrete structures come from failures in conception, design, and execution stages.

Therefore, to prevent or minimize pathological manifestations appearance, structure protection must be present at all stages of construction (from design to maintenance), in order to reduce costs and guarantee the service life. Sitter [30] reports that intervention costs to fix pathological problems increase progressively during the time, so that structure repairability costs increase in geometric progression with ratio 5, as a function of decision-making time Fig. 1. For this reason, his law is known as “Law of Fives”.

According to Sitter [30], when the construction of a structure is interrupted, some technical care (structure protection activities, waterproofing and drainage, among others) must be taken in order to reduce costs and minimize (or eliminate) failures when the construction restarts.

In this sense, this paper presents a case study aimed to protect a set of reinforced and prestressed concrete structures

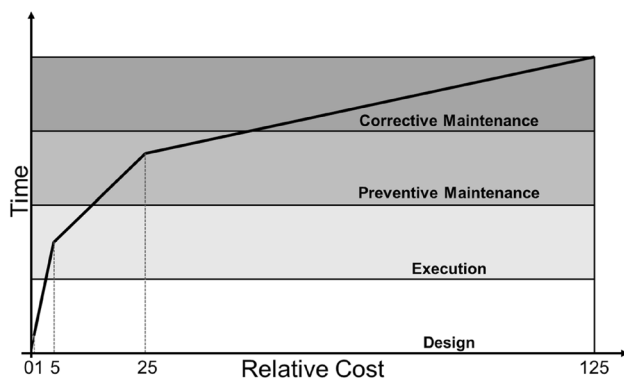


Fig. 1 Sitter law or law of evolution of maintenance costs [30]

that were discontinued in 2014, in order to demonstrate the importance of the measures adopted in view of the benefits obtained, especially in reducing or minimizing pathological manifestations. This paper also aims to ensure safety of the structure conditions in a future work resumption process.

3 Case study

3.1 Description of the structure

This case study approaches preventive maintenance actions carried out at Federal University of Latin American Integration (UNILA) interrupted construction, located in Itaipu Hydroelectric Dam security area perimeter, in Foz do Iguaçu, Paraná, Brazil Fig. 2.

At the end of its implementation, the university project Figs. 3, 4 will total 155,000 m² of gross construction area Table 1, as well as a parking area for vehicles and walkways that interconnect all buildings, which will have capacity to serve approximately 10,000 students.

The university campus first stage construction provided partial or total construction of central building (Figs. 5, 6), classrooms building (Figs. 7, 8), restaurant (Figs. 9, 10), utility center (CUT), utility gallery and part of general deployment (such as parking lots and access). The other global project buildings listed in Table 1 would be completed in a second stage.

3.2 General features from the project

The interrupted main structures Table 1 were made in a mixed construction system (reinforced and prestressed concrete) with ribbed slabs. The characteristic concrete strength (f_{ck}) is 50 MPa for central building columns and 35 MPa for other structural elements. At the construction end, the concrete will not be coated (apparent concrete structure).

3.3 Construction history

The Unila's architectural project was developed by Architect Oscar Niemeyer between 2009 and 2010 and it was donated to UNILA, in implementation at that time, by Itaipu Hydroelectric Dam. The university campus construction was divided into stages Table 1. In July 2011, the first stage works were initiated by Brazilian Federal Government with a total of 380,700 m² construction area. However, in 2014 the buildings were paralyzed by the consortium responsible.

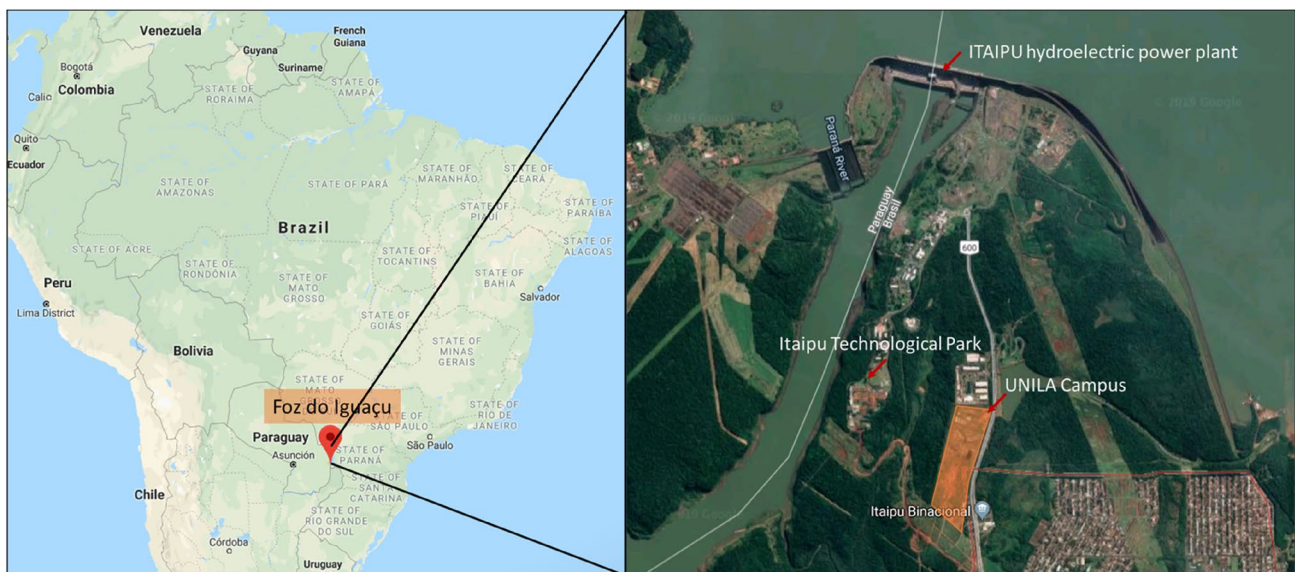


Fig. 2 UNILA campus location [11]

