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Argamassa armada
Textile Reinforced Concrete, social inclusion
through technology and design

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ABSTRACT

In the last decades, composites have been employed to develop innovative solutions in order to increase performances and reduce environmental footprint. The researches about TRC (textile reinforced concrete technology) have shown promising results. Because the steel reinforcement is replaced by textile nets, TRC solutions are not subjected to oxidation phenomena and qualities as lightness transportability durability and sustainability are enhanced. Under the hypothesis that composite materials and composite solutions are widely diffused and accessible on the market, this project investigates the potentiality of this technology in a low-income context where issues as transportability, constructability and durability are extremely important. Solutions as ferrocemento developed by Pier Luigi Nervi or Argamassa armada developed by Joao Filgueiras Lima in Brazil have proved that lightweight reinforcement concrete technology is able to provide cost effective structures with impressive architectural output. Through prefabrication it has been possible to involve low class unskilled labour in the construction process. Aware of the main technology assets the favela of Rocinha, in Rio de Janeiro has been studied and analysed to develop a constructions system where TRC technology is employed to address sociological, technological, economical, construction and architectural necessities of this peculiar settlement. TRC technology fits the basic know how about concrete technology and could be eventually employed to provide, thank to prefabrication, a more suitable solution easy to deployed and transported on the worksite.

This project is not only focused on develop a technology but also design a possible intervention inside the community with the aim to boost the adoption of this solution and to provide a robust know-how about construction techniques inside the community. For this purpose, the project has been integrated with the urban vision of PolimiParaRocinha project. Ongoing project promoted by local actors and supported by the Universidade Federale do Rio de Janeiro it is carried out by a multidisciplinary team leaded by the IMMdesign laboratory. The IMM (Integrated Modification Methodology) have been employed to analyse the favela and pitch the impact of possible local and global actions implemented in the community. Finally, the PolimiParaRocinha project integrates the argamassa armada purpose providing a robust and consistent frame about urban context and urban strategic actions to implement locally.
SINOSSI

Negli ultimi anni i materiali compositi sono stati oggetto di ricerche al fine di sviluppare soluzioni con migliori prestazioni e con un minore impatto ambientale. Fra queste, gli sviluppi riguardanti il TRC (textile reinforced concrete) hanno portato a risultati promettenti per un possibile futuro impiego in ambito edile. Questa tecnologia permette la realizzazione di elementi in calcestruzzo estremamente fini, leggeri e resistenti. Ciò è possibile grazie a reti in materiali compositi che garantiscono alte prestazioni meccaniche e di durabilità. Partendo dall’ipotesi progettuale che le soluzioni composite siano diffuse e accessibili sul mercato, questo progetto vuole investigare le potenzialità di tale tecnologia in contesti economicamente poveri dove aspetti tecnici quali trasportabilità, approvvigionamento, resistenza e durabilità sono estremamente importanti. La favela di Rocinha a Rio de Janeiro è stata oggetto di studio per sviluppare un sistema costruttivo che impieghi il TRC per rispondere a problemi sociali, tecnologici, costruttivi e architettonici propri di un contesto così complesso e particolare. Rocinha è situata in prossimità del centro economico della città essa ha accesso a un mercato dei materiali costruttivi vasto e aperto, tuttavia i lavoratori locali non hanno alcuna formazione tecnica. Il TRC, attraverso l’impiego della prefabbricazione, ha le potenzialità per fornire un sistema costruttivo che possa supplire alla mancanza di conoscenze proprie di questi contesti informali.

Questo progetto non si focalizza unicamente sullo sviluppo di una tecnologia ma anche sulla progettazione di un intervento su scala locale che abbia l’obiettivo di promuovere la soluzione e di dotare la comunità di un’adeguata educazione sui temi basilari riguardanti la costruzione. Ne consegue che il progetto è stato integrato alla visione progettuale su scala urbana del progetto PolimiParaRocinha. Promosso da attori locali e sostenuto dall’Università Federale do Rio de Janeiro, il progetto vede la collaborazione di un team multidisciplinare ed è gestito dal laboratorio IMMdesign del Politecnico di Milano. L’approccio dell’ IMM (Integrated Modification Methodology) è stato impiegato per analizzare la favela e comprendere e valutare l’impatto di possibili azioni implementate a livello globale e locale. Questo ha permesso un solido inquadramento del progetto in un contesto già studiato e sufficientemente sviluppato. Sono state perciò introdotte solide strategie multidisciplinari di intervento su scala urbana al fine di introdurre efficacemente un progetto che ne sviluppa in dettaglio un singolo aspetto.
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1 Textile reinforced concrete
1.1 Technology overview

Today reinforced concrete, thanks to the large availability of raw materials for concrete production and low costs associated to casting structural elements, reinforced concrete (RC) can be considered as one of the most widely used construction materials. In the last decades the knowledge about technological aspects RC have drastically improved. Nevertheless many issues related to its environmental food print remains unsolved, for instance, the amount of CO2 generated during the production of the cement clinker. For ordinary RC construction, to ensure resistance and durability a minimum level of clinker as well as a minimum coverage, from 20 to 60 mm is needed. In consequence constructions in RC are associated with relatively massive constructions.

Reinforce concrete with stainless steel and/or non-metallic reinforcement could be a possible approach to reduce minimum thickness of the structural elements. In consequence a more rational use of the material, reducing the use of clinker could bring to an overall reduction of the environmental footprint of concrete construction. Within this context, the technology of structural textiles has widely developed in the last decades. An increased demand has generated more efficient production techniques, making these products more competitive and spreading in different sectors.

Pic: 1.1.1 Textile reinforced concrete sample (from: https://en.wikipedia.org)
Textile reinforcement

Since some years, these structural textiles have started to be used as embedded reinforcement for cementious materials in order to overcome the restrictions of ordinary RC regarding cover and durability issues. The textile fabrics are obtained by the assemble of continuous filaments of diameter ranging between 7-27 $\mu$m bundled together to get a row. The size and surface of the rows depends on proprieties requested as resistance and concrete bonding conditions. For textile reinforcement the rows could be directional oriented, planar bidirectional oriented and three-dimensional. In this project bidirectional nets would be employed. The main advantages in employing a textile mesh in a concrete structure are related to homogeneous microcracking state, a notable increase in ductility and a low-weight to strength ratio and overcoming of durability requirements. Finally the amount of reinforcement can be tailored to the acting internal forces and the textiles provide architectural flexibility of shapes. On the other hand, nowadays an initial high cost, in employing this material has to be taken in consideration. Nowadays the for structural applications, bidirectional textile grids made of carbon (CFR), alkali resistant-glass (AR-GFR) or basalt fibers are most commonly used. In addition to the insensitivity to corrosion, these textiles provide high strength and stiffness on two axes. Other natural or organic fibers have been experimented too, but on the other hand they show a smaller tensile resistance.

- Glass fiber textile AR-GFR represents the most cost-effective and available solution on the market. They are produced from melting process of inorganic non-metalizing materials. On the other hand, AR-GFR is sensitive to temperature increasing.
- Carbon textile CFR is produced by a chemical process that requires more energy that all the others listed textile typologies. On the other hand is the one with better tensile characteristic and more durable.
- Basalt fibers textile come a promising solution due to the availability of raw materials and affordable production process. On the other hand issues about durability has not been asset yet.
Concrete matrix

For TRC application is usually requested a different mortar matrix from the one applied for common RC structure. The main requirements are in detail are in terms of grain size and compatibility between mortar and fabrics.

- Concrete grains: to allow a good and homogeneous casting and an adequate bond able to ensure load transfer between matrix and fabric, a maximum dimension of 2mm of aggregate is typically employed. However the literature has shown that this value could be eventually increase to a maximum size of 4-6 mm depending on design thickness of the TRC elements.
- Chemical compatibility: as seen before the matrix employed to reinforce TRC elements could be various. In consequence the mortar mix should be designed to ensure both mechanical and geometric requirements but also chemical compatibility. About sustainability, the literature reports also example of mortar matrix made of reduced level of clinker, which had been substitute with ashes or with the use of so called “green concrete”.

According to literature, TRC can be casted in low thicknesses (typically 1 – 5 cm) with satisfactory mechanical and durability properties. These experiences have shown that the use of thin-walled cross sections with considerably high reinforcement ratios require the use of fluid mortars. As a result, cementitious matrices with a fine grained structure are used, that can usually be associated with high mechanical performances and linear-brittle behavior.
1.2 State of art

The scientific literature traces first researches on TRC to the characterization of its tensile behavior and resistance, with some pioneer works of Avenston and Kelly in 1973. These authors presented a model (the ACK-model) incorporating many essential assumptions characterizing TRC based on simple mechanical parameters. Following this work, Ohno and Hannat refined in 1994 the ACK-model by introducing further material parameters. As the textile technology developed, the research community also explored more in-depth other aspects related to TRC, giving rise to a number of research projects. Some of the most comprehensive research programs were developed in Germany starting from 1998 at RWTH Aachen and Technische Universität Dresden. These efforts were dedicated both to the design of new structures and to structural rehabilitation.

- Pavilion RWTH: reproduction of the hyper construction approach by Félix Candela on the RWTH campus in Germany: Four independent shells, point supported at the centre, with in-plane dimensions of 7 m × 7 m and a thickness of 6 cm;
- Brücke Albstadt: Single span (15 m) pedestrian bridge without use of metallic reinforcement.

On the purpose of this master project the attention had been focused not on recent project in TRC but rather to the work carried out by Joao Filgueiras Lima, known as Lelé, Brazilian architect from the 70’s. Succeeding in introduce the technology of Ferrocemento developed by Pier Luigi Nervi to Brazil context, he didn’t only achieve remarkable architectural results but also promotes a social tool, a low cost prefabrication technology able to involve in the construction phase the high potential of Brazilian low class unskilled labor.
João Filgueiras Lima, known as Lelê, was a Brazilian architect known for its ability to embrace, through the architectural design, construction, structural and environmental issues. Born in Rio de Janeiro in 1932 he graduated in architecture and urbanism at Euniversidade do Brasil in Rio de Janeiro, nowadays called Universidade Federal do Rio de Janeiro. Right away he was involved in different residential project, among them the construction of the campus of the University of Brasilia unB. All the buildings were prefabricated and the project team was coordinated by Oscar Niemayer. The latter had a huge influence in the architectural practice of Lelê, nevertheless he took part in defining its ideological and political identity, both the two friends were involved in the partido comunista do Brasil PCB. The architectural influence of Niemayer is evident on shapes of Lelê design, always pure and clear underlining the prevalence of shape more than function in defining the architectural identity of a building.

Pic: 1 1.2.3 DISBRAVE, Brasilia (from: www.archdaily.com.br);
Por uma contingencia de vida, o destino me jogou por outro lado, eu foi obrigado a absorver essa coisa de tecnologia, e o Oscar sempre trabalhou com o concreto da forma mais livre possível... escultórica, E eu fiquei assim, quer dizer não estou querendo me comparar com o Oscar, sou um subproduto. Estou apenas justificando como é que foi a forma de influência [1]

What had characterized all the work of Lelè, from detail to urban scale, is a peculiar ability and talent in analyze and taking account different variables involved during the project, from the early design till the construction and the maintenance. "racionalização nao depende da escola" [2]. This effort is a constant of its work, his signature, an artistic flair to involve during the design structural environmental, worksite issues as well as social, urban and architectural topics.

In Brasilia Lelè experienced worksite with prefabricated elements. Architects, as Niemayer, used to consider prefabrication as an alternative in case of lack of time and economic resources, Lelè saw in it a potential and alternative tool to craftsmanship throughout Brazilian architecture could find a creative expression. Lelè’s work was an important contribute in recognize and assert the potentialities of prefabrication and industrial processes applied to construction in Brazil. He embraced the design principles which stands beyond prefabrication; a process where construction as architectural definition complement each other avoiding waste. From the 60’s he studied in and experimented prefabrication construction; he experienced worksite and techniques used in the east of Europe after the second world war and implemented them in Brasilia and Salvador da Bahia.

Pic: 1 1.2.4 hospital regional de Taguatinga, Brasilia (from: www.archdaily.com.br);
For Lelè it wasn’t just a matter of construction issues but a design process where also environmental and structural issues were integrated.

“sempre se preocupou com as questões ambientais e o aproveitamento de recursos naturais como a iluminação e a ventilação incorporando esses aspectos de maneira totalmente integrada aos princípios da industrialização” [3]

In 1970 he met in Sao Paulo the engineer Federico Schieel, he helped Lelè in developing the first prototypes of Argamassa Armada.

“A argamassa armada pode ser definida como um micro concreto armado, resultante da associação de argamassa (cimento/areia/água), com uma armadura de aço constituída por fios de pequeno diâmetro e pouco espaçados entre si (telas soldada).” [4]

Argamassa armada is what is commonly known thanks to Pier Luigi Nervi Ferrocemento. It is composed of two elements a concrete matrix and a thin net of reinforcement, in this case a metal one. Thanks to Schieel and Lina Bo Bardi, Lelè got in touch with Nervi’s work about ferrocemento and prefabrication. He had the chance to study its drawings and understanding the potentialities of its work and apply them to Brazilian reality.

“Eu vejo um potencial enorme na argamassa armada como estrutura, que o Nervi, chegou a explorar” [5]

He envisioned in the argamassa armada an architectural tool to mediate between social and economic issues as well as techniques and aesthetics ones. The use of “argamassa armada” implies a different vision of worksite: for Lelè there were two essential characteristics:

• Lightness: the elements were designed in order to be transported and assemble by workmen, usually the maximum weight was around 100 kg. That was due to easy transportation of materials and mostly to use of unskilled labour reducing overall construction cost.

• Readability of the construction process: The construction or assemble should be intuitive and any worker should be able to carry it on. Again to reduce the need of specialized workers and to face the economical and social issue of availability of a huge unemployed and unskilled labour.

“Nenhuma etapa construtiva se sobrepõe a outra de maneira a destruí-la. Todas as etapas saí evidencia-das. Há quase um certo lírismo, pois cada corpo produtivo pode se expressar com uma grande autonomia, no melhor dos seus possíveis. Eu comparava essa poética como jazz, onde você tem cinco, sei. Ate dez músicos, que tocam uma só musica, mas cada um deles pode fazer um solo com todo o virtuosismo que e capaz., sem que isso destrua o conjunto oí que cada um desses desapareça na massa” [1]

In 1979 Lelè took part to the Companhia de Renovação Urbana de Salvador (RENURB) which who founded the first large scale factory for argamassa armada production. After this first structure on the suburbs of Salvador da Bahia it was founded in 1889 the FAEC fabricade equipamentos comunitarios. Lelè built a total of 12 factories on the country among them one in Rio de Janeiro which contributes to build more than two hundreds schools in poor settlement as Rocinha.
Founded in 1885 the FAEC was one of the biggest structure to pre-fabricate elements in argamassa armada. The FAEC experience had a short duration (3 years), it was built to support the urban renovation of the city of Salvador da Bahia and it was place for the technological researches.

Argamassa armada prefabrication process:

**Preliminary activities:**
- Preparation of the materials
- Transportation of the materials

**Execution:**
- Formwork arrangement
- Pouring of concrete
- Concrete care
- Demoulding

**Later activities**
- Finishing
- Storage

Pic: 1.2.5, precasting phase of production of argassa armada (from: CANCIÓ TRIGO, C., p. 72);

Below: Pic. 1 3.2.8: Prefabrication factory of argamassa armada, ph. Patrick Lorenzo Valeri, 2017;
Thank to the politic support, Companhia de Renovação Urbana de Salvador (RENURB), Lelè had been the main actor of the renovation of the city of Salvador de Bahia. Together with Lina Bo Bardi he designed the refurbishment of a residential neighborhood in the historical center of Salvador da Bahia. The project was conceived as a prototype to implement on a larger scale for all the historical center. At the end only few buildings were refurbished employing a flexible system of retainer wall in argamassa armada.
Pic: 1.2.10 Recuperation of the historical center of Salvador da Bahia, Joao Filgueiras Lima Lelé, Lina Bo Bardi, 1988 (from: FILIGUEIRAS LIMA J., Joao Filgueiras Lima Lelé, Instituto Lina Bo e P. M. Bardi, Lisbon, 2000, p. 169);
Transitory school prototype

During the 80’s it was commissioned by the educational minister Darcy Ribeiro a transitory school prototype. The idea of a temporary school came due to the instability of agricultural politics and the transitory nature of the field worker’s. Lelè designed a cost effective prototype of school in argamassa armada that could be rapidly assembled by unskilled workers. This solution had been adapted also for urban poor context, as favelas, for the region of Sao Paulo, Brasilia and Rio de Janeiro. In the state of Rio de Janeiro more than 200 schools have been built thanks to the support of a factory:

Letter from Lelè to the educational minister Darcy Ribeiro

Darcy,

As we agreed upon, I am sending you the design for a “Children’s Home” to be installed in shanty towns. On the flat lands (urban and rural) the models tried out in Abadiâna will be used (terrace on the same level as the other rooms and long cantilevers on roof beams to enable peripheral circulation). As you suggested, the main beams of the new model have been strengthened to allow the roof level to be used as a terrace. Although the design is very simple, the change in the roof and above all the complexity of the installation problems (accesses, drainage, the acquisition of leveled platforms, etc.) has determined the creation of new pieces.

Pic: 1.2.11 Worksite of Transitory schools (from: KOPINSKI EKERMAN S., Lelè: arquitetura, urbanismo e engenharia na reestruturação de bairros populares, Universidade Federal da Bahia, December 2017, p.5)

1.3 Project hypothesis

To investigate the potentialities of such innovative and under-development technology as the TRC in a poor context as the favela proper hypothesis have to be made. The main assumptions made o this project are made about:

Analytic method for structural behavior:

Analytic method for structural behavior of the TRC solutions and consequently typology of textile reinforcement and mortar matrix taken in consideration for structural verification. This master project had been carried out with the support of the EPFL. The research laboratories I-béton and ALICE had offered technical support and resources to accomplish this project. Non the less the TRC structure are an underdevelopment topic and many investigations about the technology behavior are still to be made. In consequence, once the choice of a possible system of TRC for the community of Rocinha had been developed the structural verification was carried out thanks to the method developed by the I-béton during the last years of research. This implies the use of the similar behavior typology of textile and mortar matrix of those investigated at the EPFL. In fact, structural verifications were made under specific assumptions, verified only with specific range of mortars. Seen the academic purpose of this work, although the materials choice won’t probably be the most suitable for the favela, it was chose to work with this materials in order to be able to accurate describes TRC elements behavior.

Economic sustainability:

As would be explained in next chapters, on site survey has shown off the potentialities that such technology, mostly in terms of transportability and durability, to be employed in such peculiar context. Although, if applied today they wouldn’t be economically sustainable. The problems are both related to a technical solution not ruled and not recognized by national design norms. This would imply extra cost to face in case of application. Secondly, the material cost, both the textile reinforcement both the concrete matrix are not competitive with common and traditional materials employed nowadays in favela. Non the less, researches about TRC and composite materials have been spreading mainly in Europe
and Asia, rather than Latin America, with few exceptions. Researches on possible market for composite material in Brazil have shown few results. On the other hand, also in Brazil different academic researchers are devoted to study and improve the behavior of organic composites obtained by local plants, among them sugar cane, highly diffuse on Rio de Janeiro Region. This would be eventually a sustainable and local available source for textile reinforcement. Nevertheless, as explained before this project had been carried out under the assumption of employing specific materials, among them carbon reinforced textile. In consequence the main hypothesis is that the project would be applied in a likely future scenario where the use of composite material, also in the construction sector, would be diffused and ruled by norms. Consequently, the raw materials needed for Textile reinforced concrete would be accessible on the market and initial cost would drop. Finally, it is important to stress how the project context, Rocinha, is located in the center of a megalopolis as Rio de Janeiro. Consequently has the chance, despite many poor and rural Brazilian region, to access to a wide and dynamic construction material market.

Pic: 1.3.1 Sugarcane Bagasse Waste as possible sustainable source for composite reinforcement;
2 Rocinha and the construction issue
2.1 Building the favela: an historical review

Starting from the firstly shelter, from the third decade of the XX century, Rocinha had been place of rapid and uncontrolled changes. The building techniques as the occupancy of Rocinha had changed over the time, becoming more and more robust and solid as the new community was rooting herself over the site.