Fig. 3 UNILA campus general design [31]

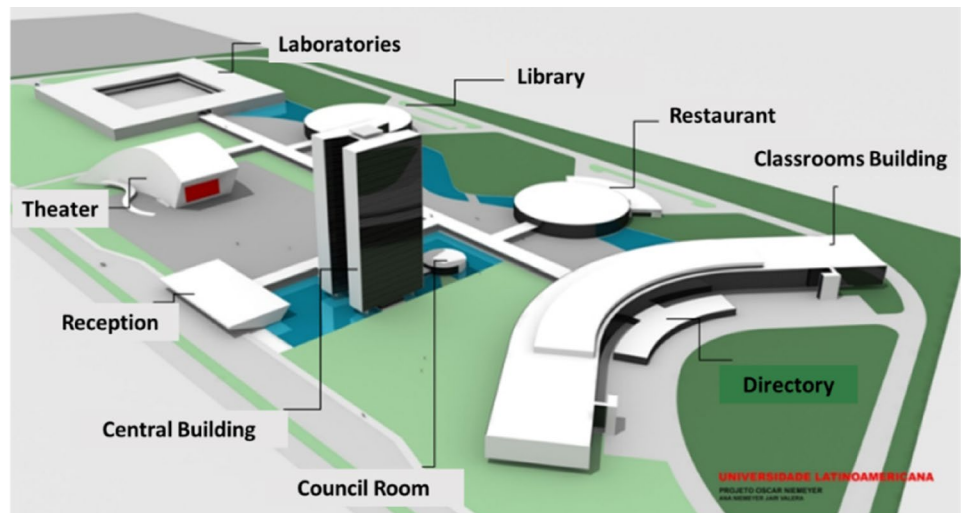


Fig. 4 UNILA campus overview [31]

Since then, the University's technical staff has been conducting studies and negotiations with the competent agencies to resume the works, whereas the University has not had its own installations until nowadays. Electoral uncertainties in 2014, Ministerial transition in 2015 and the country economic crisis in recent years have corroborated for services in conclusion.

In this context, the concern of the University technical engineering staff with the maintenance of the structures already executed ascended, aiming at guaranteeing their durability until the future construction resumption. As a result, in December 2016, a 10 months maintenance contract was signed for four hundred and thirty-four thousand dollars (\$ 434,000.00). The objective was ensuring protection against deterioration of buildings already built and the consequent damage to State Treasury. The results of this work are presented in this study.

3.4 Data survey

The data used in the study were obtained from Federal University of Latin American Integration (UNILA) in official documents used for structure protection services, especially electronic trading No. 3/2016—contract agreement 71/2016 [31].

4 Structures protection

4.1 Maintenance actions

The main protection services performed in respective structures are described in detail in Table 2. In addition to the services, other activities were also made, such as: (i) landfill of galleries and the "Technical Utilities Center", (ii) central building provisory slab construction; (iii) finalization of underground structures (galleries and technical utilities center).

Through the technical study developed [31], it was defined the essential services to minimize deleterious actions of construction structure, namely:

- (a) achievement of mud cleaning and removal services;
- (b) waterproofing execution and recovery of systems already made;
- (c) drainage services execution: construction of deep drainage wells in central building region, and others listed in Table 2,
- (d) exposed reinforcement protection (start bars);
- (c) preservation of temporary construction site installations and safety areas isolation.

Table 1 Description of Unila buildings and auxiliary structures

Campus unila buildings	Area (m ²)	Dimensions, in m (shape)	Project details	Status
Main structures				
Central building ^a	27,926.02	36 × 40 (H)	18 Floors and roof, with H-shape and a height of 82.5 m	Construction interrupted
Classrooms building ^a	33,558.26	40 × 300 (rectangular)	Curved deployment, 4 floors, with 7.5 m cantilever and 25 m continuous spans	Construction interrupted
Directory ^a	1,113.46	16 × 70 (rectangular)	Ground floor structure coupled to the classroom building	Construction interrupted
Restaurant ^a	9,352.22	70 (cylindrical)	Two floors with cylindrical structure and cantilevers up to 7 m	Construction interrupted
Library	12,854.70	80 (cylindrical)	Cylindrical structure with 10 m of cantilever	Not started
Theater	12,713.57	100 × 40 (trapezoidal)	Trapezoidal structure with width ranging from 100 m	Not started
Laboratories	37,023.20	150 × 150 (square)	2 floors plus shelter cover for installs and shape square in projection, with 75 × 75 m central open patio	Not started
Reception	2,612.50	70 × 35 (rectangular)	Ground floor with mezzanine and roof	Not started
Council room	701.26	25 m (cylindrical)	Designed in reinforced concrete	Not started
Auxiliary structures				
Access	–	–	Single lane ring road design, parking for 3.249 parking spaces	Not started
Utility center ^a	4,250.00	50 × 70 (rectangular)	Underground building	Construction interrupted
Technical gallery ^a	1,008.46 (m)	4 × 4 (linear)	Underground path (access: 3 m × 3 m) connecting all buildings	Construction completed (740 m)
Gas and diesel station central ^a	380.53	35 × 11 (rectangular)	Underground building, intended to shelter the gas and diesel central	Construction started
Catwalk/awning	7,782.57	600 × 2 (linear)	These are concrete structures with average spans of 20 m, width 12 m on the walkway and 10 m on the access to the buildings, with eccentricity 2 m in relation to the pillar's axes	Not started
Construction area without walkways				≈ 146,000 m ²
Total construction area				≈ 155,000 m ²

^aMain and auxiliary structures contemplated in the first stage of the construction

4.1.1 Mud cleaning and removal services

Firstly, the accumulated mud was removed from underground technical galleries Fig. 11a). To remove the mud, mechanical equipment (mini loaders, backhoe loaders, excavators) and manual equipment (shovels, wheelbarrow, etc.) were used. Fig. 11b). Cleaning services were conducted by applying water jet Fig. 11c).

4.1.2 Waterproofing

When construction execution services was interrupted, part of structures waterproofing systems was not adequately protected, and it suffered degradation due to weather exposure Fig. 12. As water is one of main degradation agents of concrete structures, waterproofing systems are important in ensuring their durability [32]. With this concern, waterproofing services were conducted, such as recovery of completed

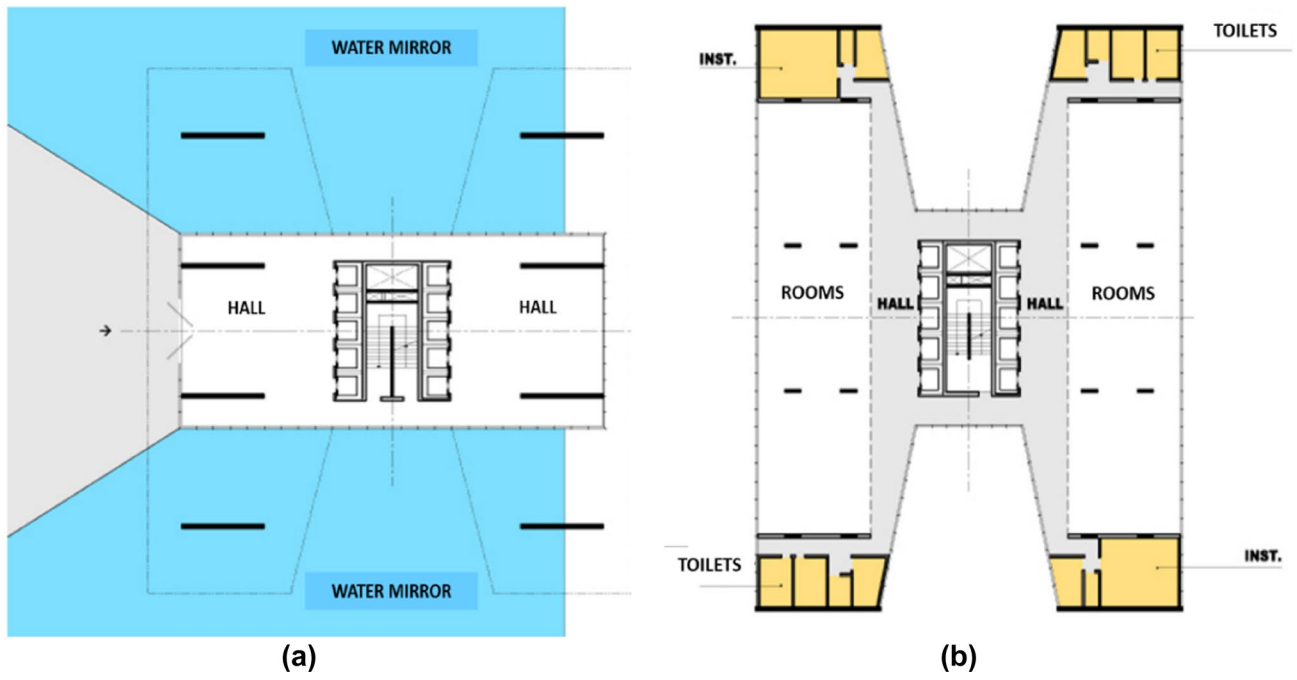


Fig. 5 Central building (scale 1/200) a Ground floor plan b standard plan [31]