When the first migrants came to Rocinha it was an un-hold propriety at the periphery of the city. A no-value area connected by a small path into the forest. Migrants without economic sources started to build shacks hoping for a better future and a forthcoming displacement to a more suitable housing. Right away was clear how they wouldn’t be able to face a rent for a formal housing solution in Rio. Therefore, the “morro” as were named before favelas, were the only affordable area enough close to the city to benefit of its opportunities. The migrants, over time, established in Rocinha their communities; nevertheless, the status of “favelados”, as they will be called, has been affected and charged of a harsh social meaning which had brought to marginalization. Living in informal shelters as slacks has being linked by citizen to negative and pejorative connotation mostly related to criminalization. With the raising of migrants fluxes the absence of the state, lack of basic formal rules as missing of house policies, titling, authority has brought to an informal and uncontrolled expansion inside the favela. Even if a strong community sense had grown between the inhabitants it had never been as powerful to structure a consistent social authority able to provide welfare politics inside the favela. From the 80’, this lack has been partially fulfilled by the drugs trafficker, known as Narcos, and by the police force. By the way, for both, a durable and sustainable development as well as urban expansion of the favela has never been a priority.
2.1.1 Historical scenario

Among Rocinha history there always been a strong bond between expansion, urban density and social stratification which have found its pivot in the housing construction issue. The meaning of own a house, in an informal settlement without legacy, has been faced over the time by the community living in Rocinha adapting their perspectives to social and economic changes. The aim of this chapter is to provide a review of the building techniques employed, from the origins till now, focusing on how social changes as well as expectations and needs of the households sharply define buildings as well as urban layout. The first buildings in the favela were mostly shacks built to provide a temporary shelter for those who moved to the city. Many of the cities of South America are known for the huge difference between poor and rich neighbourhood. This gap is hugely stressed in Rio de Janeiro since mostly of the favelas, conjuntos and other informal settlements are in the north and separated from the richest part. Rocinha, seen its peculiar position in the south, had a close relationship with the rich neighbourhood, they are both on the ayes of each other. Buildings in favelas have always been status symbol, which have meant decriminalisation and marginalisation by the citizen of Rio de Janeiro and, on the other hand, identification and community sense for the favelados.
Buildings in Rocinha could be described as “architecture without architects”. Informal settlements are generally characterized by a lack of codes and norms, as consequence needs and necessities of householder foster “spontaneous” changes in construction, expansion, and space distribution of buildings. Building techniques have been changed following availability of materials and willingness of householders to move from a temporary to a permanent solution.

In Incremental Housing and Cumulative Growth Pattern, Sonam Amble describes a typology of informal settlements in an evolutionary order called moments. Each moment is characterized by a shift from a temporary building to a more permanent one. These moments are steps of a process, in which the building can be partially or totally destroyed and then rebuilt and correspond to acceptance or awareness by the marginalized of its state of excluded from the society. In Rocinha's history is possible to read a similar path that has lead from temporary to permanency of favelados situation. Rocinha's inhabitants have always been struggled by the willingness of being recognized as citizens with equal rights and the refuse and marginalization perpetuated by Rio de Janeiro citizen. Through the community history of building technique, their evolution together with space needs and architecture is possible to define milestones which corresponds with the moments previously described. Historical, social and economic scenario had brought Rocinha's inhabitants to consider as permanent their situation in the settlement.

Phase 0

From 1930 to 1960: Early dwellings or shack built right after the migration from rural areas to Rio de Janeiro. The Rocinha’s inhabitants were still a small community with, approximately in the 40’s 1000 favelados, 50’s 4000 and 60’s 14000. Still the growth of the population was “limited” in comparison to the exceptional growth of the following decades. This phase was characterized by the firstly flows of migrations from rural areas to Rio the Janeiro. The city was the institutional and political capital of the state and, in concurrency with Sao Paulo, one of the most emergent economic centres. The perspective of migrants was, as moved to Rio to build a temporary shack and afterwards move to the city to improve their, or at least their children social status. Favelados, were subject to marginalization due to low incomes, underpaying and discrimination by Rio inhabitants for they being migrants in association to low cultural and social status.

<table>
<thead>
<tr>
<th>Building typology</th>
<th>RDJ political economical frame</th>
<th>Social economical problems of favelados</th>
<th>Favelados' expectations</th>
</tr>
</thead>
</table>
| Early shacks      | • Institutional and political capital of Brazil  
|                    | • Economic emergent center | • Underpaid, Discrimination as non Rio citizen | • Move to the city, Improve their or their children social status outside the favela |
Phase 1
From 1960 to 1980-90: By the 60’s and 70’s, due to change from agricultural to industrial mass production, the migration rate had exponentially augmented. Rocinha passed from 14000 inhabitants in 60’s to 30000 in 70’s and 130000 in 1977. This period was characterized, at the beginning by a large employment rate thanks to industries, mostly located in the port area. The GDP of Brazil had grown of the 326% from the 40’s to the 1978 at which had corresponded a rise of the life cost of 1528%. On the other hand, the increase of salaries for common worker had been subjected only to an augmentation of the 108%. As the favelas were becoming larger and commons their inhabitants suffered of new forms of discrimination above all, being a favelados. Moreover, Rocinha inhabitants lived in constant fear of seen their home destroyed and be displaced by the authorities, how it happened in the 70’s for Catacumba, a favela on the south of Rio. On the same time from the 80’s favelas had become headquarters for drugs trafficker, leading to a further decline of their inhabitants’ social status. Future perspectives were downsized by self-assessment of being considered as a marginal and awareness that moving from Rocinha would meant, in the best case, live in a “conjuntos”.

<table>
<thead>
<tr>
<th>Building typology</th>
<th>RDJ political economical frame</th>
<th>Social economical problems of favelados</th>
<th>Favelados’ expectations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early shacks, buildings one/two stores</td>
<td>Loss of institutional and political power but still one of the most economic emergent centers</td>
<td>Underpaid, Discrimination as Favelados, Fear to be displaced</td>
<td>Move to conjuntos, Improve their conditions inside Rocinha without future perspective</td>
</tr>
</tbody>
</table>

Phase 2
From 1990: During this period Rio had faced job loss due to deindustrialization and displacement of the national capital to Brasilia and the move of business, commercial, cultural, and intellectual centrality to Sao Paulo. Nevertheless, a new domestic problem Narcos raised fear for violence starting from the mid-80s. Nowadays, favelados labour has been gradually substituted for machineries in mostly of industrial sector, today unemployment Rio’s rate is 47.5% while Rocinha’s 40.5%.

“Yet Rio has managed to remain one of Brazil’s major economic centers, second only to Sao Paulo in per capita GDP. The degree of upward mobility of Rios urban poor, however, is constrained by its legacy of inequality, its declining employment potential, and its lagging economic growth rates. According to calculations by Valeria Pero, Rio has the lowest rates of social mobility among all the metropolitan regions of Brazil” [1]

Despite the recent raise of interest and attention to favela’s status, Rocinha community is still subjected to marginalization processes and discrimination by Rio’s inhabitants. Future perspectives are more introverted, led by disillusion toward the state, looking for possible improvements inside the favelas as an independent entity inside a wider urban frame. Even, the actual status of missing codes and legacy to exploit the construction area, nowadays building its own house in a favela is consider as one of the most profitable investments.
“The easiest part was investing in the project. Not necessarily saving but investing and paying. For me it was easy because I know that I will have a large return on the investment in the house. Including if I want to rent or sell the house, everything that I want to do that I have spent or that I will spend will never lose its value, it will always increase.” [2]

<table>
<thead>
<tr>
<th>Building typology</th>
<th>RDJ political economical frame</th>
<th>Social economical problems of favelados</th>
<th>Favelados' expectations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings from one to multiple (8) stores</td>
<td>declining employment potential, lagging economic growth rates</td>
<td>Unemployment, Discrimination as Favelados, Narcos (from mid-80’s)</td>
<td>Improve their conditions inside Rocinha as independent community</td>
</tr>
</tbody>
</table>
2.1.2 Construction typologies development

The development of buildings techniques and typologies in Rocinha is described by the book “Architects des Favelas” written in 1981 by Didier Drummond. From the 40’s the building techniques has been developed inside Rocinha as consequence of materials cost and availability and of social status of Rocinha’s inhabitants.

The Early shacks
The early construction built in rocinha by migrants were raise employing ancient and rural techniques that they have learn form they place of origin. This typology was a minority inside the Favela, during the 80’s there were approximately the 5% of the buildings in Rocinha. Nowadays we can assume that they have been almost destroyed and rebuilt. This is a construction typology that was implemented by the first migrants, soon this typology became obsolete due to long deployment time and problems of maintenance.

- Technology: the walls were built thanks to wooden frames on which rammed earth were disposed. In a second time the walls were covered entirely by an extra layer of rammed hearth and depending on availability also from lime. The Roof was composed by three branches and leaf. Over the time the construction was improved by a wooden roof and surrounded by vegetation in order to mitigate the water erosion of the walls.
- Architecture and space disposition: The space was usually characterized by a unique piece where usually were installed 2 openings: the door and a window facing the kitchen. Almost all the domestic actives took place at the exterior.

<table>
<thead>
<tr>
<th>Positive aspects</th>
<th>Negative aspects</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to build, cheap materials</td>
<td>Difficult construction and minimum comfort in management of space and domestic activities</td>
<td>No. Water thanks to the use of bins</td>
</tr>
</tbody>
</table>
Pic: 1.2.1 Early shack in Rocinha, (from, DRUMMOND D., Architectes de favelas, p.23;) 

Pic: 1.2.2 Early shack plant and section; 
1: Kitchen 
2: Open space/living room
The wooden shack

This construction was made of cheap and simple material depending on availability. It was a typical temporary shelter for early come migrants from the 40’s till the 80’s. Nowadays, these buildings represent just a minority of Rocinha’s ones. They are built, due to lack of money by the poorest inhabitants with a future perspective to build their home with most durable material as brick and concrete.

- Technology: the skeleton was composed by a wooden frame laying on the soils or, depending on the topography, on wooden “pilotis”. The structure was covered and reinforced by wooden or metal scrap, which aid to reinforce the unbraced structure. The roof, as the walls, had the same technology and was the heaviest part of the building.

- Architecture and space disposition: Different factor define the space disposition, among them: dimension on the shack, availability of materials to build interior walls and furniture. Despite from the previous case most of the dwellings used to have a separation between kitchen and the main piece. A more “urban” disposition which confer to the space a more private character.

<table>
<thead>
<tr>
<th>Positive aspects</th>
<th>Negative aspects</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to build, cheap materials</td>
<td>Minimum comfort, Low management of space and domestic activities</td>
<td>No, Water thanks to the use of bins</td>
</tr>
</tbody>
</table>

Pic: 1 2.2.3 Early wooden shack in Rocinha, (from, DRUMMOND D., Architectes de favelas, p.25);
Pic: 1 2.2.4 Wooden shack plant and section;
1: Open space/living room
When a shack must become permanent

The wooden house: These dwelling could be considered as an evolution a refinement of the examples previously exposed. For mostly of the case they were an enlargement of existent shacks which were usually consolidated from a structural point of view. Nevertheless, a relevant change is in spaces arrangement and furniture more and more likely to urban ones as a claim for a place in the city draw.

• Technology: As previously the skeleton was composed by a wooden frame, in this case the elements were usually properly selected. Braces were added to old and new structures. The wooden board as the metal sheets were also selected and cut at proper dimensions. Where electricity was reachable the houses were lighted.

“N’est pas rare de voir ainsi des ampoules suspendues à l’extérieur des maisons, même si l’électricité n’y parvient pas encore ; elles témoignent du souci de l’apparence et de la volonté du favelado de se rapprocher, même de manière illusoire, de les modélés urbains. “ [3]

• Architecture and Space disposition: The small shacks start to be enlarge with new spaces, the interior was often disconnected from the exterior at the entrance by a landing. The old shacks were mostly used as stockage or workshop and loggias and terraces were added. The entrance were personalized, underlined with wooden elements and doors and shutters were added. The most remarkable transformation was on furniture, seen the constant fear of eviction the houses looked basic from the exterior, on the other hand the furniture was meticulously chosen.

“Enfin, la télévision, outre symbole de réussite, vient à achever l’équipement de la maison. Présente dans le 10% des baraques elle fonctionne en permanence et parfait l’influence urbaine. Par son intermédiaire elle s’impose le modèle culturel dominant : la télévision devient pour l’habitants une sorte de miroir, une source de rêves qu’il ne réalisera jamais mais verse laquelle il tendra toujours.” [3]

<table>
<thead>
<tr>
<th>Positive aspects</th>
<th>Negative aspects</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implementation and improvement of the previous dwelling</td>
<td>Still temporary situation with low comfort and performances</td>
<td>No. Water thanks to the use of bins</td>
</tr>
</tbody>
</table>
Pic: 1 2.2.5 Wooden shack in Rocinha, (from, DRUMMOND D., Architectes de favelas, p.43);

Pic: 1 2.2.6 Wooden shack plant and section;
1: Entrance/stockage
2: Kitchen
3: Bathroom
4: Open space/living room
Two stores house: first bricks second wood

From the 70’s a new Rocinha starts to be overcrowded, rising the density issues. One store buildings were not enough to satisfy the space requests and as a necessary evolutive step many of the favelados envisioned the idea to build multiple store buildings. The wooden existing dwellings were not able to load and extra floor therefore they had to change building technique. Brick, concrete and mortar were already used in Rio de Janeiro and the favelados adopted these materials to build the ground floor, on top of which, they used to build the second floor with common wood.

• Technology: These buildings represented a gradual shift from more “temporary” materials as structural elements in wood, wooden boards and metal sheets to more “permanent” materials as bricks and concrete. The favelados approached this new building techniques with almost no know-how; creativity and experience were guiding craftsmen ad well as inhabitants to design construction and spaces. Firstly the buildings were laying on weak foundations obtained from a simple mixture of big-size stones and cement. Over this layer bricks were disposed, and pillars were made firstly in wood and after by reinforced concrete and finally a plaster layer was put to cover the facades. The second floor were still built as the wooden dwellings previously analyzed since the expensive cost of the materials from the first floor.

• Architecture and space disposition: The introduction of one extra floor allowed the favelados to better design the interior spaces. This was a crucial passage that signed the step between a common space to multiple rooms allowing different activities and privacy between them. Previously the family used to live at ground floor, now it is devoted to the daily activities, the kitchen is separated from the living room and a possible workshop. Despite the disadvantages due to wooden construction, the first floor is used to host the bed rooms that, in mostly of the cases, are facing a wooden loggia. Stairs were, if possible, inside the building granting privacy.

<table>
<thead>
<tr>
<th>Positive aspects</th>
<th>Negative aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent situation with medium comfort and performances</td>
<td></td>
</tr>
<tr>
<td>Privacy and better management and flexibility of spaces</td>
<td>Low level of comfort and performances at the upper floor.</td>
</tr>
</tbody>
</table>

Pic: 1 2.2.7 Two stores house: first bricks second wood in Rocinha, (from, DRUMMOND D., Architectes de favelas, p.27);
During the 80’s-90’s the use of bricks had almost replaced the wooden technology. Favelados could afford to buy and choose construction materials as wood brick and concrete. As in the city, houses were customized by the householders thanks to second hand doors, windows and shutters and furniture accurately chosen. In the community “new riches” started to build their house entirely with reinforced concrete and bricks. Buildings in “barrio barcelo” and those ones facing “Rua Gavea” used to host shops, restaurant, bars and other commercial activities; moreover, most of the householders used to rent part of their homes. Rocinha was finally assuming an urban appearance also thanks to the proximity with the city center which allowed a truly upgrading of quality of life. Despite phenomena as marginalization and diffusion of criminality new generations, born in Rio de Janeiro, fulfilled partially the cultural gap with the citizen. Favelas’ inhabitants started to fight for their rights setting up associations and electing their representants, schools were built in Rocinha as well some social infrastructure. These new generation of favelados have a cultural and social background largely different from the migrant’s ones. On the other hand, what didn’t change is their social status as marginals. For the migrants the discrimination was a social and cultural issue, for these new generations, which had benefit of the advantages of being born in Rio and in Rocinha, marginalization is a social statement at which they are just used to:

“My study revealed that residents of favelas are not “marginal” to society but tightly integrated into it, albeit in an asymmetrical manner. They give a lot and receive very little. They are not on the margins of urban life or irrelevant to its functioning, but actively excluded, exploited, and “marginalized” by a closed social system.” [1]

The author of “Architectes des Favelas”, describe this change through total-brick construction on a double perspective: it was both a shift from new building techniques but also a social tool which allowed Rocinha to become an urban settlement where, also due to the gap of regulation, space becomes more an object of exchange then an architectural value.

“pour les habitants de la Rocinha être considère comme des cariocas comme les outres et non comme des favelados qui habitent des baraques en bois est plus fort que le simple processus d’adaptation des espaces construit aux besoins quotidiens que faisait la qualité des premiers édifices.” [1]

As for cities, land has a value in Rocinha, therefore it became expensive for migrants, which moved to the north of Rio, and neighborhood as “Barrio Barcelo” becomes a safe home for the richest while the highest part of the favela was a dangerous settlement with lack of electricity and sewer occupied by the poorest. This is the ultimate state of transformations inside Rocinha which

2.1 Building techniques today

The main goals of the survey inside the favela of Rocinha were:

- Studying in details the current construction technologies in terms of:
- Recognized which one are the main materials and construction elements employed in Rocinha.
- Understanding whether it exists, if there is a common construction background or practice followed in Rocinha, from the design to construction phase and the maintenance.
- Outline the main problems related to the construction technologies in the specific site of Rocinha.

All these data were taken both from site inspection inside Rocinha, included worksites both from interviews to local workers and material sellers that were carried out inside the favela.
2.2.1 Materials and construction elements

One of the main issues about construction that has as consequence an important increase of costs and management is the accessibility to the worksites inside the favela. In Rocinha, the accessibility is a significant problem that concerns many social and economic practices. Nevertheless, in the construction field this has consequence on different steps of the construction phase and radically influence costs and material choices. High density of urban texture and lack of infrastructure have indirectly consequences on stockage and transportation.

Construction material market

The lack of space for permanent or temporary warehouses implies that all the construction materials and tools have to be purchased outside the favela and directly deployed in the worksites. As consequence, materials are bought from Rio de Janeiro’s market, but despite common thinking, they are more expensive once they are deployed in the favela. The market requires big purchases, while in Rocinha small quantities are often needed. Due to lack of stockage available sites, two scenario are possible. It could be a company with one or more worksites inside the favela can manage to directly deploy those materials on the worksites, without raising of costs. Otherwise materials are stocked in construction shops where small quantities can be purchased for an higher price by local inhabitants. In this case the price usually duplicates. For example buying a stock of wooden formwork costs around 600 R$ outside the favela. Once it is brought inside a construction material shop the final price is around 1300 R$. Once the product was bought it has to moved till the worksite. In this case the increase of costs depends on the location of the worksite and on construction materials weight and transportability. Once again, the price of a single element can easily duplicates.
Transportation of construction materials

Transportation depends on the accessibility to the worksites and consequently to the topography and the morphology of the road. Cars and tracks are used as far as it is possible, mainly to transport big amount of supplies from outside, on the remaining areas transportation is mainly carried out by human labour.

To accomplish this task, when it is possible Carts are usually employed. Nevertheless, due to the extreme narrowness of favela’s paths simple actions as crossing some-one else or push the material to the steepest part are complicated. Finally, the majority of the materials are moved by men itself, causing healthy problems. In consequence the possibility to move large quantities of material in a short time is reduced to those worksites on main roads. Rather, many buildings became almost inaccessible due to the extreme road width reduction, that can reach the minimum of 60 cm, and high verticality of the site, 40cm of step height.
Basic construction materials

The market of construction materials is peculiar inside Rocinha. As said before, everything comes from Rio de Janeiro’s market, that is supposed to have a large variety. Inside the favela this is extremely reduced depending on the product target. The choice is wide for materials employed to do the finishing as wall paintings, tiles etc. or furniture. On the other hand the number of available structural and construction elements or materials is extremely limited. That’s probably due to economic reasons, costs get higher increasing materials performances. Anyway, that’s not a sufficient explanation to this scenario, especially whether compared to other sectors as the furniture one. Another reason, as would be further explained, could be related to the construction techniques knowledge (un)diffused inside the community. Masons relay only on their previous experience. The construction is not supported by any technical knowledge and any construction worker has a any education except the empirical one known on site. Very little is known about materials and structural behavior. This fact could also explains how, once is known how a specific material works, it is largely employed in the favela. Furthermore, it justifies also the reason why the material employed are almost the same in the past 20 years.

Concrete:

This material is usually stocked in small bags, till 30 kg, to be transported by people. It is equally used to produce structural and no-structural concrete mixing it with sand, rocks grains and water. Concrete is produced on site, mostly by hand. This is the main reason of bad quality of concrete that engenders phenomena able to compromise the structural stability of the element. According to different interviews mortar and no structural concrete is produced both using the same ratio of sand, grains and water employed for the structural one. On the other hand someone else said that is used to increase ratio of sand and water.
One of the main issues concerning concrete structures inside the favela is the difficulties faced by construction workers in mixing concrete on the worksite. Due to accessibility issues this operation is mostly handled without the use of mixing machineries or mechanical tools. Usually concrete is mixed by hand, an issue that implies the augmentation of water ratio. Moreover construction workers tend to reduce the overall quantity of concrete to produce on site, decreasing the coverage of steel bars. That usually reaches the 1 or 2 cm. In consequence the durability of the structure is reduced causing early deterioration of the structures.
Steel

Steel bars could be both simple or already bonded and folded with the shape of pillars and beams. Again, as it raises from the interview, steel length defines standardize dimensions of structural elements, and in consequence of spans and floors height. Also in this case, the typology and the quantity of steel isn’t a consequence of a predesign but a “unwritten knowledge” related to previous experience end market contingency.