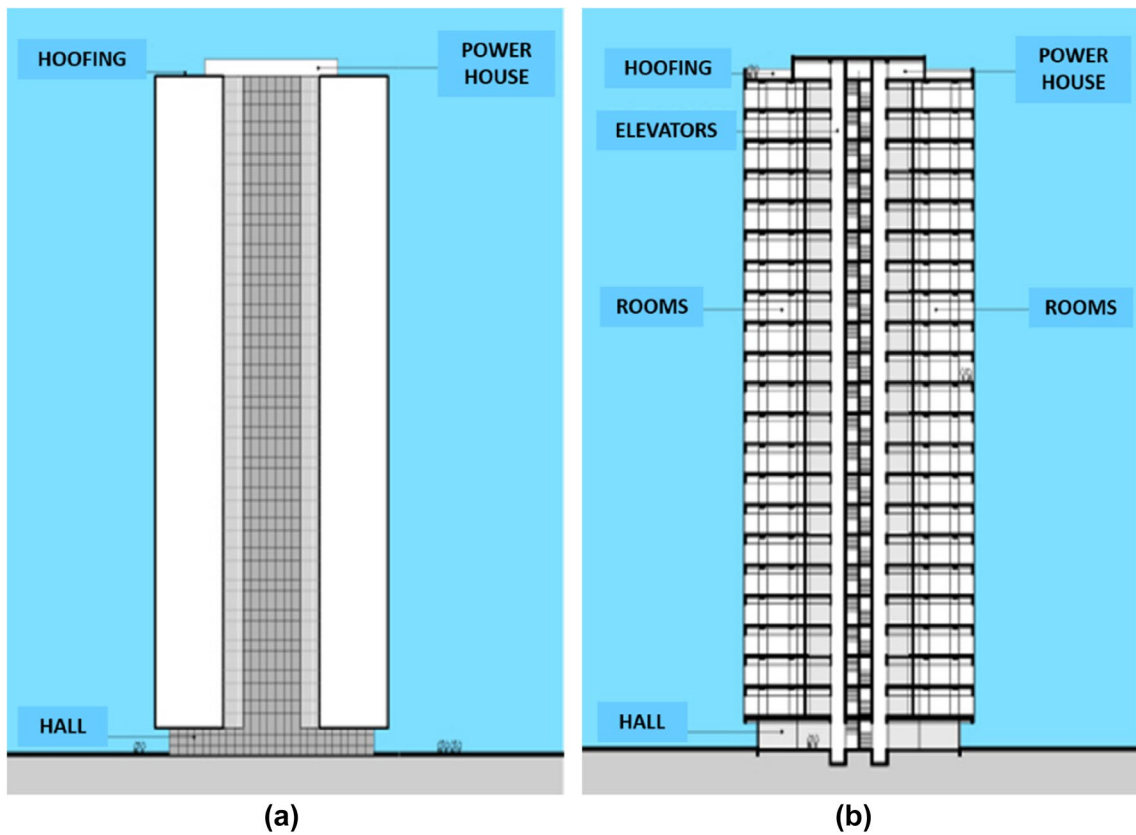


Fig. 6 Central building (scale 1/500) a front view b cut view [31]

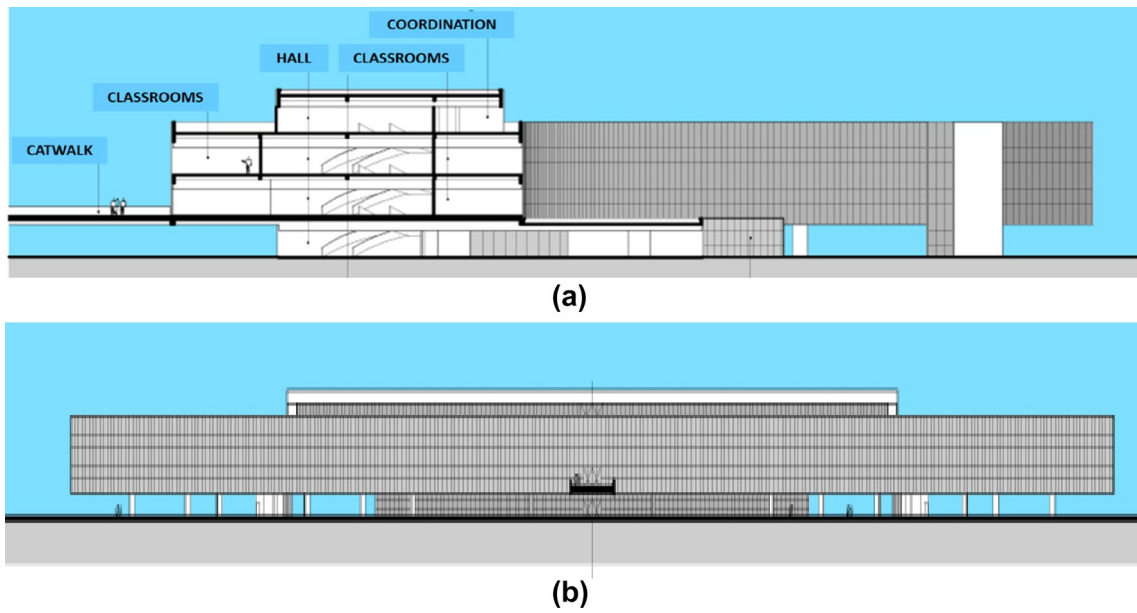


Fig. 7 Classrooms building (scale 1/250) a cut transverse view b front view [31]

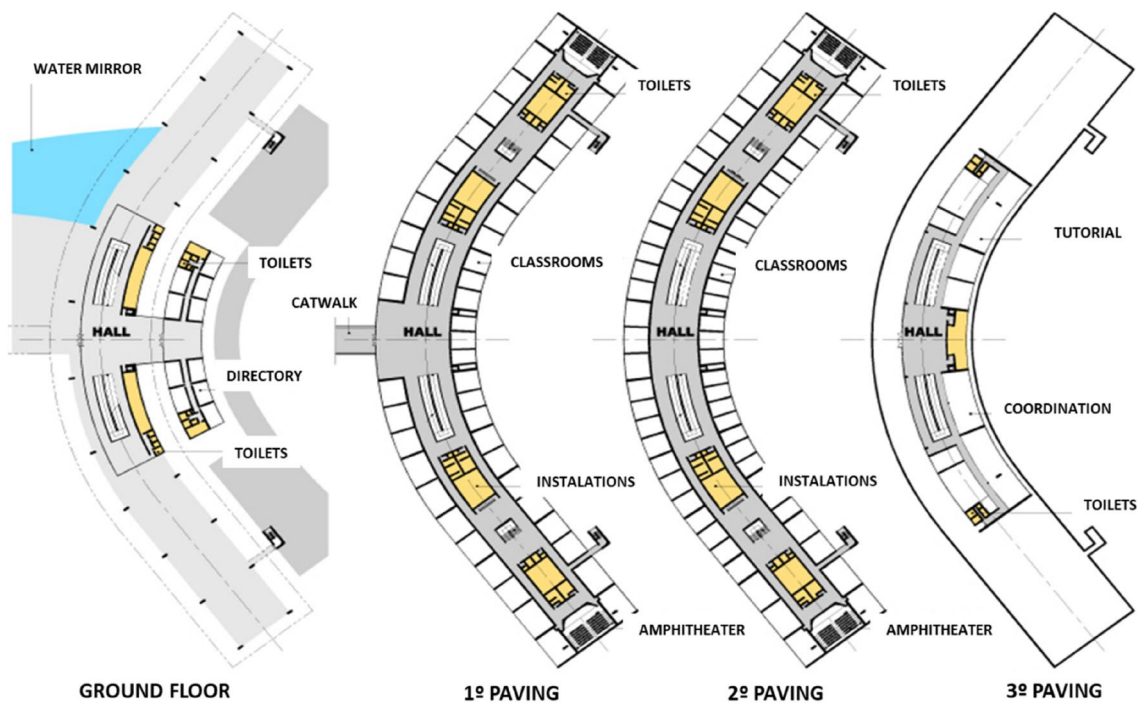


Fig. 8 Classrooms building—ground floor plan (scale 1/1000) [31]

systems with damage Fig. 13b and new systems implementation Fig. 13a, b.

During recovery actions, visual inspection was made on existing structures, identifying locations where mechanical protection had failures (cracks and displacement) and/

Fig. 9 Restaurant—cut view (scale 1/500) [31]

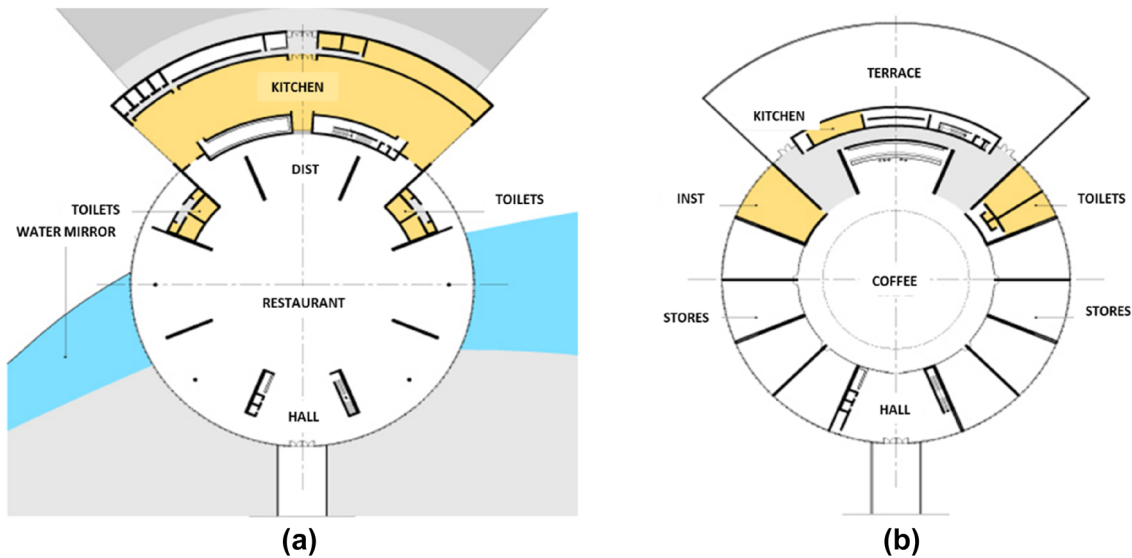


Fig. 10 Restaurant floor plan (scale 1/500)—**a** first pavement **b** second pavement [31]

Table 2 Main services performed × location/structure

Location/structure	Services				
	Cleaning	Waterproofing	Drainage	Protection of reinforcements	Preservation of the installations
Central building ^a	X		X	X	
Classrooms building ^a				X	
Restaurant ^a					
Galleries ^b	X	X	X		
Technical utility centers ^b	X	X	X		
Temporary installations ^c					X

^aMain structures

^bAuxiliary structures

^cAccording to NBR 12284 [42]—equivalent to ASTM F3342-19:2014, and NBR 6118 (ABNT [34])—equivalent to ACI 318R-19:2019

or it was not performed. Where failures were found, the existing waterproofing system (membranes and protection) was removed, and it was replaced by a new system (double polymeric cover for gallery ceiling and utility center, and painting on gallery walls). The polymeric cover was mechanically protected before structures grounding, as

recommended by NBR 9574 [33], which is equivalent to ASTM D7832M-14:2014.