Bricks

In Rocinha two kind of bricks are employed, the regular hollowed ones (dimensions: 9x19x29 cm or 13x9x18 cm). Those bricks are used mainly for building external and internal walls, but also for slabs, employed with prefabricated concrete joists. A second typology of brics is used for ventilate the pieces and depending on ceramic orientation it can also shade and hide the interior spaces.
2.2.2 Construction practices in Rocinha

As already said, construction product and materials comes from the same market that supplies “formal worksites” in the city of Rio de Janeiro. This fact is stressed out by the visual evidence of seeing, mostly of the times, tools and materials as scaffolding and wooden formworks employed both in the city both in favela. The difference between how a worksite is carried on in a formal context respect in Rocinha depends on:

• The relationship between client and construction workers is inconstant. In consequence construction is carried on by phases in different time depending on money availability
• The lack architectural and engineering design. In consequence construction principles come from empiric knowledge learnt on the worksites

Finally, in the community each building, as well each worksites has a strong similarities in terms of materials employed, construction process and volume and spatial dimensions.

The first evidence, making a sharp difference on the final building, is the economic resources of the client. There are two possible scenario, the first is a client commissioning the whole construction, that’s quite uncommon. For the majority of the people, that are common workers inside the favela, or in the city for a low profile job, is impossible to afford such amount of money in once. Therefore, the construction as well the payment is managed in different time steps. As soon as they have money, they invest them to build a new part and as far as they are not able to cope with the task, they hire a builder. If could happens
that people improvise being construction workers, making errors, on the other hand the most complicated parts as structural elements are always carried out by construction workers. After the land has been bought, there isn’t any intermediate design step but the construction is directly managed by the construction worker with the client. The common house has 9 columns for 45 m², it has one or two rooms and an unique piece for the entrance and the living room. The kitchen and the bathroom are always parallel and placed depending on sewage and electricity system. The interior layout is defined by the client but also the extremely reduced size of the lot, mainly defines the spatial settings.

Once the construction is handled by local masons, there is no structural or architectural design to support their work. The overall principles followed by masons come both from their experience both from market availability. The steel bars are already pre-folded to fit 3 or 3.5 meters spans or pillars height. That module defines the main dimensions of the majority of the buildings, that look like colourful rectangular “shoe boxes” one piled on the other. Once main spans are defined, walls and slabs became a standard too. A medium building takes around 40 days to be raised up. The construction phases, followed by construction in all Rocinha are simple and repetitive. Foundations, pillars and beams, brick walls and finally stairs and slab casted all together. One of the main issue about stability safety and quality of the buildings is the lack of technical education of construction workers inside the settlement. Due to the informality of the context and the lack of rules many buildings included sensitive part as foundation and structure are handled by unskilled workers. Consequently, often the quality of the final results is lacking and many mistakes compromise safety and durability of the structure.
Pic: 1 2.2.14-17, Worksite in Rua 1, Rocinha, ph. Perego Francesca, Oct 2018;
Left: Pic: 1 2.2.18, Worksite in Rua Apia, Rocinha, ph. Perego Francesca, Oct 2018;
Below: Pic: 1 2.2.19, Worksite in secondary road of Rua 2, Rocinha, ph. Perego Francesca, Oct 2018;
2.2.3 Interviews

Material seller 3.10.18
Construction worker and material seller on the Rua 2 (inside the project area)

Mostly of the time are the construction workers to build the whole building, common people use to put the plaster or the final finishing

Could you describe me the main construction phases?
Foundations on rocks, those are always totally built by the construction workers. Usually rocks are broken on the surface then concrete is poured in the hole with steel. Pillars and beams, brick walls and slabs.

Are slabs complicated to be built or expensive?
Slabs are usually not complicated to do, but expensive. Prefabricated slabs done using insulating layers are cheaper since the use of wood is reduced, meanwhile slabs with bricks fillings are most expensive.

Which are the most difficult or expensive part of the construction process?
There are no main difficulties, since all those elements has to be build for any construction while are the finishing that changes depending on the owner

Therefore which one is the overall more expensive part?
The most expensive part are usually furniture for kitchen and bathroom, especially the pipes and finishing as tiles

To accomplish a medium size construction how many people are employed?
Two construction workers and a beginner for easy works.

How long takes to build a medium size construction?
30-40 days

Right after the foundation construction are the construction builders keeping on with the building? If there is a lack of money, people prefer to wait for new money or carry on the construction alone?
Usually the structure is entirely built by construction workers. Often people can’t afford the whole building so they wait to earn enough money to get another part built by construction workers.

So is it common to spend money for the house as soon as you get enough to build another part?
Yes

Have you seen the wooden construction that were usually built in the favela? Why have them change?
Yes I’ve been there since wooden construction were built in the favela. Nowadays brick buildings are safer.

Are building materials changing over the time?
Yes they are changing a lot, thorough more “technological direction” more resistance and lighter.

Form your point of view what people need to build better inside the favela?
Architectural courses

About professional courses, which one is the most needed in the favela?
Electrician and plumber. Because people became construction workers learning by practice, meanwhile other skills can’t be learned on the worksite.

**Julio 3.10.18**

Julio, volunteer of the Sorriso dei miei Bimbi and favela inhabitant. During Rocinha visits.

*Happens that unskilled common people join the construction of their own house, or friends, neighbourhood house?*
Yes, most of them do. Anyway depends of what they could do, usually they put plaster and do the final finishing. Moreover the majority of people work so they can’t help with construction works.

*How people evaluates if is it possible to build a new floor on existing buildings?*
They look to the foundations, if foundations are still robust and strength they built another floor. In case they aren’t, whether you have money, as we did for our terrace* foundations and down floors are refurbished and a new floor is built. And now our new neighborhood is building an extra flor on top of ours.

*In reference to a terrace belonging to the Sorriso dei miei bimbi association.*

So building an extra floor is not expected when you build the current floor, has it nothing to do with pillars dimension? Yes, no rules

*Do you have some code that must be respected to build a new building?*
No, any code, everybody is free to build what he wants as far you have the property on the land

*Even if the new building is shading or completely obscuring the old one?*
Yes, no rules

**Construction worker 8.10.18**

Construction worker interviewed thanks to Il sorriso dei miei bimbi NGO.

*Where are the main warehouses inside the favela? In detail are them located on the highest part of the Rua 1 and Rua 2?*
There are warehouses on all the favela, but most of the people prefer to buy the construction material outside and then resell them in Rocinha. In the city you have to buy large quantities, meanwhile inside Rocinha you can buy small quantities, here you can buy per piece.

*Are people used to buy small quantities to built a single piece of the building or to build all the needed material in only one time?*
Usually people each time the needed materials. That’s due to transportation issue, as high cost of transportation and the possibility to transport small quantities each time. Moreover there isn’t place for stockage.

*Who usually choose and buy the materials? The client or the masons?*
Depends on the masons, if they are a medium company they usually buy and chose the material, in case of self-independent masons clients are usually in charge of buying and choosing materials.

Happens that unskilled common people join the construction of their own house, or friends, neighbourhood house? Usually construction workers hire medium-skilled workers as beginners to help with the construction, but could also happen that the owner join the construction.

In case he joins, what is he used to do? Whatever they are able to do, as paintings or breaking a wall. In my case (as self-independent masons) they hire me just in case they are not able to do a specific construction task.

Which are the overall construction phases that occur during a construction? Once you have the land, main axes are defined, the heart is excavated to define the base. The steel is put in place the wooden formwork too and concrete is poured. Concrete is done mixing concrete, sand and rock granules.

About pillars, in some worksites in Rocinha it happens to see un-aligned pillars, why it happens? Pillars are supposed to be aligned, looking at the photos of un-aligned pillars.

Why pillars are mostly of the time not at the corners of the building but manly located in the facades? Because is easier to locate bricks on the corners using male-female matching.

Why at each floor there is a border showing out of the facades? That’s done to protect the wall from water and is often a result of prefabricated slabs. I would rather avoided it since is the cause of infiltration and deterioration of the wall.

About slabs, is wood to build slab expensive? In Rocinha the wood price is expensive, twice the cost if bought outside the favela, 600 R$ outside, 1300 R$. Buy wood outside and paying the transportation, that is 300 R$ is cheaper than buy it here.

Infiltration problems are common? They are very common. They depends on materials as concrete employed during the construction, steel disposition. It happens that concrete delates as “pop corn” and causes big cracks. Pipes are also very sensitive elements, often they breaks and water fall from the top.

Why there are often small gaps of 40-50 centimeters between buildings? The inhabitants association establish that between each building should be 1 meter distance, but anyone never respect this rule. In consequence, when you have to install furniture as fridge and sofa you have to pull them from the windows.

Many houses facades are not aligned, could it endanger structural or logistic problems? It happens very often, you must not overpass one meter cantilever and use a very good steel, otherwise is very dangerous.

But why it happens that facades are not aligned? It’s a choice, people wants to increase the volume of their house. It also happens on the other way, people chose to build on the top floor a terrace, that usually has a smaller dimension.
So what about un-aligned pillars? If you increase the volume with cantilever they are not aligned anymore?
For the horizontality we use level tools, meanwhile about vertical pillars it depends on who had built the new pillars.
Many don’t have any awareness about the role of pillars, some of them just built a new one.

About Concrete, which kind of typology of concrete do you use?
They are almost the same, there are two typology the CPII, that is faster to get dried and the CPIII. The CPII isn’t good
to make slabs and basement, it cracks, especially when it is too warm.

And what about the sand and rock grains deposit, they are used to made structural concrete?
Yes they are used to do concrete and they are mixed. Firstly you mix concrete and sand, after you add the grains and at
the end water, only water. We don’t have any mixer, so it depends, sometimes we buy spry concrete sometimes we make
it by hand. For those who lives close to the road spry concrete is easier.

And about structural concrete, how do you make it, which are the ratios of concrete, water sand etc? how do you man-
age it? You read it on the concrete instruction or you already know?
2 wheelbarrow or 6 bucket of 18 litre each concrete bag, For mortar 10 bucket each concrete bag.

And about water ratio for structural concrete?
It depends, how much is necessary to made it fluent. It changes all the time, more it is liquid better it is. When we put
grains in concrete we use less water otherwise you get problems with the steel bars.

And how do you choose steel bars?
It depends on how many floors you want to build, when you do a pillars you use 4,6,8 steel bars. Steel bars gave ro-
bustness to the system.

And the dimension of the pillars?
The pillars are 30 or 40 cm for 10,15 cm of with, you put wood for 15 cm on one side and 30,40 on the other.

So about the final height of a pillar?
Their length is 3.5 meters to get 3 meters high and 50 cm to emerge for the next floor. If you don’t have to do the base-
ment it can be long 2.70

And about spans, there are standard dimensions for spans and beams?
Is about 3 or 3.5 meters spans, depends on steel. Longer span means more steel

There are many problems with the structure? As beams or pillars that cracks?
The main problems here are related to the rain or the ground movement. If the ground is solid there are no problems
with the structure. Obviously you have to do maintenance, maintenance is important, for the structure the plaster, the
finishing and so on.

Regarding maintenance, are people used to do maintenance of their place? Of their houses?
The majority build the house and they never maintain it. That’s why there are problems, mostly related to painting, plaster
and water pipes, where rains gather. The most sensible part of the building is the exterior, due to harsh weather as rain,
humidity and sun radiation.

Inside the favela, there are many abandoned buildings, mostly unfinished. Why you don’t think to refurbish them since
you have few free spaces? It is due to economic reasons?
There are many unfinished and abandoned buildings in the favela. All the materials get worst, wood is deteriorated. Usually is because people can’t afford to refurbish them and so they rather build a new one.

About internal layout, it is managed by owner or the client or by the builder or both together? Do the position of window influence the disposition of internal pieces?
The owner defines the interior space. Firstly you place the kitchen and the bathroom, depending on sewer drain, after that is the client to choose how to mange the space left over. Usually the owner choose where to place the bathroom, than I check if it feasible depending on pipes disposition, avoiding a too long path.

Do you know the main principle that usually are adopted to define main piece disposition?
The living room is usually placed on the entrance, while kitchen and bathroom on the side to ventilate and parallel one to the other, to simplify water drainage.

How big is a common medium house and how many people do it hosts? In around how many rooms?
A big house has three bed rooms, plus kitchen, and bathroom. A 45 meter square house has usually a kitchen, bathroom, living room/entrance and a single bedroom. This are usually 3x3 spans.

And kitchen and living room are a single or a different piece?
Usually they are separated, by a corridor or a door. But all these dispositions depends on how much big and how it is the lot.

In 45 meter square house, how many people live inside?
Now is around 6 people, before was more, around nine. When I was young, at my place we were in fourteen people with two bedroom.

Does it happens that some pieces don’t have any window?
Usually every room has a window, but the majority of the time is just to ventilate the piece, not for light. In this case you always have to put protections to avoid rats.

About hollowed bricks, the one used sometimes in placed on walls are used mainly for ventilation or there are some other reasons?
There are two typology of them, one in diagonal to shade the interiors. They are very delicate and fragile, as glass, they need to be placed with precision. They are mainly used for ventilation.

But are they used because they are cheaper than windows?
No, you use them when you don’t have enough space to open windows, especially the diagonal one for the bathroom to hide the interior.

But there’s no problem with rains?
No usually houses have gutters to protect them.
3 Application scenario and system development

In the previous chapters were defined the subject of this research as well as the application context. This chapter is focused on analyse and understand how all those gathered information could be useful to develop one or more technology systems that could be suitable for the favela of Rocinha.

The complexity of this work can’t be resumed in only one solution or attempt to get a final technology system. As a matter of fact, the results of this project is the design of different possible systems, each of them with one or more tasks to get and compromises to arrange. The feeble line between context requirements, technology exploitation and the final architecture of the system have always been challenged.

Define and frame the application context is a key part of the overall design. Nowadays, products included construction solutions, are designed to satisfy needs that could or not match the favela’s one. That’s the case of all the construction solutions employed in Rocinha, they were designed for a different target of adopters and eventually employed to build the settlement. This project aims to define all the parties involved in the construction field of Rocinha as its adopters. It’s important to reminds that, since the application scenario is that peculiar, both in morphological and topological way and for the social and informal context, the requirements of Rocinha’s inhabitants could deeply change from the ones of its formal neighborhoods.
3.1 Task clarification & problem framing
3.1.1 Stakeholders

The stakeholders are groups, people, enterprise who have a direct or indirect influence on the project; or in other words, stakeholders exert an impact on the decision whether to adopt or not the solution. Two categories of stakeholders can be identified: firstly who has a direct role during the decision making phases, also called players, secondly who exerts an indirect impact and is not directly involved in the project, generally called stakeholders. To identify the stakeholder firstly was considered the context of which they operate.

The choice to divide them in two groups was in consequence of these considerations:

- Firstly the analysis of possible stakeholders was mainly focused on Rocinha, since it is the application scenario of the project.

Rio de Janeiro/Rocinha

1) Favela residents
2) Universidade Federal do Rio de Janeiro
3) Municipality of Rio de Janeiro
4) Politicians
5) Associations for improve the condition of Rocinha’s inhabitants( Il sorriso dei miei bimbi)
6) Narcos
7) Construction workers
8) Materials and tools suppliers
9) Private investors

- The project involves different academic teams who don’t know each other and they have different scopes in carrying out this research together. As consequence, the second group was made up with all the personalities belonging or involved by the academic parties in the project.

Polimi para Rocinha

10) IMM research Lab
11) Polisocial
12) Private investors
13) I-béton Lab
14) ALICE Lab

Moreover to get a better overview of the level of influence exert by the stakeholder they were analyzed looking both to when they are involved during the project, considering the design, execution and in-use phases, and how they exert influence pointing out their role inside each phase.
## DESIGN

### Players

<table>
<thead>
<tr>
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<th>Members</th>
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<tbody>
<tr>
<td>Client</td>
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<td></td>
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<tr>
<td>Project team</td>
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<td></td>
<td>10) IMM research Lab</td>
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<td></td>
<td>14) I-béton Lab</td>
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<td></td>
<td>15) ALICE Lab</td>
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<tr>
<td>Founders</td>
<td>9) Private investors</td>
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<tr>
<td></td>
<td>12) Private investors</td>
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<tr>
<td>Consultant</td>
<td>5) Il sorriso dei miei bimbi</td>
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<td></td>
<td>7) Construction workers</td>
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<tr>
<td>Institution</td>
<td>3) Municipality of Rio de Janeiro</td>
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<td></td>
<td>3) State of Rio de Janeiro</td>
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<tr>
<td>Community</td>
<td>1) Favela residents</td>
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<td></td>
<td>4) Politicians</td>
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### Stakeholders

<table>
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<td>4) Politicians</td>
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<tr>
<td>5) Associations for improve the condition of Rocinha’s inhabitants( Il sorriso dei miei bimbi)</td>
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<td>7) Construction workers</td>
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<td>8) Materials and tools suppliers</td>
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<td>9) Private investors</td>
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</table>
## PROMOTION

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<th>POWER</th>
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<tr>
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<td>10) IMM research Lab</td>
<td>PO</td>
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<td></td>
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<td>13) I-béton Lab</td>
<td>POW</td>
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<td>14) ALICE Lab</td>
<td>POW</td>
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<tr>
<td>Construction team</td>
<td>1) Favela residents</td>
<td>PO</td>
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<td>9) Private investors</td>
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<td>7) Construction workers</td>
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<td></td>
<td>8) Materials and tools suppliers</td>
<td>POWER</td>
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<tr>
<td>Stakeholders</td>
<td>Institution</td>
<td>3) Municipality of Rio de Janeiro</td>
<td>POWER</td>
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<td></td>
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<td>3) State of Rio de Janeiro</td>
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<tr>
<td>Community</td>
<td>5) Associations for improve the condition of favela’s inhabitants</td>
<td>POWER</td>
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<tr>
<td></td>
<td>1) Favela residents (neighborhood)</td>
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<td>4) Politicians</td>
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<td></td>
<td>6) Narcos</td>
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## IN USE

<table>
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<th>Players</th>
<th>Management team</th>
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<th>POWER</th>
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<tbody>
<tr>
<td>Workers</td>
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<td></td>
<td>8) Materials and tools suppliers</td>
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<td>9) Private investors : FGV Projectos</td>
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<td>Institution</td>
<td>2) Universidade Federal do Rio de Janeiro</td>
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This analysis underlines the inconsistency of power who shift from different groups of stakeholders, moreover, there’s not a robust and relevant power relationship between client and designer. Looking to each phase:

- During the design phase the most powerful stakeholders are clients, investors and some members of the team project. The latter has the most relevant influence on whenever take or not a decision on the project.
- Next the promotion phase the power shift toward the Rio de Janeiro stakeholders’ group. The loss of control by the designer is due to the importance of the role of local promoters. Nevertheless, seen the instability inside the favela it could be a source of risks as radical changes or project failure.
- During the adoption phase who has the power to stop or support the project are stakeholders, as in first place construction workers and materials and tools suppliers and in second place the municipality, politicians or Narcos who are not directly involved.

Once the stakeholder are listed, a further investigation is carry out to understand who exerts a potential impact on the project success. Firstly the stakeholders are inserted on a chart based on two criteria: their level of interest (axis x) and their level of power (axis y). As consequence, for sub-groups are identified:

**Meet their needs**

They have requirements and even the power to stop the project and generally are not directly involved, reason why they don’t have a personal interest.

**Least important**

They are not involved in the management project since they are not salient or relevant, however they have to be considered in function of their potential dynamic to move into other sectors.

**Key players**

Since their preeminent role inside the project they are usually those with responsibilities. In case there are not, they should be considered with extreme care and be involved as far it is possible in the project.

**Show consideration**

Consists in different interest groups with low impact. They should to be considered as opportunities for potential dynamic towards “key players” as project supporter.
Trough this matrix a stakeholder management strategy can be further developed. The goal would be both minimize the negative impacts as well as emphasize opportunities due to stakeholders involvement. See the matrix results is important to say that Rio de Janeiro stakeholders represents the most sensitive and unpredictable stakeholders group. In fact, due to rapid and uncontrolled changes of the socio, economic and political scenario the chances of project success or failure could easily increase. In detail, “favela residents” belongs to the show consideration sector and they could be an element of extreme mobility in terms of power and mostly interest inside the chart. As well the “construction workers” and “materials and tools suppliers” who have an important role in defining the success of the project. As consequence the project, in function of its purpose and level of population engagement, can be easily supported by the population as well becoming a failure.
3.1.2 SWOT

The swot analysis had been performed only on the application context (Rocinha) thanks to all the data gathered during the visit to the community (see also chapter 2.2 On site survey). The goal of this analysis is to outline all the possible constraints as well as potentialities related to the application context for the TRC technology. The SWOT analysis had been structured in a matrix where Strength and Weakness had been meant as facts on which is possible to exert a change through the project development. In consequence Strength has to be exploited and enhanced to support the project as well as Weakness has to be reduced and avoided. On the other hand, Opportunities and Treats had been meant as unchangeable matter of facts with who the project has eventually to takes advantages or to cope with in order to avoid issues in its future development and application.

Pic.1 3.2.1: Photo of construction material in Rua 1, Rocinha, Ph. Francesca Perego, Oct. 2018;
**Strength**
- Accessibility to different products and solutions;
- Structural part are carried out by construction workers;
- The construction process is simple, repetitive and the same in the whole favela;
- Interest for architectural and professional courses in the field of construction;
- Interest for new solutions able to simplify the construction task;
- Tendency to credit new solutions once they had the chance to practice it (empirical approach);

**Weakness**
- Lack of knowledge about materials and structural principles.
- Empirical approach to the construction field not supported by theoretical or basic knowledge on the topic.
- Unawareness about consequence of constructive errors.
- Unawareness of the role of the designer.