4.1.3 Exposed reinforcement protection

The exposed reinforcement cleaning—start bars—Fig. 14a was performed with water blasting (on all



Fig. 11 a Cleaning services; b galleries mud removal; c main building underground cleaning



Fig. 12 a Removal of degraded waterproofing system; b correction of the same system

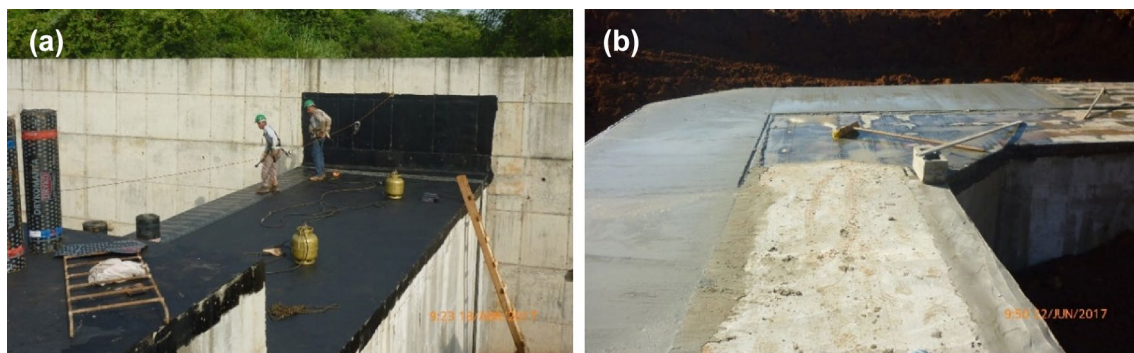


Fig. 13 a Blanket application of the waterproofing system; b application of the mechanical protection

existing structures). Subsequently, cement paste was manually applied Fig. 14b, c with the proportion 1:1 (cement:water). Among the main protection systems for exposed reinforcement (such as polymeric cement mortars), cement paste without additives was chosen due to its easy application, low cost of acquisition and considering materials in stock (cement and water), avoiding bidding necessity.

The study developed by Gomes and Sales [35] confirms reinforcements protection importance in interrupted structures. The authors found that 49% of the samples collected,

carbonation depth was similar to concrete cover layer thickness (for approximately 9 years of CO_2 exposure), indicating maintenances consideration to a possible construction sequence. In another case study, Huang et al. [36] concluded that a surface coating application would have prevented carbonation in a 35-year-old building by up to 100%, according to the coating thickness.

In the study case, where the design predicts apparent concrete, the ingress of CO_2 will not be prevented (since the concrete was not protected), and will be mainly controlled

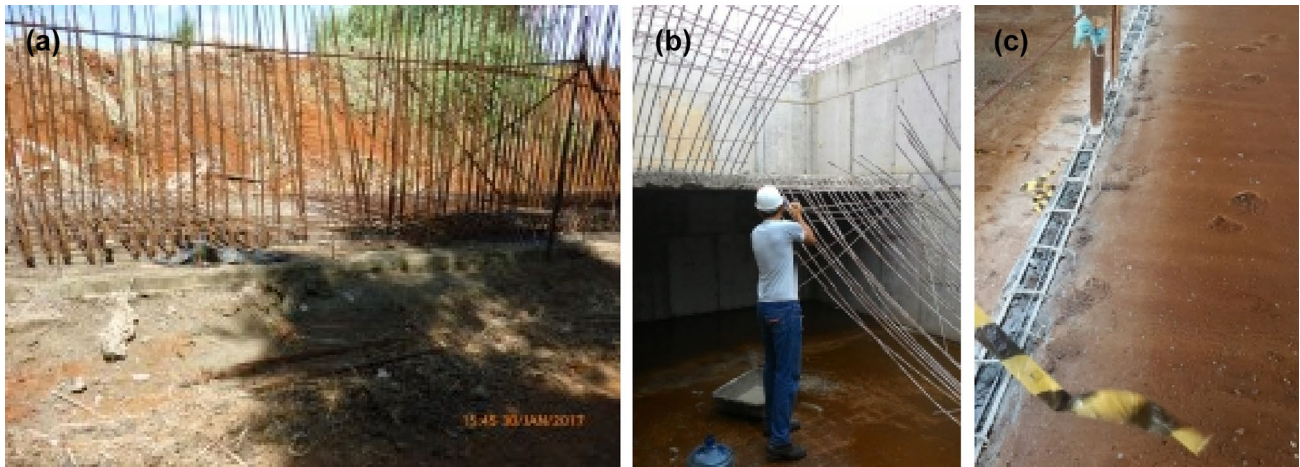


Fig. 14 a Reinforcement without protection; b cement paste treatment; c protection with cement paste

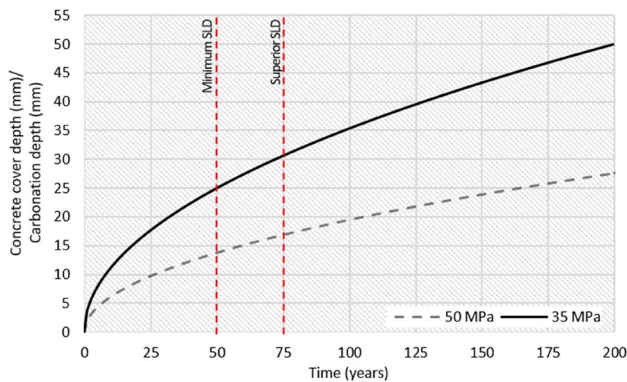


Fig. 15 Simulation for design service life (DSL) and superior performance levels as a function of concrete compressive strength

by the concrete quality (minimum f_{ck} of 35 MPa and maximum water/binder ratio of 0.55) and the cover layer thickness (minimum 30 mm for columns and beams and 25 mm for slabs).

In the document analysis, it was found that design decisions were made in favor of durability during the structure service life. The concrete quality was characterized by technological tests, analyzing the axial compressive strength and the elasticity modulus. Moreover, special care was taken in the execution of the building’s foundations (concrete mass). For footing type foundations, refrigerated concrete was used to reduce hydration heat, which can also prevent delayed ettringite formation (DEF). As the aggregates in the construction region are reactive, cement mineral additions was added to minimize the effects of hydration heat and mitigate the alkali-aggregate reaction (Fig. 15).