**Opportunity**
- Lower cost of big purchase;
- The market of construction product is various (Rio de Janeiro’s market);
- The construction process is time-phased due to economic reasons;
- Strong influence of market availability on constructive solutions;
- Unskilled people involvement during construction phase (mainly finishing and simple activities);
- The dimensions of height and spans between pillars are standardized;
- Slabs are the most expensive element, in consequence the one toward market is open for more innovative solutions;
- Lack of maintenance due to cultural and economic reasons;
- Logistic problems in mixing concrete on the worksite;
- Rocky soils able to guarantee stiffness to the structural system and avoid ground drop;
- Presence of one escola transitoria in the favela;
- Extremely reduced width and high slope of paths in Rocinha.

**Treats**
- High cost of transportation;
- Absence of warehouse;
- High cost for small purchase in Rocinha;
- Nowadays construction product demand is rigid and scarce in terms of variety;
- Unskilled people involvement during construction phase (for structural and sensitive part);
- The construction process is time-phased due to economic reason;
- Competitiveness of the existing solutions about time deployment;
- Overall careless of construction workers;
- Lack of codes and norms in the field of urbanism, architecture and engineering;
- Lack of maintenance due to cultural and economic reasons;
- Extremely reduced width and high slope of paths in Rocinha.
3.1.3 Requirements

The previous analysis has spotlight who are the main actors that could be involved in the system development as well as the one that would exert a biggest influence in the system adoption inside the favela. Moreover, this analysis also came out with the main issue related to the most impelling needs of future adopters. Those had been summarized in a list of key requirements that the system has to totally or at least partially satisfy to asset a remarkable improvement in comparison to the existing building techniques. These requirement define a standard, a target on which each solution developed had faced with. In consequence, they are measurable or comparable with the existing solution.

- **Cost**: the cost per sqm of a structure built with traditional techniques and new one (R$/m^2)
- **Transportation**: The transportation of materials to the worksite has an important influence in the overal construction cost. On the other hand this is proportional to the worksite location and how it is reachable, by car using manual tool as carriage or only by men. Due to transportation issues it has been set as limit both the element weight, no more than 100 kg and size, no more than 3-4 meters length.
- **Stockage**: in this case it is compared the possibility to better manage the worksite and buy products on Rio de Janeiro market and avoid small and expensive purchase in Rocinha.
- **Construction**: The community has a big potential in terms of unskilled workforce, on the other hand there is a total absence of skilled personalities as architects or engineers to guide and manage constructions. The quality of a technological system would be valued depending of the degree of skills necessary.

Finally the other factor that has to be consider to fulfill the project requirement is social aspect related to the system introduction in the context and its promotion. This issue is faced on the second part of the thesis that is focused on the design of a structure to promote both the adoption of this solution both to increase of awareness about the construction topic as well the architectural and technical design necessity.
3.2 System development

From the context analysis the main assets on which develop a project are:

- The existence of a construction grid of pillars and beams span that is a consequence of employment of 3 or 3.5 meters pre-folded bars;
- The necessity to study a system able to include scaffoldings of minimum 1 meter span to guarantee the possibility to increase the space as well as fit static scheme of certain buildings;
- Study a structure that could be built in different phases, following economic availability of the poor families;
- Reduce the need of expertise on the worksite and decrease the difficulties of construction task both in term of skills and tool needed;

About the technology the main assets are:

- The TRC reinforcement is better exploited when it is stressed bidirectionally. It works well in thin structure and static schemes, depending on structural element shape, where the width of the tensile part is maximize.
- The TRC doesn’t behave efficiently when it is used as punctual reinforcement, for example in case of linear element where a concentrate effort is needed. In this case alternative and expensive solution as fibre glass bars and inox bars could be used to guarantee resistance and lightness.
3.2.1 Research phase

The starting point of this research was the technology developed by Lelé. The hidden value of Lelé’s elements was expressed during the construction phase. Thanks to the lightness of each piece was possible to avoid the use of heavy and expensive machineries. The details and connections were carefully designed to require the minimum effort of craftsmanship and still being elegant actors of the pace architecture. The key of the Lelé architecture employing the argamassa armada was the definition of space which founds its relationship with the human being through the proportion intrinsic to each elements and their articulation. The proportion of the element is bonded with the proportion of the space defining the strong architectural identity of each building prototypes. The work of Lelé had set the target for any further development of the Argamassa Armada in Brazil. Among different systems designed by Lelé, the elements developed for the Escola Transitoria or transitory school project have already been implemented with success in context as the favela, included Rocinha. Therefore, the model of the escola transitoria has been taken as example to begin this research.

Pic. 1 3.2.1: Shool of Abadiana; (from: CANCIÒ TRIGO, C., Pré-fabricados em argamassa armada, Dissertation directed by C. T. de Andrade Oliveira, Universidade de São Paulo, 2009, p113);
Formal roules are not applied inside the favela and no predesigne is usually carried out before construction. On the other hand, standard prefoded bars for beams and pillars are used to guarantee structural stability. Consequently the span and shapes are generally standardized. The first phase of the project is focused on dimension and proportion. Pillars and beams are usually very thin and slender in the favela.

The first exercise was to rethink the shapes of Lelè inside favela’s proportions. In detail this study was focused on the element of the beam. Different possibilities have been studied and experimented through graphical and physical models. These beams shapes have the characteristics to be thin and consequently lightweight and o at the same time make a better use of TRC. On the other hand, the structural resistance of the elements has not been verified and looking to Lelè solutions those beams would probably need punctual reinforcement as bars.

Above, Pic.1 3.2.2:sections of generic pillars and beams employed inside Rocinha;Below, Pic.1 3.2.3:Sections of generic beams inspired by Lelè beams;
Pic. 1 3.2.4: Plaster beam;
Pic. 1 3.2.5: Plaster beam;

Pic. 1 3.2.6: Plaster beam;
Pic. 1 3.2.7: Plaster beam;

Pic. 1 3.2.8: Plaster beam;
Pic. 1 3.2.9: Plaster beam;
After this first phase of experimentation the goals was to decline the system studying the articulations between different elements as pillars beams and pillars, or beams and slab. Looking to Lelè’s work, even if some structures were built in favelas or poor settlement, each building prototype was not designed to address necessities and issues proper to the favela context. Basically the buildings of Lelè, whether they were schools or hospitals or other structures were designed and organized on a specific space distribution at which corresponds a defined structure and consequently a static system. The structure in argamassa armada have been designed to be built on an empty lot with determinate boundary conditions. The technology and the connections have been studied to work within a precise static system. For example to avoid casted on site joints the beam joints is made by bolts and is located where the moment are close to zero. Or the bracing is guaranteed by the columns, which are cantilever columns embedded in the foundations. Consequently the buildings can’t be higher than 3 meters. Roof slabs and intermediate slabs have the same shapes, but the first one use to work on negative moment to optimize the use of steel net, on the other hand intermediate slabs, since they are subjected to positive moments are reinforced with steel bars.
Right: Pic.1 3.2.14: Joint between the beams and pillar, Rocinha, ph. Francesca Perego, Oct. 2018; Pic.1 3.2.15: Joint between the beams and pillar, Rocinha, ph. Francesca Perego, Oct. 2018;

The issue to fit Lelè technology in a different static system and with different requirements, first of all the possibility to build multi store buildings, has brought to difficulties and changes in elements shapes. The two main issues to face are firstly technological as the study of joints, technical performances and structural resistance. Other questions raise about the architectural output. In fact, the elements were designed to be used in different context for different uses and in the favela the original space proportions and necessities have changed.

The pillar joint has been one of the most critical to face. In common prefabricated structures the continuity of the pillars is generally ensured thanks to small cantilever joints where beams are placed. Due to transportation issues it was set as limit both the element weight, no more than 100 kg and size, no more than 3-4 meters length. In consequence a joint between pillars has to be designed. The possible way to guarantee stability of the structure is to cast the joint or eventually employ walls to brace the structure. The other issue was the design of the joint between beams and slab. Lelè’s beams have a peculiar shape to satisfy technological and structural requirements as a big static height and the possibility to be used to discharge rainwater in the pillars. On the other hand this specific shapes cause problems in handle the joint between beams and slabs. In detail the use two webs in order to provide an higher static height and rigidify the structure. On the joint between beam and slab the bending in moment is almost zero and this static height is not needed, on the other hand the shear force is maximum.

The main issues concerning the redesign of Lelè’s system were focused on the effectiveness of the joints, overall cost of the structure, seen the necessity to use punctual reinforcement as reinforcement bars in expensive materials to avoid corrosion, and finally the production cost. Many of the elements designed would need a specific and complicated form-work to be produced and this preliminary cost could make the solution unaffordable for a poor context as the favela.

Possible solutions for pillars design:
Possible solutions for slab design:

Possible solutions for beams design:

Pic.1 3.2.18-19: Possible solutions for slab design; Pic.1 3.2.20-21: Possible solutions for beam design;
The joint between beam and slab can be handled placing the slab on the beam. It would be easy to put in place and managed in terms of formwork. Reducing the section at the level of the joint. In consequence the section needs to be reinforced with bars, eventually in steel, glass fiber or resins, raising the overall cost of the element.
In consequence the idea to redesign Lelè system could not be the most suitable answer to the favela necessities and further a new system was designed. Firstly the new system has been developed taking in account the cost issue and consequently different strategies have carried out.

- The formworks have been simplified to reduce the preliminary cost and the level of craftsmanship and tools and materials needed to build them.
- The structure static system has been considered as a possible solution to better exploit and minimize the use of the textile net and the overall cost.
- Cast on site joints has been introduced as well as hybrid structures have been designed, combining use of composite and steel reinforcement.

Moreover, in a context as the favela where space is lacking and people have limited resources the architecture is mostly defined by exterior conditions as plot and presence and position of sewer. In detail, space is one of the most important issue in the settlement. During the survey it was noticed how the constructions in Rocinha tend to have thin walls and scaffolding systems to increase the available interior surface. The new system has to include and embrace architectural issues first of all space lack, to provide a solid and robust answer to Rocinha’s inhabitants necessities. Otherwise this problems would be solved in any case with less reliable solutions by favelados.

Textile reinforcement has the characteristic of being flexible, easy to handle and to fit any mold. A liquid material as concrete has gained more freedom in assuming easily complex shapes. In reference to light and slender proportion inside the favela, aware of the technology potentiality, it has been set as a goal design of an architecture able to emphasize the lightness and the potentialities of the TRC technology.
The further developments are the attempt to provide a solution able to address all these issues. The most important question to solve is the pillar joint. To allow the construction of multistorey buildings it is necessary to guarantee the structural continuity of the column, in consequence the possibility to have a cast on site joint would be the most suitable and easiest to put in place. The other question was the slab joint, how to guarantee a good static height. At this purpose the first idea was to rethink the beam shape. Instead of placing the slab on the beam it could be placed inside the beam, guaranteeing a remarkable increasing of static height and the possibility to gain space.
Columns
The columns have been studied to weight less than 100 kg have a compact shapes and at the same time a big inertia. Moreover, the cavities could be used to place the walls and the electric or hydraulic services. Bars have been placed at the joints, on the other hand this solution doesn’t guarantee the minimum concrete coverage requested in case of common bars (4cm), therefore no corrosive materials have to be used.

Beam
The beam have been studied to locate the slab, at the same time its shape allows the use in the base of textile and at the top of punctual reinforcement. Once again the issue of minimum coverage has to be verified, at the same time to guarantee the transportation requirements in terms of weight, the solution would need the use of punctual expensive materials.

Slab
The static height of the slab has been increased. On the other hand the solution works with a simple static scheme and the slab is subjected only to positive moment, which means that the zone where is possible to locate the majority of reinforcement is the compressed one.

Pic.1 3.2.26: detail joint between pillars beam and slabs, system 3;
3.2.2 Final solution

The next step to develop the final solution implies further analysis of the topic of cast in site joints. As seen before, one of the main problems of worksites in favela is the obstacles that construction workers have to face transporting material and mixing concrete on the worksite without tools. That justify the reluctance in employing cast on site joints. On the other hand, cast in site joints represents a cheaper alternative to other solutions, as bolts and mechanical joints that need to be sufficiently durable to resist oxidation.

The other topic that was further developed was the architecture of the system and the space conception, both the plasticity of the element as well as the topic of cantilever that are usually built in the favela to increase the surface of the building. In fact the cantilever is the element that inspired the new system. The TRC technology could be better exploited in the slab, in consequence the design begins with the conception of this element and consequently by the others. In fact it was firstly designed as a cantilever to accentuate the negative moments to better exploit the use of textile reinforcement, that could be easily and widely located on the highest and planar part. The element shapes follow the efforts on the slab emphasizing its lightness and spatial qualities. Finally it lies on the beam which is made of a prefabricated part in textile reinforced concrete and an other cast on site, studied to locate common steel bars. This solution allows to use cheap steel bars, since minimum cover requirements are satisfied and to have different span depending on reinforcement design guaranteeing a better level of flexibility and adaptability.
Pic.1 3.2.2.3 Final system development;
The pillars have been designed to weigh less than 100 kg, in order to be easily transported with lightweight and manual tools. To address structural requirements the pillar has a compressive strength equal to an area-equivalent pillar of few more than 10 cm side. On the other hand, it has an inertia on the most stressed side of 3.4 time bigger. In this preliminary phase the reinforcement layout had been roughly designed with both textile reinforcement to confine concrete and one steel bar in the middle. In detail the number of bar is limited by the necessity to respect the 4 cm coverage imposed by law. The pillar has been conceived as the thinner and lighter possible to enhance the lightness of the system.

Pic.1 3.2.2.4Detail of the final solution, pillar (left), beam (right);
**Cast on site joints**

Cast on site joints have been introduced to guarantee structure continuity and to reduce the size and weight of prefabricated elements. The joints have been designed to guarantee continuity of reinforcement. The joint between slab and beams has been designed to guarantee the continuity of the longitudinal reinforcement. At the same time the shape of the beam guarantees the possibility to locate longitudinal steel bars reinforcement. In consequence the beam span could be increased depending on longitudinal reinforcement and expensive solution as inox or glass fiber bars.

The structural continuity join between beams and pillars is guaranteed by bars, textile reinforcement and poured concrete. Firstly the beams and slabs are placed on the supports. Afterward concrete has to be poured.

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**Pic.1 3.2.2.5 Slab and beam cast on site joint;**

**Pic.1 3.2.2.6 Column and beam cast on site joint;**
Walls

The issue of the walls has not been faced in previous researches. The main reasons is that common bricks walls are the easiest and less expensive constructive element to put in place. Therefore, the main problem is about economic competitiveness of the final solution. The most common typology of wall built in Rocinha is made of one layer of brick, nine centimeter thick, joined by common mortar. Bricks are diffused and one of the cheapest material inside the favela. Rocinha is characterized by a temperate tropical climate. During the coldest month the temperature has an average of 20.6° in the hottest month of 27.5 °. The solar radiation have a minimum angle of 43.5 to a maximum of 89 degrees. In consequence, walls are less subject to overheating than roof, meanwhile there isn’t a need of high insulation layers in winter season.

Pic. 1 3.2.2.7 Slab and wall panel cast on site joint;
Taking in consideration climate conditions as well as construction necessities a system of prefabricated walls have been designed. To address architectural demands one of the main goal was to minimize the wall thickness. Space is valuable in the favela and this issue explains also why commonly walls are extremely thin inside the settlement. Many of the houses have structural problems as unaligned pillars due to the attempt by the owner to enlarge as much as possible the house building. Therefore, space have been considered as a main requirement stressing out the question of acceptable wall thickness to be built in Rocinha, especially whether compared to the employed 8/9 cm wall solution. In this specific case the issue of sustainability that is commonly quantified by technical performances and life cycle has to match specific requirements of such dense urban space. An important topic included in the design of this system is the constructibility. Generally, finishing and external coating layer of envelope are built from the exterior using scaffolding system. In Rocinha, scaffolding are generally avoided due to high cost of the solution and to the lack of physical space between buildings. From this point of view, in an informal and unruled context as Rocinha, a brick wall is a good solution since construction workers could built it from the interior.
In consequence the system has to be built employing the less possible of scaffoldings and eventually should be displaced from the interior. To address all these requirements a system of precasted wall has been designed. It is conceived as a sandwich panel with exterior faces in TRC and infilled with an insulation layer in polyurethane. The solution works with modular panel with variable dimension, width and length, to fit the transportation requirements. These modulus are supposed to be put in place sustained by punctual and temporary reinforcement and after merged with a cast on site joint. The idea was to use common prefabricated concrete panel technology adapting it to Rocinha context. One feature that has been designed is the exterior face finishing. Since the exterior face is made of concrete it is possible to use a mold to change the exterior finishing. This solution has been studied to easily provide variety and to create a dynamic facades. At the same time it was possible to address technical requirement. In this specific case a geometric pattern was used to auto-shade the panels in order to reduce the overall irradiate surface.
Since the solution is made of prefabricated modular walls that are easily piled and merge together by cast on site joints it gives also the freedom to articulate the building envelope depending on boundaries conditions. Window surfaces could be eventually increased or decreased depending on orientation and space uses.

Pic.1 3.2.2.9 Wall sandwich panel;
Construction

In Rocinha the construction market is dynamic and rentable. Despite the city is overcrowded it is full of worksites and new constructions due to the strategic position of the settlement inside the city of Rio de Janeiro. The community has a big potential in terms of unskilled workforce, on the other hand there is a total absence of skilled personalities as architects or engineers to guide and manage constructions. Whether this lack would be filled or not in future is almost impossible to predict. The quality of a precast system could be valued depending on the degree of skills necessary to put in place. Nonetheless it is impossible to imagine a worksite managed only by construction workers with low skills and no technical education ahead, which is actually the case of Rocinha. The first system investigated didn’t required the cast on site joints, and as for Lelé’s system, once the elements have been brought to the worksite they have only to be easily assembled. On the other hand this system didn’t satisfy technical requirements. The final solution developed demands that each piece is joined with cast on site joints, as happens for many prefabricated solutions. On the other hand the level of expertise has augmented. As it would be shown below different construction steps need a minimum level of expertise to manage steel bars and concrete joints.

Transportation and system deployment

In Rocinha, due to the informality of the context and the lack of basic rules, it is difficult to manage a possible design for a typical worksite. In fact as seen during the different surveys inside the favela, each worksite is handled differently depending on workmen expertise and location and accessibility to the site. In detail, probably due to the lack of resources and the difficulties to deploy the solution, scaffoldings are rarely employed, non the less cranes or heavy machineries are never employed. Usually the minimal safety requirements are not applied. Wheth-

Pic. 1 3.2.2.10 Argamassa armada channel for the RENUB project of Salvador da Bahia;

Pic. 1 3.2.2.11 Argamassa armada slab displaced by hand by construction workers on an escola transitoria worksite;
er the worksite is no at ground floor barrier or protections are not deployed and in general construction materials are stocked whether there is possible both inside or outside the worksite without caring of the own or others safety. As far as is difficult to foreseen how exactly the argamassa armada elements would be deployed it is possible to design how they would eventually equipped to be easily transported and deployed on the worksite. The main advantage of the TRC technology and of the system developed is the lightness of the solution. In fact each element has been designed to weigh less than 100 kg. As shown by Lelè’s experience, especially with the case of the escola transitoria, elements in argamassa armada could be easily deployed by hands or using simple solutions as temporary scaffoldings or lifters. Lelè’s elements weren’t equipped with special gadget to easily the transportation or the deployment. For this project, since the elements would be eventually transported by hand for medium long distances and probably lifted by hand to be deployed. Therefore each element has been equipped with proper hooks or holes to locate ropes for the transportation and the deployment. In detail, this gadget has to be designed and located while the element is poured. To avoid problems or issues with the formwork and since all the elements would be probably casted vertically each device has been strategically located at the top and the bottom.

Above: Pic.1 3.2.2.12 Transportation detail of trc sandwich wall;
Below: Pic.1 3.2.2.11 Transportation joint of beam and joint beam and pillar;
Construction phases:

Firstly adequate traces and measurement has to be taken to define where foundations would be casted (Phase I). The first step is the excavation of the foundations. They are usually made by plinth foundation connected by beams. In this case the pillars and walls have to be put in place after the deployment of the reinforcement bars ensuring verticality. In consequence the pillar would be embedded on the plinth ensuring a solid tie (Phase II). Consequently beams are put in place and in a second time slabs and walls.
On the same time also scaffoldings and punctual supports have to be put in place as well as all the reinforcement, steel and net reinforcement have to be ensured on place (Phase III). The final step is the casting on site of the joints (Phase IIII). Firstly it would be casted the joint between walls panels and after the joints between beams and slabs. Moreover, regarding the joint between slab in a first phase it would be casted the joint between pillar and beams and in a second place the joint between pillars and pillars, in case of multi store structure.
Pic.1 3.2.2.15 Render of the final solution;
4 Structural analysis

In the previous chapter a system was chosen as eventually suitable for implementation in a context as the Favela of Rocinha. This system allows a certain degree of flexibility, since spans could be changed. Moreover, due to the small size of slab elements they could be easily displaced and stocked. Nevertheless, the deployment on the worksite is more complicated and expensive, due to the necessity of scaffoldings for slabs and poured concrete to fill joints. On the other hand, with this system is possible to add common steel bars for beams and column joints. In consequence, two important goals are achieved: the possibility to design and size the section resistance of the beam without employing expensive solutions as composite reinforcement or expensive stainless steel bars and provide a certain degree of ductility to the structure, meanwhile the lightness of the structure is preserved.