Although Brazilian regulations specify only the minimum compressive strength and the maximum water/cement ratio as design requirements for a concrete structure, it is known

that other factors are of importance for durability and structural safety.

Cement type and content, CO_2 content, relative humidity and rain protection also influence the diffusion of CO_2 into the concrete. For this reason, the model proposed by Possan et al. [37], was chosen to perform the service life simulations (Eq. 1).

$$y = k_c \cdot \left(\frac{20}{f_c}\right)^{k_{fc}} \cdot \left(\frac{t}{20}\right)^{\frac{1}{2}} \cdot \exp\left[\left(\frac{k_{ad} \cdot a_d^{\frac{3}{2}}}{40 + f_c}\right) + \left(\frac{k_{CO_2} \cdot CO_2^{\frac{1}{2}}}{60 + f_c}\right) - \left(\frac{k_{ur} \cdot (UR - 0,68)^2}{100 + f_c}\right)\right] \cdot k_{ce}, \tag{1}$$

where y is the average carbonation depth of concrete, in mm. f_c is the average characteristic axial compressive strength of concrete, in MPa. k_c is the variable factor relative to type of cement used Table 3a). k_{fc} is the variable factor related to concrete compressive strength, giving to type of cement used Table 3a). t is the concrete age, in years. a_d is the pozzolanic admixture content in concrete, in % of concrete mass. k_{ad} is the variable factor relative to pozzolanic admixtures in concrete—silica fume, metakaolin and rice husk ash, according to type of cement used Table 3a). UR is the average relative humidity, in %/100. k_{ur} is the variable factor related to relative humidity, according to type of cement used Table 3.a). CO_2 is the atmospheric CO_2 content, in %. k_{CO_2} is the variable factor related to CO_2 content in the environment, according to type of cement used Table 3a). k_{ce} is the variable factor related to rain exposure, according to exposure conditions of structure Table 3b).

The model was chosen due to good carbonation depth estimation results for concrete structures produced with different cements, explaining more than 85% of the tested cases

Table 3 Coefficients of the model according to: (a) concrete characteristics and environment conditions; (b) exposure conditions (Possan et al. [37])

(a)					
Type of cement	Properties of concrete			Environmental conditions	
	Cement	f_c	Addition	CO_2	UR
	k_c	k_{fc}	k_{ad}	k_{co2}	K_{ur}
CP I	19.80	1.70	0.24	18.00	1300
CP II E	22.48	1.50	0.32		1300
CP II F	21.68	1.50	0.24	18.00	1100
CP II Z	23.66	1.50	0.32	15.50	1300
CP III	30.50	1.70	0.32	15.50	1300
CP IV	33.27	1.70	0.32	15.50	1000
CP V ARI	19.80	1.70	0.24	18.00	1300

(b)	
Exposure conditions of structures	
Sheltered from rain	kce
Indoor sheltered from rain	1.30
Outdoor, sheltered from rain	1.00
Outdoor, exposed to rain	0.65

[37]. Figure 9 presents the simulation result for the structure under study considering concrete degradation by carbonation action over time, in order to evaluate the structure DSL. For the simulation, the conditions of the structure's exposure environment were included the model (Eq. 1), considering the average relative humidity 73% and a CO_2 content of 0.038% (380 ppm), for the outdoor, sheltered from rain condition. Pozzolanic Portland cement with 7% and 8% of silica fume was used to produce concrete with compressive strength of 35 MPa applied in slabs and columns and 50 MPa used in columns, respectively.

According to NBR 6118 [34]—which is equivalent to ACI 318R-19:2019—the structure under analysis is in a zone of moderate aggressiveness (Class II, urban environment), with small deterioration risk. Using Eq. 1 for simulate the carbonation advance over time Fig. 9, a period of 235 years can be estimated or CO_2 to reach the reinforcement in columns and slabs (compressive strength 50 MPa and concrete cover 30 mm). Thus, it is noted that the structure will possibly meet NBR 6118 [38] as well as the Performance Standard regarding the minimum service life of 50 years, NBR 15575 [39]—equivalent to EN 1992-1-1:2014.

For the slabs, with 35 MPa compressive strength and 25 mm cover thickness the simulation indicated a 48-year service life, so that the carbonation front is equal or greater than the concrete cover thickness used. This value is slightly below the minimum SLD stipulated in the Brazilian performance standard [39], which is not desirable from a durability standpoint. Possan [40] reports that Portland cement without

pozzolanic addition could increase the service life of these structures, since they have more alkaline reserve, which slows the advancement of carbonation front.

4.1.4 Drainage services

After cleaning central building underground, two sewage pumps with automatic drive were installed to prevent flooding in this space. These machines are in permanent operation. The drainage system was also finalized Fig. 16a and a retaining wall execution, both located near to the utility center, in order to finish the campus earthworks services.

4.1.5 Preservation of temporary construction site installations and Isolation of safety areas

In direction of maintain NR 18 minimum conditions [38], so that construction provisional installations could be reused Fig. 16b), wooden walls transformed and/or damaged were replaced by new elements. The roof was also repaired with damaged roofing tiles replacement. Finally, areas were isolated to provide safety, with doors and barriers installed to prevent access to buildings or part of them and to prevent possible accidents and thefts.

4.2 Cost survey

Table 4 presents the data about the investments made and the areas constructed, until the moment that activities were

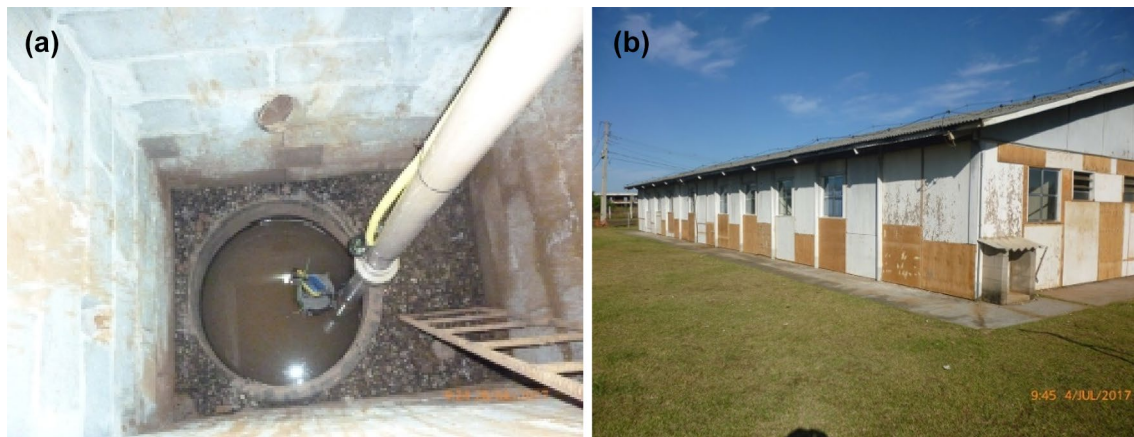


Fig. 16 **a** Drainage well executed; **b** existing temporary structure

Table 4 General construction data for the three main structures

Structure	Area (m ²)		% Completed ^a	Costs (\$)*		
	Total	Constructed		Total of construction	Investments made	Protection of the reinforcement ^b
Central building	27,926.02	14,660.10	52.49%	20,148,079.28	6,542,381.35	1900.00
Classrooms building	33,558.26	12,400.77	36.95%	27,223,923.89	7,932,882.50	3585.63
Restaurant	9352.22	9352.22	100%	4,162,193.25	4,162,193.25	–
Total for main structures				51,534,196.43	18,637,457.10	≈ 6000.00
Total for other structures				80,000,000.00	12,219,685.76	–
Total invested in interrupted structures					≈ 50,000,000.00	–
Total for protective constructions					434,000.00	–

^aRefers to the slab area of the structural design, without foundations, finishes and installations

^bEstimated cost, investment made by the University maintenance area

paralyzed, for the three main structures of first stage project's implementation (central building, classrooms building and restaurant).

It is noted that the classrooms building is the structure with the lowest percentage of work performed. This occurred due to a delay in the execution agenda, since that a geological fault was detected only after the works start, which required the projected foundation system alteration. The initial design was sloped footing foundations that were changed to deep foundations in the region where the fault was detected.

The Table 3 shows that costs required for reinforcement protection are insignificant when compared to overall structures cost, being less than 0.03% of the monetary value already invested in the structure. Regarding the contract value for the structure's protection execution, it is observed that it represents 1.4% of the total invested and this value is considered low in view of its application (interrupted structures protection and incomplete constructions completion).

Time estimated of repairs, quality of provisional services performed, as well as the materials used, are, therefore, helpful to these types of constructions. It is also important to consider what is stated by Gardner et al. [41], in order to have an even greater cost–benefit in maintenance processes, the use of materials that have an ability to adapt, self-heal and respond to their exposure environment is required. This means that the number of repair and maintenance interventions during the service life of the structure (or interrupted structure) are as short as possible and therefore maintenance costs are reduced over the construction life.

5 Conclusions

In the present study, in an interrupted engineering construction, protection and maintenance actions can be adopted with reduced costs, in order to avoid the concrete structures degradation until the moment of works returning.

In the document analysis, it was found that design decisions were made in favor of durability during the structure service life. For footing type foundations, refrigerated concrete was used to reduce hydration heat, which can also prevent delayed ettringite formation (DEF). Cement mineral additions was also used to mitigate the alkali-aggregate reaction, as the aggregates in the construction region are potentially reactive. For the superstructure concrete, the project also adopted durability-friendly measures, such as the use of concrete with compressive strength greater than 50 MPa.

According to the durability model used [37], which considers the environmental exposure (moderate), concrete characteristics, especially water/binder ratio and cement type employed, associated with covering thickness used, ensure a structure service life more than 200 years.

It was observed that the protection services made on specified interrupted structures, were mainly related to exposed reinforcement protection, waterproofing and protection of structures in contact with the ground, and, finally, drainage services execution.

Protection costs were approximately 1.4% of investment value. The reinforcement protection cost was less than 0.03%, indicating the technical and economic importance of adopting protective actions in concrete structures that had their works interrupted.

Therefore, the study demonstrated the importance of measures adopted in view of the benefits obtained in relation to demanded costs, especially to reduce or minimize pathological manifestations. Hence, it would be useful as a model for other constructions in same situation, corroborating for diffusion of practical engineering works, guaranteeing the durability and extension of reinforced and prestressed concrete structures service life.

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Compliance with ethical standards

Conflict of interest There is no conflict of interest.

Ethical statement The authors declare that this paper is original, that it has not been submitted to any journal.

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