This chapter is focused on predesign of prefabricated TRC slab components. In detail all the system elements have to be verified depending on boundary conditions, as variable loads, number of floor, horizontal loads, etc. On the other hand, the slab is the element where the textile reinforcement proprieties could be better exploited, since it works on both directions. In fact it is the only one where the reinforcement is guarantee only by the use of textile reinforcement. Consequently, a preliminary study about the structural design of the slab element has been carried out to define the most important assets for further designs, as concrete matrix and textile reinforcement.

To better forecast possible employment inside the favela three loads cases have been investigated: intermediate slab, flat roof and small bridge or gangway.
4.1 Preliminary analysis for slab structural design

The slab is the element where the textile reinforcement is more exploited since it could work in both directions as the efforts are distributed. From a structural point of view, due to negative moment, this specific system is the one that exploits better the composite net performances. The tensile area is located on the flange where the maximum area of textile could be located.

Pic. 4.1.1: Static scheme of a generic slab element, transversal and longitudinal scheme.
This preliminary analysis is focused on studying the influence of different variables on the structural resistance at the Ultimate State Limit and on the Serviceability State limit. In detail, since the factor which has the most impact on product cost is the textile reinforcement, different solutions have been investigated. Two typologies of textile reinforcement have been analyzed, both of them having different parameters as material composition, and consequently ultimate resistance, area of the composite filament, and spacing of net have been evaluated.

For a deeper analysis, three different use scenarios have been hypothesized:

Interior
1. Finishing layer in ceramic tiles, dim. 30x30 cm, thk. 0.7 cm;
2. Grout filling for ceramic tiles, thk. 0.4 cm;
3. Cement adhesive for ceramic tiles, \( \lambda = 2.3 \text{ W/mK} \), \( \rho = 2400 \text{ kg/m}^3 \), \( c = 780 \text{ J/kgK} \), thk. 1 cm;
4. Laying and service layer in portland concrete lighted thanks to expanded polystyrene sphere (\( \Theta 2 \text{mm} \)), \( \lambda = 0.104 \text{ W/mK} \), \( \rho = 515 \text{ kg/m}^3 \), \( c = 1000 \text{ J/kgK} \), thk. 5 cm;
5. Acoustic insulation layer in felt sheets for floating floors, thk. 0.6 cm;
6. Floor slab in textile reinforcement concrete, \( \rho = 2500 \text{ kg/m}^3 \), \( c = 780 \text{ J/kgK} \), thk. 2 cm;

Interior
PH. The residential intermediate slab:

Pic. 4.1.3: Example of generic flat roof technical solution.

Exterior
1: Finishing layer in ceramic tiles, dim. 30x30 cm, thk. 0.7 cm;
2: Grout filling for ceramic tiles, thk. 0.4 cm;
3: Cement adhesive for ceramic tiles, \( \lambda = 2.3 \text{ W/mK}, \rho = 2400 \text{ kg/m}^3, c = 780 \text{ J/kgK}, \text{ thk. 1 cm}; \)
4: Leaning layer in concrete, \( \lambda = 2.3 \text{ W/mK}, \rho = 2400 \text{ kg/m}^3, c = 780 \text{ J/kgK}, \text{ thk. 3 cm}; \)
5: Protection layer in sand, \( \lambda = 0.35 \text{ W/mK}, \rho = 1400 \text{ kg/m}^3, c = 800 \text{ J/kgK}, \text{ thk. 1 cm}; \)
6: Nonwoven fabric layer, thk. 0.2 cm;
7: Water proof membrane root-proof in polymer-bitumen, thk. 0.5 cm;
8: Thermal and acoustic insulation layer in high density glass-fiber \( \lambda = 0.037 \text{ W/mK}, \rho = 97 \text{ kg/m}^3, c = 1030 \text{ J/kgK}, \text{ thk. 5.0 cm}; \)
9: Vapor resistant membrane in elastoplastomeric with aluminum reinforcement, thk. 0.4 cm;
10: Protecting and anti-defect base in water based bitumen primer, thk. 0.5 cm;
11: Leaning and service layer in portland concrete lighted thanks to expanded polystyrene sphere (\( \Phi 2\text{mm} \)), \( \lambda = 0.104 \text{ W/mK}, \rho = 515 \text{ kg/m}^3, c = 1000 \text{ J/kgK}, \text{ thk. 8-4 cm}; \)
12: Floor slab in textile reinforcement concrete, \( \rho = 2500 \text{ kg/m}^3, c = 780 \text{ J/kgK}, \text{ thk. 2cm}; \)

C.H. The flat roof:
B. Small bridge or gangway

Pic. 4.1.4: Example of generic Small bridge or gangway.
4.1.1 Method of work and Legislation references:

For the structural analysis was assumed that the basis of simple material laws and well-established assumptions generally employed in ordinary reinforced concrete structural works could be employed, under specific hypothesis for the TRC slab analysis.

The structural analysis and verification had been performed taking as references:

- ABNT NBR 6118 “Projeto de estruturas de concreto - Procedimento”;
- ABNT NBR 6120 “Cargas para o calculo de estruturas de edificaciones”;
- D.M. 14.01.2018 “Norme Tecniche per le costruzioni”;
- EuroCode 2 Design of concrete structures;

Work method:

Work method: The Brazilian norms had been employed for the definition of loads and actions and minimum requirements that employed materials as concrete and reinforcement have to satisfy. On the other hand the EuroCode 2 had been employed to perform an analytical structural analysis and verification of the chosen solutions. The TRC is a developing technology still not regulated by shared laws. In consequence, to describe the tensile response of the materials behavior, textile reinforcement and mortar, an analytical model had been defined on previous researches carried out in the I-béton (EPFL) laboratories. According to the project hypothesis formulated in chapter 1.3 part 1, this implies the assumption that the same materials, employed for the epfl researches would be employed for the structural verification too. As would be further explained this implies the choice of a similar concrete matrix and textile reinforcement studied at the EPFL of which a database about structural behavior is available.

4.1.2 Description of employed materials

Concrete:

Firstly, the concrete chosen for the project has to address to the minimum requirements defined by the Brazilian norm ABNT NBR 6118 “Projeto de estruturas de concreto - Procedimento”.

The project had been set in a Class III (strong) of environmental aggressiveness due to humidity high rates and proximity with the sea.

In consequence the law defines the maximum rate between water and cement and the minimum requirement for mortar resistance. Therefore the ratio between water and cement has to be less than or equal to 0,55, while the mortar, to satisfy the minimum resistance has to belong at least to a class C30.
Since the material employed for the reinforcement, the composite net, isn’t subjected to corrosive phenomena a minimum concrete covering is not required for the slab. Nevertheless further analysis on beams has outlined the necessity to use punctual reinforcement as steel bars. In that case the minimum cover is set by the table 7.2.

Pic. 4.1.5 environmental aggressiveness classes (from: ABNT NBR 6118 Tab. 6.1 Classes de agressividade ambiental).

Pic. 4.1.6: Concrete quality minimum requirements (from: ABNT NBR 6118 Tabela 7.1 - Correspondência entre classe de agressividade e qualidade do concreto).
For the preliminary design had been employed a mix design for the mortar that satisfies the minimum requirements defined by Brazilian law.

Mortar employed:

TRC section small thickness needs to be casted a concrete matrix able to guarantee satisfactory mechanical and durability properties. As a result, cementitious matrices with a fine grained structure are used, that can usually be associated with high mechanical performances. Moreover, the TRC technology requires specific concrete mix to have high flowability and a small aggregate size. The database and the design modes employed in this project, based on EPFL know-how, have been developed with reference to a specific tailored mortar mix that was designed by CemSuisse to be employed in combination with the textile fabrics. The mortar is composed of nearly 40 % binder with low carbon blast furnace cement (CEM III/B), a low amount of high quality micro silica and nearly 60 % aggregate (quartz powder and various quartz sands). The small aggregate size of $d_{g,\text{max}} = 1.60$ mm ensures the penetration of the mortar in-between the reinforcement grid even for higher reinforcement ratios. A very low water-to-cement ratio is also used ($w/c \approx 0.25$) ensuring high mechanical properties and combined with the addition of a second generation superplasticizer (BASF: MasterGlenium ACE 30) to maintain the required fluidity.

Resistance values:

- Compression strength at 68 days ($f_c$) equal to 121 MPa on average, with a standard deviation of 4.04 MPa (results based on 4 tests, two per batch);
- Modulus of elasticity at 68 days ($E_c$) equal to 31.0 GPa on average with a standard deviation of 1.40 GPa (results based on 4 tests, two per batch).
- The average value of the tensile strength $f_{ct}$ = 4.08 MPa and a standard deviation of 0.16 MPa.
Textile reinforcement:

As shown in chapter 1.1 there are different typology of textile reinforcement that could be employed for the TRC technology, each one with different characteristic and economic and environmental impact. On the other hand to As previously explained this chapter is focused on the design and verification of the element based on I-béton know-how based on previous researches. Therefore, two different typology of textile reinforcement has been selected and studied among those already tested and analyzed by the I-béton.

To verify the structural resistance the Eurocode had been employed and the with the following about textile reinforcement:

- The post-peak tensile strength of the mortar is neglected;
- A constant modulus of elasticity for the rovings is assumed since straightening effects of the embedded rovings do not happen;
- For low tensile loads, not exceeding the cracking resistance of the member, perfect bond conditions are assumed between the matrix and textile reinforcement $\varepsilon_c = \varepsilon_{tx}$;
- For load levels exceeding the cracking resistance, a trilinear bond-slip relationship is assumed;
- Crack spacing is assumed to be governed by the grid spacing (and not by the reinforcement ratio)

$$s_m = e_{grid}$$

- All cracks are assumed to develop at the same time, yielding a direct transition from stage I (uncracked response) to stage III (stabilized cracking state);
- The $\eta=0.8$ efficiency factor is introduced to take in account the effects of:
  - Effective cross-area of the rovings, in order to transform the non-uniform stress profile to an equivalent one with a constant stress distribution.
  - The failure load value of embedded rovings is lower than for naked strands. Due to the non-uniform stress distribution, in consequence of undulation of the strand and the concentration of stresses at the edges of a crack.

<table>
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<tr>
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<tr>
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<td>10 mm</td>
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| Atx* for each net element |
| *ftxd = ftx/ γd with γd=1.4 |

<table>
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<th>Value</th>
<th>Unit</th>
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</thead>
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</tbody>
</table>

| Atx* for each net element |
| *ftxd = ftx/ γd with γd=1.4 |

Tab. 4.1.1a Textile reinforcement typology 1;

Tab. 4.1.1b Textile reinforcement typology 2;
4.1.3 Load analysis

The actions operating on the structures can be various and they are classified as:

- **Permanent (f_{g1})**: actions that act throughout the nominal life of the building, whose intensity variation in time is so small that can be considered as a constant.
  They are divided into:
  - Structural elements own weight, f_{g1}^{s};
  - Non-structural elements own weight, f_{g1}^{n};
- **Variable (f_{q1})**: actions that act on the structure with variables values that may differ from one another over time. They are divided into:
  - long term actions: they act with a significant intensity for not a negligible period. They are the variable loads related to the planned use of the buildings, f_{q1}.
  - small term actions: they act for a limited period of time compared to the whole life of the structure; they can be divided into:
    - variable loads by wind action, f_{q2};
- **Exceptional (A)**: actions that occur exceptionally during the nominal life of the structure, such as explosions, impacts and fires;
- **Seismic (E)**: actions deriving from the earthquakes.

For this analysis had been considered the Permanent loads, the variable one, in detail the long term actions that changes by different slab use

5.1.3.1 Structural elements own weight (f_{g1})

This value is provided by the weight of only structural elements employed in the structure. Since all of them are made of TRC (textile reinforced concrete) the value density considered to quantify the structural weight (f_{g1}) was 2.500 kg/m³ (reinforced concrete value). The value for each structural elements, for each shape and height solutions, are reported on the table 4.1.3

<table>
<thead>
<tr>
<th>Area [m²]</th>
<th>Density [kN/m³]</th>
<th>Lin.Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab 0.022</td>
<td>25.00</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Tab. 4.1.2 Structural elements own weight f_{g1}
5.1.3.2 Non-structural elements own weight:

### Tab. 4.1.3 P.H non structural elements own weight $f_{g2}$

<table>
<thead>
<tr>
<th>No</th>
<th>Layer</th>
<th>Thickness [kN/m]</th>
<th>Density [kN/m³]</th>
<th>Weight [kN/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>Finishing layer in ceramic tiles</td>
<td>0.01</td>
<td>23.00</td>
<td>0.16</td>
</tr>
<tr>
<td>2.00</td>
<td>Grout filling for ceramic tiles</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3.00</td>
<td>Cement adhesive for ceramic tiles</td>
<td>0.01</td>
<td>24.00</td>
<td>0.24</td>
</tr>
<tr>
<td>4.00</td>
<td>Leaning and service layer in lighted portland concrete</td>
<td>0.05</td>
<td>10.00</td>
<td>0.50</td>
</tr>
<tr>
<td>5.00</td>
<td>Acoustic insulation layer in felt sheets</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>0.90</td>
</tr>
</tbody>
</table>

### Tab. 4.1.4 C.H. non structural elements own weight $f_{g2}$

<table>
<thead>
<tr>
<th>No</th>
<th>Layer</th>
<th>Thickness [kN/m]</th>
<th>Density [kN/m³]</th>
<th>Weight [kN/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>Finishing layer in ceramic tiles</td>
<td>0.01</td>
<td>23.00</td>
<td>0.16</td>
</tr>
<tr>
<td>2.00</td>
<td>Grout filling for ceramic tiles</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3.00</td>
<td>Cement adhesive for ceramic tiles</td>
<td>0.01</td>
<td>24.00</td>
<td>0.24</td>
</tr>
<tr>
<td>4.00</td>
<td>Leaning layer in concrete</td>
<td>0.03</td>
<td>24.00</td>
<td>0.72</td>
</tr>
<tr>
<td>5.00</td>
<td>Protection layer in sand</td>
<td>0.02</td>
<td>14.00</td>
<td>0.28</td>
</tr>
<tr>
<td>6.00</td>
<td>Nonwoven fabric</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7.00</td>
<td>Water proof membrane</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8.00</td>
<td>Thermal and acoustic insulation layer in high density glass-fiber</td>
<td>0.05</td>
<td>0.97</td>
<td>0.05</td>
</tr>
<tr>
<td>9.00</td>
<td>Vapor resistant membrane</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10.00</td>
<td>Leaning and service layer in lighted portland concrete</td>
<td>0.08</td>
<td>10.00</td>
<td>0.80</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>2.25</td>
</tr>
</tbody>
</table>

About the small bridge or gangway any no structural weight had been considered.
5.1.3.3 Variables loads, Operative loads:
They are depending on the building use and are defined in Table 2 of ABNT NBR 6120. The table 4.1.6 is based on the intended use of the building and shows the values considered for the structural analysis.

<table>
<thead>
<tr>
<th>Technical element</th>
<th>Srf Load [kN/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential area (P.H.)</td>
<td>2.00</td>
</tr>
<tr>
<td>Terrace (C.H.)</td>
<td>3.00</td>
</tr>
<tr>
<td>Bridge (B.)</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Tab. 4.1.5, operative loads (from: Table 2 of ABNT NBR 6120)

5.1.4 Slab structural design

Load combinations factors:
To verify the limit states, the following combinations of actions are defined:
- Fundamental combination, generally used for the ultimate limit states (ULS):
  \[ \gamma_{G1} G_1 + \gamma_{G2} G_2 + \gamma_P P + \gamma_{Q1} Q_{k1} + \gamma_{Q2} \psi_{Q2} * Q_{k2} + \gamma_{Q3} \psi_{Q3} * Q_{k3} + \ldots \]
- Characteristic combination, generally used for the irreversible serviceability limit state (SLS):
  \[ G_1 + G_2 + P + Q_{k1} + \psi_{Q2} * Q_{k2} + \psi_{Q3} * Q_{k3} + \ldots \]
- Frequent load combination, generally used for reversible serviceability limit state (SLS):
  \[ G_1 + G_2 + P + \psi_{Q1} * Q_{k1} + \psi_{Q2} * Q_{k2} + \psi_{Q3} * Q_{k3} + \ldots \]
- Quasi permanent load combination, generally used for reversible serviceability limit state (SLS):
  \[ G_1 + G_2 + P + \psi_{Q1} * Q_{k1} + \psi_{Q2} * Q_{k2} + \psi_{Q3} * Q_{k3} + \ldots \]

Those combinations are multiplied by the coefficients of combination \( \psi_{Q1}, \psi_{Q2}, \psi_{Q3} \) and \( \gamma_{G1}, \gamma_{G2} \).
### Pic 4.1.8: Combination factors $\psi_{ij}$ (from: ABNT NBR 6120 table 2)

<table>
<thead>
<tr>
<th>Combinações de ações</th>
<th>Ações</th>
<th>Permanentes ($g$)</th>
<th>Variáveis ($q$)</th>
<th>Protensão ($p$)</th>
<th>Recalques de apoio e retração</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$D$</td>
<td>$F$</td>
<td>$G$</td>
<td>$T$</td>
</tr>
<tr>
<td>Normais</td>
<td></td>
<td>1,4(^1)</td>
<td>1,0</td>
<td>1,4</td>
<td>1,2</td>
</tr>
<tr>
<td>Especiais ou de construção</td>
<td></td>
<td>1,3</td>
<td>1,0</td>
<td>1,2</td>
<td>1,0</td>
</tr>
<tr>
<td>Excepcionais</td>
<td></td>
<td>1,2</td>
<td>1,0</td>
<td>1,0</td>
<td>0</td>
</tr>
</tbody>
</table>

Onde:
- $D$ é desfavorável,
- $F$ é favorável,
- $G$ representa as cargas variáveis em geral,
- $T$ é a temperatura.

\(^1\)Para as cargas permanentes de pequena variabilidade, como o peso próprio das estruturas, especialmente as pré-moldadas, esse coeficiente pode ser reduzido para 1,3.

### Pic 4.1.9: Combination factors $\gamma_i$ (from: ABNT NBR 6120 table 11.2)

<table>
<thead>
<tr>
<th>Ações</th>
<th>$\gamma_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\psi_4$</td>
<td>$\psi_{1}^{(1)}$</td>
</tr>
<tr>
<td>Locais em que não há predominância de pesos de equipamentos que permanecem fixos por longos períodos de tempo, nem de elevadas concentrações de pessoas 1)</td>
<td>0,5</td>
</tr>
<tr>
<td>Locais em que há predominância de pesos de equipamentos que permanecem fixos por longos períodos de tempo, ou de elevada concentração de pessoas 2)</td>
<td>0,7</td>
</tr>
<tr>
<td>Biblioteca, arquivos, oficinas e garagens</td>
<td>0,8</td>
</tr>
<tr>
<td>Vento</td>
<td>0,6</td>
</tr>
<tr>
<td>Temperatura</td>
<td>0,6</td>
</tr>
</tbody>
</table>

1) Para os valores de $\psi_i$ relativos às pontes e principalmente aos problemas de fadiga, ver seção 23.

2) Edifícios residenciais.

3) Edifícios comerciais, de escritórios, estações e edifícios públicos.
Minimum reinforcement:

The minimum and the maximum reinforcement are defined in the Ec2 § 9.2.1.1

$$A_{s,\text{min}} = 0.26 \left( \frac{f_{ctm}}{f_{yk}} \right) b_t d$$

When:

$$b_t = \text{width of the tension zone}$$

<table>
<thead>
<tr>
<th>Data</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l$</td>
<td>1.00</td>
<td>m</td>
</tr>
<tr>
<td>$h$</td>
<td>0.24</td>
<td>m</td>
</tr>
<tr>
<td>$A_{\text{real}^*}$</td>
<td>23700.00</td>
<td>mm²</td>
</tr>
<tr>
<td>$A_{\text{eq}^{**}}$</td>
<td>22348.00</td>
<td>mm²</td>
</tr>
<tr>
<td>$x_{cg}$</td>
<td>0.00</td>
<td>cm</td>
</tr>
<tr>
<td>$y_{cg}$</td>
<td>207.67</td>
<td>mm</td>
</tr>
<tr>
<td>$l$</td>
<td>62134625</td>
<td>mm⁴</td>
</tr>
</tbody>
</table>

Tab. 4.1.4.1.1 Characteristic value of the slab 2(* equivalent area employed to calculate the structural own weight f(g1))

Therefore, the minimum reinforcement is guaranteed in case of 1 layer of net for the first typology of textile reinforcement and 2 layers for the second typology.
## Loads combinations:

<table>
<thead>
<tr>
<th>Action</th>
<th>Load Section</th>
<th>f</th>
<th>Lin. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>g1</td>
<td>0.56</td>
<td>1.40 - 0.78</td>
<td></td>
</tr>
<tr>
<td>g2</td>
<td>0.90</td>
<td>1.40 - 1.26</td>
<td></td>
</tr>
<tr>
<td>q1</td>
<td>2.00</td>
<td>1.40 - 2.80</td>
<td></td>
</tr>
</tbody>
</table>

**Total:** 4.84

<table>
<thead>
<tr>
<th>Action</th>
<th>Load Section</th>
<th>f</th>
<th>Lin. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>g1</td>
<td>2.25</td>
<td>1.40 - 3.15</td>
<td></td>
</tr>
<tr>
<td>q1</td>
<td>3.00</td>
<td>1.40 - 4.20</td>
<td></td>
</tr>
</tbody>
</table>

**Total:** 8.13

<table>
<thead>
<tr>
<th>Action</th>
<th>Load Section</th>
<th>f</th>
<th>Lin. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>g1</td>
<td>0.56</td>
<td>1.40 - 0.00</td>
<td></td>
</tr>
<tr>
<td>q1</td>
<td>5.00</td>
<td>1.40 - 7.00</td>
<td></td>
</tr>
</tbody>
</table>

**Total:** 7.35

<table>
<thead>
<tr>
<th>Action</th>
<th>Load Section</th>
<th>f</th>
<th>Lin. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>g1</td>
<td>0.00</td>
<td>1.40 - 1.26</td>
<td></td>
</tr>
<tr>
<td>q1</td>
<td>2.00</td>
<td>1.40 - 1.00</td>
<td></td>
</tr>
</tbody>
</table>

**Total:** 2.80

<table>
<thead>
<tr>
<th>Action</th>
<th>Load Section</th>
<th>f</th>
<th>Lin. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>g1</td>
<td>2.25</td>
<td>1.40 - 0.45</td>
<td></td>
</tr>
<tr>
<td>q1</td>
<td>3.00</td>
<td>1.40 - 1.50</td>
<td></td>
</tr>
</tbody>
</table>

**Total:** 3.18

<table>
<thead>
<tr>
<th>Action</th>
<th>Load Section</th>
<th>f</th>
<th>Lin. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>g1</td>
<td>0.00</td>
<td>1.40 - 2.50</td>
<td></td>
</tr>
</tbody>
</table>

**Total:** 3.06
Bending moment:

Previous studies carried out at the I-béton laboratory at the EPFL on few beam samples subjected to simple bending had been employed as reference to describe the flexural response characterized in terms of its moment-curvature relation \((M-x)^n\). The latter is characterized by common behavior during the stage I and II, uncracked and crack development phases, meanwhile the stage III, stabilized cracking phase, is characterized by the structure linear response.

The verification is carried out on the following hypothesis:

- Bernoulli hypothesis, plain sections remains plain;
- Concrete is assumed to behave in a linear-elastic manner in compression and tensile strength of the mortar after cracking is neglected;
- The contribution of the reinforcement in the uncracked stage is considered for the calculation of the centroid \(y_G\) and moment of inertia \(J_{el}\);
- Tension stiffening effects are neglected as the high reinforcement ratio generates a relatively narrow crack spacing;

Stage I: Uncracked response, the tensile strength remains below the tensile strength of the mortar. In consequence the stress distribution in the cross section is linear and the structure behaves in a linear elastic manner.

Stage II: Crack development stage. After cracking the behavior change drastically and the tensile stresses are mainly carried by the reinforcement.

Stage III: Stabilized cracking stage, further increases of the load yield to larger crack openings. The structural response is similar to a linear one and slightly influenced by the tension-stiffening effects.

Pic. 4.1.4.1.2, Flexural response of members reinforced with the selected carbon textile grid (from: VALERI P., FERNÁNDEZ RUIZ M., MUTTONI A. Experimental research on Textile Reinforced Concrete for the development of design tools, Lausanne, 2018)
• The tensile behaviour is governed by the reinforcement assuming linear elastic behaviour of textile reinforcement with a constant reduction factor of $\eta=0.8$ taking into account the effects described by an activation degree $\eta_A$ and an efficiency at failure of $\eta_f$;

• Perfect bond between matrix and reinforcement is assumed (reinforcement is fully anchored at the critical section);

• Textile contribution in the compression zone is neglected;

For the verification on bending resistance the longitudinal section has been studied as a beam, meanwhile the transversal section had been studied as a slab with bidirectional reinforcement.

<table>
<thead>
<tr>
<th>P.H. Intermediate Slab</th>
<th>Span [m]</th>
<th>$p_{(x \text{ dir.})}$ [kN/m]</th>
<th>$\text{Med, max } (x \text{ dir.})$ [kN]</th>
<th>$V_{\text{med, max}}$ [kN]</th>
<th>Span [m]</th>
<th>$p_{(y \text{ dir.})}$ [kN/m]</th>
<th>$\text{Med, max } (y \text{ dir.})$ [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.H. Flat roof</td>
<td>1.50</td>
<td>4.84</td>
<td>5.45</td>
<td>7.27</td>
<td>1.00</td>
<td>4.06</td>
<td>-0.43</td>
</tr>
<tr>
<td>B.H. Gangway</td>
<td>1.50</td>
<td>8.13</td>
<td>9.15</td>
<td>12.20</td>
<td>1.00</td>
<td>7.35</td>
<td>-0.73</td>
</tr>
</tbody>
</table>

Pic. 4.1.4.1.3: Value of ULS efforts for each load scenario.

Longitudinal design:

To verify the longitudinal section the element had been studied as a T shaped beam. In consequence the effective flanges width had been calculated. The effective flanges width value to be employed for structural verification is defined by the $b_{\text{eff}}=553$ mm

Pic. 4.1.4.1.4: Longitudinal section equilibrium (at $x=0$), stage III, under Bernoulli hypothesis (strain and stress distribution).
Transversal design:

The analysis had been carried on verifying the structure on 1 meter section.

To guarantee the equilibrium (the section at Stage III is suppose to behave with a linear response):

\[
Z = C
\]

\[
0.5 \cdot \sigma_c \cdot (b_w \cdot x) = (A_{tx} \cdot \sigma_{txd})
\]

Solving the second degree equation the value x could be calculated:

\[
M_{kd} = A_{tx} \cdot \sigma_{txd} \cdot (d-x/3)
\]

\[
\chi = \varepsilon_{tx} / (d-x)
\]

\[
\varepsilon_c = \chi \cdot x
\]

\[
Z = \sigma_{txd} \cdot A_{tx}
\]

<table>
<thead>
<tr>
<th>x [mm]</th>
<th>(\chi) [1/mm]</th>
<th>(\varepsilon_c) [%]</th>
<th>(E_c) [GPa]</th>
<th>(\sigma_c) [Mpa]</th>
<th>(\sigma_{c,max}) [Mpa]</th>
<th>d [mm]</th>
<th>bw [mm]</th>
<th>C [kN]</th>
<th>C-Z</th>
<th>MRd [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4E-05</td>
<td>0.2372</td>
<td>31</td>
<td>73.5</td>
<td>80.7</td>
<td>230.0</td>
<td>30</td>
<td>63.2</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>57.3</td>
<td>0.71</td>
<td>200.0</td>
<td>1429</td>
<td>1429</td>
<td>0.80</td>
<td>55.3</td>
<td>63.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tab. 4.1.4.1.10 Results of maximum bending moment for mortar resistance class and typology 1 of textile reinforcement.

<table>
<thead>
<tr>
<th>x [mm]</th>
<th>(\chi) [1/mm]</th>
<th>(\varepsilon_c) [%]</th>
<th>(E_c) [GPa]</th>
<th>(\sigma_c) [Mpa]</th>
<th>(\sigma_{c,max}) [Mpa]</th>
<th>d [mm]</th>
<th>bw [mm]</th>
<th>C [kN]</th>
<th>C-Z</th>
<th>MRd [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4E-05</td>
<td>0.2162</td>
<td>31</td>
<td>67.0</td>
<td>80.7</td>
<td>230.0</td>
<td>30</td>
<td>53.7</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>53.4</td>
<td>0.71</td>
<td>200.0</td>
<td>1429</td>
<td>1429</td>
<td>0.80</td>
<td>47.0</td>
<td>53.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tab. 4.1.4.1.11 Bending moment verification for mortar resistance class and typology 2 of textile reinforcement and 2 layers.

Transversal design:

The analysis had been carried on verifying the structure on 1 meter section.
Pic. 4.1.4.1.6: ULS moment on the transversal direction;

Pic. 4.1.4.1.6: Transversal section equilibrium (at x=0), stage III, under Bernoulli hypothesis.

<table>
<thead>
<tr>
<th>x [mm]</th>
<th>( \chi ) [1/mm]</th>
<th>( \varepsilon_c ) %</th>
<th>( E_{cm} ) [Gpa]</th>
<th>( \sigma_c ) [Mpa]</th>
<th>( \sigma_{c,max} ) [Mpa]</th>
<th>d [mm]</th>
<th>bw [mm]</th>
<th>C [kN]</th>
<th>C-Z</th>
<th>MRd [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.2</td>
<td>0.0009</td>
<td>0.7990</td>
<td>31</td>
<td>247.7</td>
<td>80.7</td>
<td>17.5</td>
<td>100</td>
<td>114.4</td>
<td>0</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>( \varepsilon_{tx} ) %</td>
<td>( E_{tx} ) [Gpa]</td>
<td>( \sigma_{tx} ) [Mpa]</td>
<td>( \sigma_{tx,max} ) [Mpa]</td>
<td>( \eta )</td>
<td>( A_{tx} ) [mm²]</td>
<td>( Z ) [kN]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.71</td>
<td>200.0</td>
<td>1428.6</td>
<td>1428.6</td>
<td>0.80</td>
<td>100.0</td>
<td>114.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tab. 4.1.4.1.12 Results of maximum bending moment for mortar resistance class and typology 1 of textile reinforcement.

<table>
<thead>
<tr>
<th>x [mm]</th>
<th>( \chi ) [1/mm]</th>
<th>( \varepsilon_c ) %</th>
<th>( E_{cm} ) [Gpa]</th>
<th>( \sigma_c ) [Mpa]</th>
<th>( \sigma_{c,max} ) [Mpa]</th>
<th>d [mm]</th>
<th>bw [mm]</th>
<th>C [kN]</th>
<th>C-Z</th>
<th>MRd [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.8</td>
<td>0.0007</td>
<td>0.6085</td>
<td>31</td>
<td>188.6</td>
<td>80.7</td>
<td>17.5</td>
<td>100</td>
<td>82.6</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>( \varepsilon_{tx} ) %</td>
<td>( E_{tx} ) [Gpa]</td>
<td>( \sigma_{tx} ) [Mpa]</td>
<td>( \sigma_{tx,max} ) [Mpa]</td>
<td>( \eta )</td>
<td>( A_{tx} ) [mm²]</td>
<td>( Z ) [kN]</td>
<td></td>
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<tr>
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<td>1214.3</td>
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<td>85.0</td>
<td>82.6</td>
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</table>

Tab. 4.1.4.1.13 Bending moment verification for mortar resistance class and typology 2 of textile reinforcement and 4 layers.
Shear force:
The design approach employed was based on the stress field method, (struts angle: $\theta = 45^\circ$).

From the equilibrium:
$R = V_{rd,c} + \frac{(b/2+zcotg\theta)}{q} + C'sen\alpha$ (vertical)
$C=C'cos\alpha + V_{rd,c}(cos\theta/sen\theta)$ (horizontal)
Where (hypothesis $z=0.9d$)
$Z=M_{ed}/0.9d=C$

The maximum value of shear force is at the $x=0$. The reinforcement is constant in all the section since it is made by one or more net layers. On the other hand the static height ($z$) changes in proportion to the shear-force.

The verification to the shear resistance was carried out following the Ec2 § 6.2.3 (Members requiring design shear reinforcement), the shear resistance $V_{rd}$ is the smaller value of:

Shear reinforcement:
$V_{rd,s} = (A_{sw}/s)*z^2*t_{hid} cot\theta$
Where:
$A_{sw}$: area of vertical shear reinforcement
$z=d*0.9$

<table>
<thead>
<tr>
<th>$s$ [mm]</th>
<th>$A_{tw}$ [mm²]</th>
<th>$d$ [mm]</th>
<th>$ft\times d$ [kN/m²]</th>
<th>$\eta$</th>
<th>$V_d$ [kN]</th>
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<td>10</td>
<td>3</td>
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<td>78.9</td>
</tr>
<tr>
<td>20</td>
<td>1.7</td>
<td>230</td>
<td>1214</td>
<td>0.80</td>
<td>19</td>
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</tbody>
</table>
Compression struts:

\[ V_{rd,max} = \theta_{cw} b_w \frac{v_i f_{cd}}{(\cot \theta + \tan \theta)} \]

Where:

\[ v_i = 0.9 - \frac{f_{ck}}{200} \geq 0.5 \quad \text{for } f_{ck} > 60 \text{ Mpa} \]

\[ \alpha_{cw} = \begin{cases} 1 + \frac{\sigma_{cp}}{f_{cd}} & \text{for } 0 < \sigma_{cp} \leq 0.25 f_{cd} \\ 1.25 & \text{for } 0.25 f_{cd} < \sigma_{cp} \leq 0.5 f_{cd} \\ 2.5 \left(1 - \frac{\sigma_{cp}}{f_{cd}}\right) & \text{for } 0.5 f_{cd} < \sigma_{cp} \leq f_{cd} \end{cases} \]

\[ \frac{V_d}{\sin \theta} \]

\[ z \]

\[ z \cos \theta \]

\[ b_w \]

\[ v_m \]

\[ f_{cp} \]

\[ f_{cd} \]

\[ \frac{v_m f_{cp}}{f_{cd}} \]

\[ \alpha_{cw} \]

\[ v \]

\[ V_{rd,max} \]

<table>
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<tr>
<th>P. H.</th>
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<th>207</th>
<th>146</th>
<th>30</th>
<th>2.11</th>
<th>80.7</th>
<th>0.03</th>
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<td>0.5</td>
<td>86.88</td>
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<tr>
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<td>0.04</td>
<td>1.04</td>
<td>0.5</td>
<td>86.73</td>
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Tab. 4.1.4.1.15: Compression struts \( V_{rd,max} \) results.

**SLS, Stress limitation:**

The verification of the stress limitation is carried out following the Ec2 § 7.2 Stress limitation. The maximum tension had to be verified with:

- \( \sigma_c = 0.6 f_{ck} \) (characteristic combination)
- \( \sigma_{tx} = 0.8 f_{tx} \) (characteristic combination)
- \( \sigma_c = 0.45 f_{ck} \) (quasi-permanent loads combination)

To guarantee the equilibrium (with \( x \): neutral axis right after the first cracking):

\[ C-Z = 0 \]

Where:

- \( C = 0.5 \sigma_c b^x \)
- \( Z = \sigma_y A_y \)

\[ 0.5 \sigma_c b^x - \sigma_y A_y = 0 \]

The relationship between \( \sigma_c \) and \( \sigma_{tx} \) can be written as:

\[ \frac{\sigma}{m/(d-x)} = \frac{\sigma}{x} \]

\[ \sigma_{tx} = m \sigma_c (d-x)/x \]
Where:
- \( m = 15 \) represents the homogenization coefficient which takes into account the viscous effects produced by the permanent fraction of loads;
- \( A_s \): Steel bar area depending on the section analyzed

In consequence:

\[
0.5 \sigma_c^* b^* x - (m \sigma_c^* (d-x)/x) A_s = 0
\]

Once solved the second degree expression and excluded the non-admissible solution the equilibrium:

\[
0.5 \sigma_c^* b^* x^*(d-x/3) = M_{Ed}
\]

\( \sigma_c^* \) is obtained both for Characteristic combination and quasi-permanent combination

<table>
<thead>
<tr>
<th>m</th>
<th>bw [mm]</th>
<th>d [mm]</th>
<th>x [mm]</th>
<th>Med [kNm] (Ch.)</th>
<th>Med [kNm] (Qu. P.)</th>
<th>( \sigma_c, \text{Ch} ) [Mpa]</th>
<th>( \sigma_{c, \text{max}}, \text{Ch} ) [Mpa]</th>
<th>( \sigma_c, \text{Qu. P.} ) [Mpa]</th>
<th>( \sigma_{c, \text{max}, \text{Qu. P.}} ) [Mpa]</th>
<th>( \delta t_x, \text{C.H.} ) [Mpa]</th>
<th>( \delta t_{x, \text{max}}, \text{Ch} ) [Mpa]</th>
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<td>230</td>
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<td>4.83</td>
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<td>83.157</td>
<td>1600</td>
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<td>230</td>
<td>123.71</td>
<td>3.44</td>
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<td>4.68</td>
<td>54.45</td>
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Tab. 4.1.4.1.16: ELS stress limitation results for typology 1 of textile reinforcement;

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<th>d [mm]</th>
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<th>Med [kNm] (Qu. P.)</th>
<th>( \sigma_c, \text{Ch} ) [Mpa]</th>
<th>( \sigma_{c, \text{max}}, \text{Ch} ) [Mpa]</th>
<th>( \sigma_c, \text{Qu. P.} ) [Mpa]</th>
<th>( \sigma_{c, \text{max}, \text{Qu. P.}} ) [Mpa]</th>
<th>( \delta t_x, \text{C.H.} ) [Mpa]</th>
<th>( \delta t_{x, \text{max}}, \text{Ch} ) [Mpa]</th>
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<tr>
<td>15</td>
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<td>54.45</td>
<td>620.75</td>
<td>1600</td>
</tr>
</tbody>
</table>

Tab. 4.1.4.1.16: ELS stress limitation results for typology 2 of textile reinforcement;
4.1.5 Conclusion

The structural results shows how that:

- The element has a good resistance and that few layers of textile reinforcement are sufficient to provide enough reinforcement to face with the possible loads scenario.
- The analysis show that eventually bending moment would be the cause of slab failure and not shear-force despite the small thickness of the rib.
- The elements is also verified at the SLS for stress limitation, while about cracking verification has not be carried out since the crack opening path is defined by textile spacing.
- Both the textile fabrics investigated has guarantee sufficient structural resistance therefore for future analysis the textile typology 2 would be employed since the ratio of reinforcement is smaller.

In the next chapter the topic of the slab element would be further experimented and investigated. In fact the analytical predictions and assumptions carried out on this chapter would be experimented and tested thanks to a physical model. Finally, topics as SLS behavior about vibrations and fatigue behavior or technological performances of the elements won't be further investigated.
5 The mock-up

With the support of the I-béton and ALICE laboratory of the EPFL was possible to build a 1:1 slab element and verify the hypothesis previously made. The main output expected from the Mock-up were:
Verification and comparison of the analytical prediction with a final test (Bending on 3 point) both at the ELS and ULS.
- Verification of the constructability of the system and the feasibility of the formwork
- Have an architectural back up to set the spacial qualities of the element.
The main phases of this experimental test were:
- predesign and analytical structural verification of the element
- Design and formwork construction and casting phase
- Experimental test
5.1 predesign and analytical structural verification of the element

The main goal of this test was to verify the design previously developed and verified by analytical predictions. In detail, in the previous phase the reinforcement had been quantified to cope with design moment, which had been identified as the cause of the element failure. In that case the reinforcement was augmented to exploit as much as possible structural capacity of the element. In other words, while designing with composite materials, since they have an elastic behavior, the failure at bending could happen both for fabric failure both for concrete brittle failure. In reference to the section bending behavior explained at chapter 4 part 1, after the comparison of the first crack, at stage 3, the relationship between stress in concrete and textile reinforcement is defined by the curvature $c$ and the equilibrium on the section is imposed for $C=Z$. In consequence, once defined the design mortar and the layout of the element is possible to augment the reinforcement to obtain the maximum resistance moment. For the test 4 layer were employed. In particular, the failure moment is obtained on the concrete side. On the other hand the values are very close to each other and the analytical prediction are based on hypothesis and general assumption that both have a limited degree of precision (e.g. $\eta$) both change based on charge and test conditions (e.g. $b_{eff}$: effective flange activated area).

**Tab 5.1.1, failure bending moment for textile reinforcement failure;**

<table>
<thead>
<tr>
<th>x [mm]</th>
<th>$\chi$ [1/mm]</th>
<th>$\varepsilon_c$</th>
<th>$Ecm$ [Gpa]</th>
<th>$\sigma_c$ [Mpa]</th>
<th>bw [mm]</th>
<th>d [mm]</th>
<th>C [kN]</th>
<th>C-Z</th>
<th>Med [kNm]</th>
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<td></td>
<td></td>
<td>$\varepsilon_t x$</td>
<td>$Etx$ [Gpa]</td>
<td>$\sigma_t x$ [Mpa]</td>
<td>$\eta$</td>
<td>Atx [mm²]</td>
<td>Z [kN]</td>
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<td></td>
<td></td>
<td>0.01</td>
<td>200.0</td>
<td>2000.0</td>
<td>0.80</td>
<td>94.0</td>
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<table>
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<th>x [mm]</th>
<th>$\chi$ [1/mm]</th>
<th>$\varepsilon_c$</th>
<th>$Ecm$ [Gpa]</th>
<th>$\sigma_c$ [Mpa]</th>
<th>bw [mm]</th>
<th>d [mm]</th>
<th>C [kN]</th>
<th>C-Z</th>
<th>Med [kNm]</th>
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<td>27</td>
<td>230.0</td>
<td>122.0</td>
<td>0.0</td>
<td>25.0</td>
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<td></td>
<td></td>
<td>$\varepsilon_t x$</td>
<td>$Etx$ [Gpa]</td>
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<td>$\eta$</td>
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<td>Z [kN]</td>
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<tr>
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<td>0.81%</td>
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<td>122.0</td>
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</table>
5.2 Design and formwork construction and casting phase

As seen in chapter 3 part 1, one of the main issues about to TRC prefabricated elements is the formwork. In fact the thickness of the element as well as its spatial articulation implies difficulties not only in building but also in conceiving the mold. In particular in case of the element in "argamassa armada" designed and prefabricated by Lelè the mold was made of steel. The use of steel was useful both for reuse the mold both for facilitate demolding and retain concrete pressure after the pouring. In this case, since the mold was made only to be used once, it was made entirely of formwork wooden panels at the exception of some steel parts. It was possible to use steel since both the material both cutting and folding machines were available. Before face the construction of the slab element few test were carried out to evaluate both the quantity of superplastycizer to add to the concrete mix design both to evaluate, with the specific employed net, the number of net layer that would fit the 2 cm thickness of the final mold (Pic 5.1.1-3). The formwork was designed to pour in only one time the entire slab element of dimensions: 3x1 meter included e part of beam in the center. The choice to produce only one element, and not to join the two slab with the beam in a second time, was made due to timing reason. As consequence the element was casted horizontally. As experimented previously experiences cast the element vertically would have been more suitable, on the other hand,
er hand an horizontal cast was easier to handle both for the formwork management both to have a better control during the casting phase.

The main issues related to formwork design were:

• Shrinkage of the high strength mortar that can lead to significant actions on the formwork. In consequence punctual reinforcement were added to reinforce the formwork and avoid deformations. (Pic 5.1.4)

• The articulation of horizontal and vertical joints should let sufficient space to let the folding of reinforcement at 90° and consequently cause a local failure during the test phase. In consequence 45° gussets were added. (Pic 5.1.5)

• Locate the tensile net and assure position and spacing between each layer and avoid displacement during the pouring phase. At this purpose different devices were added to the net (Pic 5.1.6, Pic 5.1.7) once the element was casted;

• Manage the joint between steel part and wooden formwork. In this case the metal sheet was mechanically fixed when was possible to remove

Pic 5.1.4, punctual reinforcement for steel reinforcement;

Pic 5.1.5, formwork 45° gussets;

Pic 5.1.6, reinforcement set devices;

Pic 5.1.7, Metal mold sheet;
The screw during the demolding phase (Pic 5.1.7) both the joint was ensured with a specific foam.

- Ensure the uniformity and the planarity of the surface. In this case the planarity of the mold was verified before the casting and a wooden panel was added at the end of the casting phase. This panel was provided with a hole and a cylinder to let air exit the mold.

The mold was built separately in different phases. Firstly the slabs webs, then they were joined with the beam mold, made of wood and steel, at the end the base for the slab were added (Pic:5.1.8). The textile reinforcement as the bars had been added phase by phase once the mold was built (Pic:5.1.9-10). The casting phase was easily handled without concrete leaks. Firstly the beam was slowly casted from one point, to ensure and control the homogeneous distribution of the mortar. Then the slab was easily casted before from the ends to ensure the web fillings then with large quantity of concrete in the middle. At the end a wooden panel was added to ensure the planarity of the surface. Despite it was provided with holes to allow the air out the mold the solution didn’t work properly and the surface was left with random small flaws. On the other hand the other hand it was not a problem during the test since the top part was supposed to be in tension and the value of the moment at the first crack was similar to the one predicted. The element was easily demolded three days after the pouring.
Pic: 5.1.11-13, Slab casting;
Pic:5.1.14-16, Slab casted and post casting treatment;
Pic:5.1.17-18, Slab element;
Pic: 5.1.18-19, Slab element;
5.3 Experimental test

A 3 point bending test was performed to evaluate the ultimate resistance of the slab solution and compare the analytical predictions with the experimental results. The test was set up thanks to the use of 4 sensor U4 for displacement and 2 LVDT to measure vertical displacement. One important thing about the test was the setup of the supports and the application force. They have been arranged in order to avoid local failure, especially at the point of force application. In detail the deformation expected was around 60 mm and on the point where the jack was expected to push pieces of wood were located to avoid the reaching of the maximum stroke before the end of the test. To ensure that the force would be distributed on the element length a steel plate was laid on the beam profile and neoprene was put in between. (Pic: 5.3.1). Finally the test was performed. The element has a good resistance of the element: the element performed a multistage failure, where in comparison to the analytical prediction the elements performed similar and good results at Mr, first crack moment. Meanwhile the elements was subjected to early failure due to an error during the assemble and the element. In detail the insulation layer, added to lighting the structure was supposed to stop where the ribs of the slab meet the beams. Since the layer was continuous the elements failure is probably due to compressive stress, which are maximum in that point, and insufficient height of the compressed zone.

- Good resistance of the element: the element performed a multistage failure, where in comparison to the analytical prediction the elements performed similar and good results at Mr, first crack moment. Meanwhile the elements was subjected to early failure due to an error during the assemble and the element. In detail the insulation layer, added to lighting the structure was supposed to stop where the ribs of the slab meet the beams. Since the layer was continuous the elements failure is probably due to compressive stress, which are maximum in that point, and insufficient height of the compressed zone.
- Good crack opening and good cracking distribution
- Good deflection control: in reference to the load cases analyzed at chapter 4 part 1 the case with the maximum moment at ELS is the flat roof case. In detail the maximum moment is equal to 3.35 kN that corresponds to an equivalent punctual force of 4.46 kN at wich corresponds a deflection of 2.8 mm ≤ 12 mm defined by the Eurocode 7.4.1 deflection control (l/250). Moreover, the element have shown a extremely good overall deflection before and after failure.

Pic: 5.3.1, U4 sensors;
Pic: 5.3.2, LVDT sensors;
Pic: 5.3.3, test arrangement;
Pic:5.3.4, test development;
$F = 26.0\, \text{kN}$
$\Delta_L = 22.7\, \text{mm}$

$M_u = 18.2\, \text{kN}$
$K' = 3.67 \times 10^{-5}\, \text{1/mm}$

Pic: 5.3.5, test results;
Right: Pic:5.3.6, cracks opening on before the slab failure;  
Pic:5.3.7, cracks opening on the compression zone before and after the slab failure;

Right: Pic:5.3.8, Slab element after failure;
Beside the slab test other two elements were tested. Both of them were realized in the field of the unite d’en-
seignement Argamassa armada, a multidisciplinary course that take place every year about the topic of the
TRC technology and Lelè’s argamassa armada work. On the legacy of Lelè work, the curse goal is to study
design and realize in scale 1:1 thin element in concrete employing the TRC technology. In detail, the element
tested were all reproduction of Lelè designs one from gangways projects and one wall element, taken from
Escola Transitoria project. The latter could act both as a wall both as a slab. Both of them were tested with a
3 point bending test.

The gangway element was reinforced only by two glass-fiber bars on the side and by carbon textile reinforce-
ment. On the other hand the central part of the flange was not reinforced. The failure occurs by detachment
of the two part and not due to longitudinal reinforcement failure. On the other hand, the analytical prediction
were closer to the performed ones. Moreover, the element showed a good crack opening and good cracking
distribution. At failure stage shearforce cracks were visible and well distributed all over the element.

\[ F_u = 19.7\, \text{kN} \]
\[ d_u = 40.0\, \text{mm} \]

\[ M_u = 9.8\, \text{kN}\cdot\text{m} \]
\[ K_u = 18.5 \times 10^{-5}\, \text{1/mm} \]

Pic:5.3.9, Gangway element;
About the wall elements, different problems occur when the element was put on the machine test. Firstly, since the element has some imperfection at mid-span the force application point was not placed on the middle. In a second place, due to the large section of the element it didn’t lay entirely on the support. The element failure was brittle and was caused both by bending moment on the transversal direction and by compression zone failure in the longitudinal direction. The element showed many cracks on the web flange.

Generally, both the two elements showed a smaller deflection capacity compared with the project slab element.
6 Conclusion

Finally, as analyzed before in chapter 3.1 part 1 project framing, a list of important requirements was set to compare the final solution with the traditional concrete technology now employed in the favela. In detail, many variables involved in the construction are not countable. For example the cost of the single construction unit has to be augmented considering cost of stockage and transportation. As seen in chapter 2.2 buildings techniques today, the cost of material, depending on stockage and transportation, could be increased from the 50% to 100% or even more. On the other hand, seen the informality of the context, there are not defined parameters to evaluate precisely, depending on each material, the overall cost increasing. Therefore the final comparison have been made evaluating cost without the increasing of price due to transportation and stockage. Meanwhile, the other variables have been evaluated qualitatively or under defined hypothesis. Finally, the comparison have been carried on a sample of 3x3 meters construction with one façade completely open and the rest of the envelope without windows.
Cost

The main issue related to this voice is to obtain reliable price about construction materials. The first step was to look for the equivalent of “prezzario” in Italy or list of generic price, included workforce price, produced by some reliable entities, as the municipality of Rio de Janeiro. Unfortunately, it wasn’t possible to find a price list to quantify the overall construction cost. On the other hand it was possible to find on the website of the trade union of construction workers “Sindicato da Indústria da Construção Civil” the overall price for a residential building in Rio de Janeiro. In fact as stated in the norm ABNT NBR 12721 “Avaliação de custos unitários de construção” translated, Evaluation for unit costs and elaborations of construction budget, the overall cost of the construction, is generally defined taking as reference a similar building. In the trade union website it was possible to find different prices for residential building. Among those it was taken the lowest, which corresponds to a building with low performances and low quality of finishing and construction material employed. This value is reported to be equal to 1.304 R$/m². This value is similar to the one reported by the construction worker during the on site survey in Rocinha in October 2018.

To define the overall cost of the construction with the use of TRC technology a generic building of 6x3 meters was considered. The cost of the structure and the wall has been evaluated assuming that the cost of a composite net has been assumed around 20 €/m² the equivalent of 85 R$/m². The system is meant to be put in place easily and fast and the raw materials cost are high. In consequence, the impact of workforce cost has been evaluated as equal to the 10% of materials price and the enterprise benefit has been considered equal to the 10% too. About the raw material cost it has been taken from construction material Brazilian websites and for the structural concrete it has been used the price of an high performance concrete.

<table>
<thead>
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<th>Element</th>
<th>Work Description</th>
<th>Source</th>
<th>Sigle price(R$)</th>
<th>Quantity</th>
<th>U.M.</th>
<th>Sigle price(R$)</th>
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<td>Deployment of TRC panel</td>
<td>High performance concrete</td>
<td>Leroy merlin Brazil</td>
<td>4</td>
<td>83.3 Kg</td>
<td>333.33</td>
</tr>
<tr>
<td></td>
<td>Textile reinforcement</td>
<td>-</td>
<td>85</td>
<td>2</td>
<td>m²</td>
<td>170.00</td>
</tr>
<tr>
<td></td>
<td>Polyurethane insulation layer (6 cm thk.)</td>
<td>Leroy merlin Brazil</td>
<td>60</td>
<td>1</td>
<td>m²</td>
<td>60.00</td>
</tr>
<tr>
<td></td>
<td>Price (without workforce cost)</td>
<td></td>
<td>563.33</td>
<td></td>
<td></td>
<td>563.33</td>
</tr>
<tr>
<td></td>
<td>Benefit</td>
<td></td>
<td>10%</td>
<td></td>
<td>56.33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Workforce cost in m²</td>
<td></td>
<td>10%</td>
<td></td>
<td>56.33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>676.00</td>
<td></td>
</tr>
</tbody>
</table>

Tab: 6.1, Cost of TRC wall/m²;
### TRC SLAB

<table>
<thead>
<tr>
<th>Element Work Description</th>
<th>Source</th>
<th>Sigle price(R$)</th>
<th>Quantity</th>
<th>U.M.</th>
<th>Sigle price(R$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High performance concrete</td>
<td>Leroy merlin Brazil</td>
<td>4</td>
<td>41.7</td>
<td>Kg</td>
<td>166.67</td>
</tr>
<tr>
<td>Textile reinforcement</td>
<td>-</td>
<td>85</td>
<td>2.25</td>
<td>m²</td>
<td>191.25</td>
</tr>
</tbody>
</table>

Price (without workforce cost) 357.92
Benefit 10% 35.79
Workforce cost in m² 10% 35.79
TOTAL 429.50

---

### TRC STRUCTURE (Pillar, Beam)

<table>
<thead>
<tr>
<th>Element Work Description</th>
<th>Source</th>
<th>Sigle price(R$)</th>
<th>Quantity</th>
<th>U.M.</th>
<th>Sigle price(R$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam (x3 mt)</td>
<td>Leroy merlin Brazil</td>
<td>4</td>
<td>181.3</td>
<td>Kg</td>
<td>725.00</td>
</tr>
<tr>
<td>Textile reinforcement</td>
<td>-</td>
<td>85</td>
<td>2.25</td>
<td>m²</td>
<td>191.25</td>
</tr>
<tr>
<td>Steel bars</td>
<td><a href="https://acos">https://acos</a> ul.com.br/</td>
<td>4.75</td>
<td>9</td>
<td>m</td>
<td>42.75</td>
</tr>
</tbody>
</table>

TOTAL 959.00

<table>
<thead>
<tr>
<th>Element Work Description</th>
<th>Source</th>
<th>Sigle price(R$)</th>
<th>Quantity</th>
<th>U.M.</th>
<th>Sigle price(R$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillars</td>
<td>Leroy merlin Brazil</td>
<td>4</td>
<td>68.75</td>
<td>Kg</td>
<td>275.00</td>
</tr>
<tr>
<td>Textile reinforcement</td>
<td>-</td>
<td>85</td>
<td>2.1</td>
<td>m²</td>
<td>178.50</td>
</tr>
<tr>
<td>Steel bars</td>
<td><a href="https://acos">https://acos</a> ul.com.br/</td>
<td>4.75</td>
<td>3</td>
<td>m</td>
<td>14.25</td>
</tr>
<tr>
<td>Glass fiber bars</td>
<td>Leroy merlin Brazil</td>
<td>3.82</td>
<td>6</td>
<td>m</td>
<td>22.92</td>
</tr>
</tbody>
</table>

Total pillars (2) 981.34
Price (without workforce cost)/m² 107.80
Benefit 10% 10.78
Workforce cost in m² 10% 91.63
TOTAL /m² 210.20

---

Tab: 6.2, Cost of TRC slab/m²;

Tab: 6.3, Cost of TRC structure/m²;
In total only the structure and the envelope would cost around 1997 R$/m². It means an increasing of 50% on the base price and considering the basic equipment as window, leaning layers, finishing and hydraulic and cooling services the final price would probably become the double (2600 R$/m²).

**Transportation**

The transportation incidence change depending on worksites location and how it is reachable, by car using manual tool as carriage or only by men. In this case it was considered the third option, that is the more likely to happen and the comparison have been made with each element: slab, beam and pillar on a sample of 3x3 meters. As explained by Julio, from il sorriso dei miei bimbi, there is not a precise limit of weight that is carried by construction worker. Anyway it was supposed that a single man could carry a maximum of 25 kg. In consequence in case of TRC elements which weight is around 100 Kg it was supposed that 4 men would carry them at the exception of 3 men for the slab element which weights 69.5 Kg.

The comparison show that for built the same module employing traditional materials 1.8 times, almost the double of trips is needed. As seen in chapter 2.2 the transportation increase the material price in general of 50%.

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Quantity</th>
<th>U.M.</th>
<th>Trip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillar</td>
<td>Pillar (3 m)</td>
<td>1</td>
<td>piece</td>
<td>4</td>
</tr>
<tr>
<td>Beam</td>
<td>Beam (3 m)</td>
<td>1</td>
<td>piece</td>
<td>4</td>
</tr>
<tr>
<td>Slab</td>
<td>Slab (1x1.5)</td>
<td>1</td>
<td>piece</td>
<td>3</td>
</tr>
<tr>
<td>Wall</td>
<td>Sandwich wall/m²</td>
<td>1</td>
<td>piece</td>
<td>4</td>
</tr>
<tr>
<td>Cast on site joint (3x3 case)</td>
<td>concrete</td>
<td>196.3</td>
<td>Kg</td>
<td>7.9</td>
</tr>
<tr>
<td>Scaffolding</td>
<td>Punctual support</td>
<td>12.0</td>
<td>piece</td>
<td>4</td>
</tr>
<tr>
<td><strong>TOTAL 3X3 case</strong></td>
<td></td>
<td></td>
<td></td>
<td>150</td>
</tr>
</tbody>
</table>

Tab: 6.4, Transportation trips needed for a 3x3 TRC structure case;
<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Quantity (kg)</th>
<th>U.M.</th>
<th>Trip</th>
</tr>
</thead>
<tbody>
<tr>
<td>concrete</td>
<td></td>
<td>93.75</td>
<td>Kg</td>
<td>3.75</td>
</tr>
<tr>
<td>PRECAST concrete</td>
<td></td>
<td>62.5</td>
<td>Kg</td>
<td>2.5</td>
</tr>
<tr>
<td>Slab beam (30x10 cm)</td>
<td></td>
<td>145.8</td>
<td>Kg</td>
<td>5.83</td>
</tr>
<tr>
<td>Wall brick</td>
<td></td>
<td>2</td>
<td>piece/m²</td>
<td>-</td>
</tr>
<tr>
<td>Wall bricks</td>
<td></td>
<td>8</td>
<td>piece</td>
<td>-</td>
</tr>
<tr>
<td>Brick wall</td>
<td></td>
<td>40.0</td>
<td>Kg</td>
<td>1.60</td>
</tr>
<tr>
<td>Wall bricks</td>
<td></td>
<td>166666.6</td>
<td>piece</td>
<td>-</td>
</tr>
</tbody>
</table>

Tab: 6.5, Transportation trips needed for a 3x3 RC traditional structure case;
Stockage

In this case it difficult to state how much this value would influence on the final cost. On the other hand, the employment of a prefabricated could allow to better manage the purchase of materials stocks. As seen in chapter 2.2 the materials in Rocinha are in a first place bought in large quantities and then stocked in small shops in the settlement where they are retailed for a higher price. With a prefabricated solution these steps could be avoided reducing the overall final cost.

Construction

To manage the system is needed a minimum knowledge about concrete structure. Finally to avoid expensive solutions and to reduce the shape of the element, it was chosen to increase the level of skills and expertise required to deploy the system. This choice is justified by the fact that today construction workers are used to manage daily concrete structures in Rocinha. Non the less, their skill, whether sufficiently developed, are based only on empiric knowledge. As seen in the site survey this represent a limits and many times construction workers made basic and relevant errors that could compromise the structure durability and eventually its stability. As would be shown in the next part of the thesis is important to promote the introduction of a new technology providing at the same time a technical and educational support. That could be provided thanks to an hypothetic promoter that would be interest in invest consistently in Rocinha. This scenario is necessary to assets the favelados knowledge on the concrete structure and introduce them to TRC topic. On the other hand, in such informal and instable context, that is affected by internal and external social and politic issues, is extremely difficult to predict whether there would be actors interest in promote educational polices and wheter those could be effective on the long therm.

Conclusion

The final results show a considerable increasing of cost compared to traditional solution. On the other hand, the TRC partially prefabricated technology reduce drastically the impact of transportation and stockage costs and the demands of expertise and the management level on the worksite. The constructions phase are simpler and easily affordable by anyone who has a minimum knowledge in construction field and TRC technology. Furthermore, the durability of the structure is dramatically increased due to the reduction of steel and materials subjected to oxidation. This last issue is nowadays the cause of short life cycle of buildings inside the settlement. Due to harsh conditions as proximity to the sea and to the tropical forest as showed in chapter 2.2, the building structure are subjected to early deterioration and many buildings are abandoned. Finally, the cost factor could be in the future reduced. As explained in chapter 1.3 project hypothesis, the issue of economic sustainability could be faced when composite materials would be more diffused and accessible in the market. Moreover, organic fibers that today are R&D subject, could become a sustainable alternative for textile composite. The employment of this solution would decrease the cost of the solution as the environmental foodprint since they could be produced locally.
PART 2

The first part was focused on the investigation of the project context and the development of a TRC system solution which addresses to precise requirements defined by stakeholders necessities. This second part is focused on the implementation of a facility inside Rocinha which has the task to promote and support the argamassa armada adoption in the community. As said in the previous part one of the main goal about the introduction of a prefabricated system is the decreasing of skills level needed to deploy the solution. As consequence, the system addresses to new construction demands with a system able to exploit and to fit, providing a better quality of the final solution, the low skill labour potential of the community. Construction workers in Rocinha have not a technical background and their know how is based only on empirical experiences on the worksite. In consequence this action is focused both in promoting the new system solution both in providing the indispensable basic skills needed to face construction issues.

The Favela of Rocinha is a complex urban settlement whit structural problems due to basic lack of public services, facilities and infrastructures. While an action is carried out in such sensitive context the goal is to exploit as much as possible the opportunity to act in multiple directions to improve the life quality inside the settlement. At this purpose this project is integrated into the vision of PolimiParaRocinha project. Polimipara-Rocinha, awarded Polisocial project by Politecnico di Milano, is an ongoing project promoted by local actors and supported by the Univerisidade Federale do Rio de Janeiro. It is carried out by a multidisciplinary team leaded by the iMMdesign laboratory. The IMM (Integrated Modification Methodology) have been employed to analyse the favela and pitch the impact of possible local and global actions whether implemented in the community. The project has been carried out in three phases: a preliminary analysis on the global scale to define main project strategies and potential intervention areas, followed by the development pilot project to implement in the selected areaa and finally a retrofitting phase both on local and global scale. Today different areas has been analysed among those a suitable area for the introduction of the argamassa armada have been spotted. Applying the IMM methodology a local urban analysis has been carried out. Consequently, local actions both to support the development and increasing of life quality of the neighbourhood as well to promote the argamassa armada adoption has been carried out. Finally a retrofit has been performed to verify the and measure the impact of actions on the local scale. In consequence, not only an overall improvement of services and infrastructure has been achieved but, at the same time the technological system has been employed to build new service for the local community. Finally the PolimiParaRocinha project integrates the argamassa armada purpose providing a robust and consistent frame about urban context and urban strategic actions to implement locally.
1 General Overview Rocinha and Rio de Janeiro
1.1 Geography and topography

Rio de Janeiro

Brazil is the world’s fifth-largest country by area and the sixth-most populous on Earth. It is the largest state of South America. Until 1960, Rio de Janeiro was the capital of Brazil and its own state before Brasilia became the national capital.

The city of Rio de Janeiro is located on a strip on the Brazilian coast facing the Atlantic Ocean. It is close to the Capricorn’s tropic, in an area where the shoreline is oriented east–west. It is located at those geographic coordinates: latitude 22°54’25” S longitude 43°11’17” W.

Rio de Janeiro has grown surrounded by the sea and high rock complex. If we take a look at the topography of Rio de Janeiro, we can see that Rio de Janeiro’s area starts at the sea level to 1000 m at the Pico da Tijuca. Rio de Janeiro’s topography is characterized by its special hill’s morphology called “Pão de Açúcar” or “sugar loaf”. Those hills have been shaped by the wind giving them this rounded appearance. It is also surrounded by the sea. Another main recognizable mountain in Rio de Janeiro is surely Corcovado, because the famous statue of the Christ the Redeemer was built on it.

The Christ Redeemer is erected on one of the most recognisable mountain of Rio: the Corcovado. Another remarkable mountain is Pedra da Gavea, which is the highest monolithic mountain (844 m above sea level) that goes in the ocean. It is in the Parque Nacional da Tijuca. This park covers a 32
km² area. It is known for being the biggest urban forest worldwide and counting between 6 and 9.5 million trees in it.

The topography defines where different social classes live. From the sea level until the topography becomes steeper, the inhabitants belong to the high and medium class. Higher, there is the poorest areas of the city, the slum or favelas. Each favela is a city inside the city. Even if the poverty level can be extreme, there plenty of commercial activities.

The metropolitan area of Rio de Janeiro is 1182,3 km² wide. It can be divided in four: Downtown, the South Zone, the North Zone and the West Zones. Downtown can be defined as the historic centre and the financial district. Along the coast, from Downtown to the South Zone, there are three of the major beaches: Copacabana, Ipanema and Leblon. They are parts of the major touristic attractions of the city. The high and medium class are located in the South Zone, when the favelas (where the poorest live) are located in the North Zone. The favelas are usually situated next to some major landmarks like the Maracanã Stadium or the train station that leads the persons to the statue of the Christ the Redeemer.

The West Zone makes up more than 50% of the city area. It also has many touristic attractions and historic sites.

With more than 12,8 million inhabitants, Rio de Janeiro is the second most populated city in the all country. It is also the capital of the state that has the same name. Rio de Janeiro’s state is third in the country when looking at the number of its inhabitants.
Rocinha is one of many favelas that we can encounter in Rio de Janeiro. It is located in the South Zone. Its area is defined on the north side by a range of mountain, on the south by the Morro dois Irmãos and on the west and east side by Gávea and São Conrado areas. The favela is spread on a sloppy soil which extends from the sea up to an altitude of 300 m on a pass to Gávea. At the bottom, it is along the highway that connects Gávea to Leblon. The number of inhabitants in Rocinha goes from the official estimates of 70’000 up to 200’000 according to some unofficial estimations. Therefore, the ratio of inhabitants per km² oscillates between 48’611 and 138’890 on this small surface of 1.44 km².

Pic 1.1.7 Picture of Rocinha and two brother mountains, Pedra Bonita, ph. Sandie Kate Fenton, Oct. 2018;
1.2 Climate analysis

According to the Köppen climate classification, one of the most widely used climate classification systems, Rio de Janeiro is characterized by a tropical savannah climate (Aw) influenced by a tropical monsoon climate (Am). The city presents a relatively fresh season from May to October and a hot and muggy season form December to March, months also characterized by long periods of heavy rain. Actually, the rainfalls are frequent almost the whole year. Indeed, in the city, the annual precipitation average is about 1099.8 mm and the month with the higher precipitation average is December with 137.2 mm.

Temperature

The annual average temperature of Rio De Janeiro is 24.2°C. Typically the warmest month is February with standard temperature of 27.5°C, while the coolest month is July, with an average temperature of 21°C. The highest temperatures are concentrated between the months of December and March, when the maximum average temperature is above 32.9 °C and minimum one is around 22.2 °C. Indeed, from June to September, the coolest period, the average temperature is between 27.6 °C and 17.6 °C. Furthermore, according to the Köppen analysis, during the year there are 129 days which present a temperature above 32 °C and 276 days with a temperature above 26 °C.

The most important factors that influence the temperature are the winds and sea breezes. In winter, from June to September, cold winds and morning sea breezes bring mild temperatures. On the other hand, in summer, from December to March, hot fronts, strongest sea-borne winds (often from an extra-tropical cyclone) and summer evapo-transpiration bring weather reverses or storms. Specifically, the hot fronts are a Inter-tropical Convergence Zone in the form of winds from the Amazon Forest.
Relative humidity

During the whole year the city is subjected to a high relative humidity value of the air, that reaches the annual average value of 75.6%. Throughout the year, the relative humidity ranges from 73.8% in January to 77.6% in June. The high relative humidity in Rio de Janeiro is due to two factors. First, the geographic position and the tropical latitude, then the proximity to the coast and to the Atlantic Ocean. In fact, the city is bathed by warm sea currents, which favors the humid climate.

Precipitations

Regarding rainfall in Rio de Janeiro, the precipitation annual average is 1,100 mm and the rainy days are about 135 per year. Due to the tropical savannah climate, the concentration of rain occurs during the hottest months. Indeed, it’s possible to observe that the value is over 1,000 mm between December and April. The value decreases starting from May and reaches minimum values in July and August. Consequently, the drought is very rare, but it can bound to happen occasionally. The last drought period, the worst in decades, that hits Rio de Janeiro and all the South-East region of Brazil has been registered in 2014/15. The mountainous areas created a barrier to the humid wind coming from the Atlantic. For this reason, in this period in Rio de Janeiro the rainfall became less frequent. During the seasons change, especially in the hottest months, strong storms cause catastrophic floods and landslides.

Atmospheric pressure

The average configuration of the atmospheric pressure is steady because the city is in a tropical area. In September, there is the highest value of the atmo-
spheric pressure, around 1017 mb, while in January there is the lowest one, around 1008 mb. However, the atmospheric pressure goes through variations throughout the day, the so-called barometric tide, presenting two peaks of maximum pressure and two peaks of minimum pressure due to the temperature variation. Finally, it’s possible to observe a slight increase in pressure from 2010 to today.

**Wind**

The winds speed is mostly regular during all the year. However, it’s possible to notice that it decreases during the months of May, June and July and strongly increases in October, November and December. Most of the winds blow from South, and their speed is almost double than the ones coming from other directions. In particular, in the city, dominant winds are southerly during the afternoon and night (sea breeze) and northerly at late night and in the morning (land breeze). Compared with the annual pattern, in spring and summer, when the land surface heating is more intense, the temperature gradient between continent and ocean intensifies the sea breeze circulation and increases the frequency of winds blowing from the south quadrants, while in autumn and winter, winds coming from the southerly direction are less frequent, while the northerly ones increase.

**Solar radiation**

The city of Rio de Janeiro presents high values about the average daily sunshine during the year, around 8 hours per day. This value is mostly constant except for the months of September and October, when the value decrease to 7 hours per day, and January and February, when it increases to 9 hours per day. Rio de Janeiro has one of the highest solar incidences in

Pic 1.2.4 Wind speed analysis;

Pic 1.2.5 Daily sunshine analysis;
the world, due to its location. In fact, it receives a solar radiation of 1.7 MW/m² per annum, and a daily average of global solar radiation of 4.5 kWh/m². These high values are due to the solar altitude angle that is very close to 90°. The day of the year with the highest solar energy is the 8th February, with an average close to 6 kWh/m², on the other hand, the 25th June is the day with the lowest average, close to 3.5 kWh/m².

Rocinha micro-climate

Rocinha presents a particular micro-climate. In summer, winds and sea breezes blow during all day lowering the temperatures perceived but lifting the nighttime temperatures. However, it’s possible to notice a resemblance with the daily average temperature of the city; indeed, in these periods there are maximum average temperatures above 29 °C and minimum average temperatures around 22 °C. On the other hand, in winter, the temperatures are lower than those in the surrounding neighborhoods. Indeed, in this period in Rocinha, the minimum temperatures can reach 14° C. This happens because of the proximity to the Tijuca forest. Other factors that influence Rocinha’s micro-climate are: the proximity to the Atlantic Ocean, the high land use and the heat islands.

The average annual precipitation in Rocinha vary between 800 mm and 1200 mm. Winter is usually dry with only few rainfalls, while summer is humid with occasional torrential rains.
1.3 Historical scenario

Brasil: economic growth

Brazil, with a total surface of 8.5 million square kilometres, is the largest country in both South America and Latin America. It’s the fifth biggest country of the world and the fifth most populous. According to the IBGE census of July 2018 the number of estimated population of Brasil is 208 494 900. Of those approximately the 80% lives in urban areas. Brazil took part to the BRICS (Brazil, Russia, India, China and South Africa), an economical association grouping the countries that, at the beginning of the XXI century were characterized by an emerging economy with high GDP growing rates. Standing to the IMF data (International Monetary Fund) Brazil is currently the 9th world’s biggest economy. From the 1970 the country had played an international role the more and more important, although politics and protectionist had been barriers to economic and social development. In 2010 Brazil was the largest economy of Latin America with a GDP grow of 5%, anyway from the 2014 the country had faced an economical recession that seems to recover from the 2017. Today the economy of Brazil is moderately growing, thanks to internal demand of goods and services, strategic natural resources and a medium level of import and export (25 % of overall GDP). Nevertheless, Brazil hosted international events as the World Cup 2014 and the 2016 Olympic Games.

Since 1970, Brazil has been subjected to transformations from a demographical and political point of view also as consequence of migrations from inner poor regions towards the main urban districts mainly located on the coast. Metropolitan regions, like Rio de Janeiro, has been subjected to political economic and social pressure in results of unemployment and high inequality between rich and the vast majority of the population. Phenomena as “favelization” and marginalization have been consequences of decades of lack of concerning by the government toward the poorest.
Rio de Janeiro

The Portuguese funded the city of Rio de Janeiro after their firstly came in the Guanabara bay on January 1st, 1502. They firstly established on the “Morro do Castelo”, where now is located the historical centre of the city. The Portuguese took advantages of the peculiar topography of the areas and expanded both in north and south direction where mountains were physical barriers against enemies. Already from 1850 as capital of the Empire of Brazil, different investments in the utilities sector, as transportation, sewer system, gas were carried out. In the 1870 the donkey tram and steam train were built. These two infrastructure had driven the city growth. After the 1889, when Brazil became a Republic, Rio de Janeiro were the capital and the flourishing economic, cultural and political centre of the country. At the time in the northern part of the city were located the industrial areas and the workers residential sectors while the south areas were devoted to the richest part of the population. In the middle was located the business centre. Under the mayor Pereira Passos took place the biggest urban transformation of the city. The mayor led by the idea to transform Rio de Janeiro in a “tropical Paris” promoted an Hussmann large scale urban plan the “Reforma Passos”. To face population grown hills were wiped out and new streets were built as “Avenida Beira Mar” used to connect Downtown to Botafogo and “Avenida Atlantica” that contribute to refurbish the neighbourhood of Copacabana. After the Second Word War Rio de Janeiro became an high industrialized centre and in consequence its population increase hugly. New infrastructures and urban management plans were undertaken to face Rio de Janeiro basic requests: the extension of Copacabana Beach, the construction of the Rio-Niteroi Bridge, the extension of the “Perimetral Avenue”, the construction of the oceanic interceptor of the South zone and the construction of the metro lines. Since the income concentration was only located in the south areas of the city, slums were removed to allow the expansion of São Conrado and Barra da Tijuca neighbourhood.

The current structure of Rio de Janeiro is the expression of an evolution process that is at the same time both linear and discontinuous.
The Favelas and Rio de Janeiro

Brazil is one of the most urbanized country of the south America and on the south globe and at the same time one of the country with the highest level of inequalities worldwide. As consequence the largest part of poor people lives in cities. This structural poverty and a constant migration flux from rural areas to main central cities has brought to a fast increase of informal settlements inside the consolidated urban areas commonly known as Favela. The term “favela” is usually associated to high dense informal urban settlements where people exploit land without legacy. This process had been historically named as “favelization” and is still a current topic and a big challenge for many south America urban areas. No titling and missing of a shared formal rules with the city had mainly brought to structural lack of services infrastructures and to a social and political marginalisation of those who lives in favelas. In the city of Rio de Janeiro this phenomena is common and hugely diffused. The most dense informal settlements are located in the southern part of the city, which is the wealthiest with the highest employment and services rate. At the end of XIX century the slavery was abolished in Brazil, during the same decades the city of Rio de Janeiro became the capital of the state. As economic and political centre the city was the destination of many migrants that had left the rural and poorest areas of the country in search of a better life. In Rio the Janeiro the first informal settlement was built by Soldiers waiting to be paid after the war of Canudos (1895 - 1896), in the Bahia state. The soldier’s shacks were located on an area called “morro da favela”. The word used to originally name the first illegal urban aggregation became a generic term “favela” during the 20’s when the number of irregular squatter neighbourhoods increased exponentially. The public authorities tried over decades to destroy and avoid the spreading of favelas without success. The first recognition of informal settlements was documented on the 1930 on the public city plan where all these illegal and urban aggregations where defined as an “aberration”. This bias against poorest parts of the city has brought to rejection of any action of inclusion by those who lived in the formal part of Rio de Janeiro with the consequence of a radical and rooted marginalization and segregation towards who lived in favelas and conjuntos. From a political perspective the only possible solution was destroy
favelas, therefore both any kind of infrastructure and public services were built both the “favelados” used to live on a constant threat of being displaced. In 1975, in consequence of basic services appeals, together the different communities, under government request, elected for each favela a resident’s association. Those together organized coalitions, firstly the Federation of the Favela Associations of Guanabara (FAFEG), and after the Federation of Residents’ Associations of the State of Rio de Janeiro (FAMERJ). The dialog was ended by raising of criminality due to drug business during the 80’s. In the same years the number of favelas as well their population increased drastically, migrants starts to densify the settlements and to vertically built their homes with concrete and bricks. In the 1992 favela were finally included and recognized as public heritage in the Plan Director of Rio de Janeiro. From the beginning till now the expectations of favelados had changed from temporality towards a more permanent and solid perspective but their cultural and social heritage is still stained by marginalisation and social and economic inequality. Whether migration and “favelization” are still ongoing and well known phenomena, favelas are still facing health and social issues. Therefore, it is important to intervene on the urbanization for reducing disparities, but also to enhance the associative and public space, for decreasing the problem of population density and improving the living conditions. The organic development of the favelas is a self-organized process that represents an effective solution from the economic and social point of view, an important lesson regarding urban planning as an ideology and space as an expression of individual power.
Rocinha

In the XVIII century was reported a farm, called Quebra Canghala, between the area of São Conrado and Gávea. This rich area on the border of the forest, now called the Tijuca forest, was exploited to produce coffee and sugar canes, and other small crops in the middle of XIX century. This farm bordered the lands of José Magalhães Seixas and São José da Alagoinha da Gávea, Portuguese people linked to the slavery abolition movement, who encouraged the foundation of the Quilombo of Leblon at the foot of Morro Dois Irmãos. (quilombo was used to identify an African slaves community which escaped from the plantations). The abolition of slavery by Princess Isabella on 13th May 1888, legitimated the community expansion toward the forest where Rocinha stands now. The area was connected with the neighbourhood of Leblon and Ipanema by the Estrada da Gávea, but the first contacts between the offspring of the ex-slaves and the city of Rio de Janeiro was possible thanks to the tram line built in the middle of XIX century.

At the beginning of the XX century, Gávea became an industrial field devoted to the production of textile

Pic 1.3.6, Irregular allotment in Rocinha,(from: Museu Sankofa archive);
products and shoes. In the ‘20s, a powerful company “The Company Castro Guidão” was involved in the agriculture and textile business and owned some farms in Rio de Janeiro among those the Quebra Canhala farm. On the other hand, the government refuses install basic infrastructure on the farm area, in consequence the company started to sold the land to low incoming buyers. As result the farm area was divide in small lots stressing out the main roads that are still recognizable as rua 1,2,3 and 4, in Rocinha today. Since many of the goods as fruit and vegetable produced on this area were sold on the market placed at Largo das Três Vendas, now Santos Dumont Square, in the Gávea the farm land was named Rocinha, that means little garden. In the ‘30s the company went bankrupt and the site was declared without owner and people began to occupy the lots. Consequently, Rocinha grew with standing to any building code with an irregular expansion, self-built by its inhabitants becoming one of the Rio de Janeiro’s favelas. An Italian community, escaped from Europe and from the Second World War, set up its residence in Rocinha taking part to the urbanization of the lowest part of the favela, with the realization of rua Via Ápia da Rocinha and its perpendicular streets with other Italian names. This was the only part of the informal settlement with a regular urban structure. Estrada da Gávea is today the biggest street that cross the whole Rocinha, it has always been a very important street both for the urban set of Rio de Janeiro both for the development of the favela. In the colonial period, it was a mud path that connected Gávea neighbourhood with the coast. In 1916, the road network was improved by the commandant Conrado Jacob de Niemeyer, who realized also Niemeyer Avenue, an extension of Estrada da Gávea along the Atlantic coast, which connected São Conrado with Leblon. The street was paved in 1930 and was equipped with electric light in 1937. Estrada da Gávea was a part of the official circuit Niemeyer-Gávea, a route of 11 km around Morro Dois Irmãos, in the Grand Prix of Rio de Janeiro, from 1st October 1933 to January 1954. On 1st May 1938, the chapel and the school of Nossa Senhora da Boa Viagem were inaugurated in Estrada da Gávea. The church had a very important role for the community consolidation, thanks its engagement in social help for the inhabitants. The Catholic Church created the Leone XIII Foundation, to promote social help for Rio de Janeiro’s favelas and in Rocinha, the foundation the Social Action Centre of São José, inside the local church. The latter had played an important role inside the favela as work and education promotor. Rocinha followed the development of the neighbourhood of Ipanema, Leblon, Gávea, Jardim Botânico and Lagoa until ‘50s. From the ‘60s the local government promoted a favelas removal policy from the south of Rio de Janeiro to free areas for new rich residential areas expansions. Entire favelas as Catacumba in Lagoa Rodrigo were destroyed to build new luxury apartment buildings. The displacement of new homeless favelados and the increasing of migratory fluxes caused an exponential grow of the inhabitants of Rocinha that became the more and more deified. Moreover, in 1972 started the worksite of tunnel Zuzu Angel that cross the two twins mountain underneath Rocinha. Many farmers became bricklayer to work on the construction and they establish their houses around Rocinha. New settlements raised, like Vila Laboriaux, Dionéia, Vila Cruzado and Vila Verde and consequently Rocinha became the biggest favela in Rio de Janeiro. With the population increase were introduced the first basic facilities as institutions and business activities changing the urban structure of the favela. The main revolution was the employment of bricks and concrete for new multi-stores constructions that replaced the existing wooden shacks allowing the
vertical development of the settlement. Rocinha as many other favelas had always been excluded by the government, in consequence resident’s associations were raised to improve and request basic services. In 1993, Rocinha was considered an official neighbourhood by the Prefecture of Rio de Janeiro, which started to collaborate with the inhabitants promoting new development plans for the community. The Plano Setorial da Rocinha acted in the health, hygienic, safety, cultural and social fields by the construction of schools and leisure areas inside the favela. In 2005, the architect Luiz Carlos de Menezes Toledo with his team won a competition for the urbanization of Rocinha, through the development of residential buildings. The architect Oscar Niemeyer designed a pedestrian walkway on the highway, which connected Rocinha with the sport complex, realized some years before. Other projects are promoted in the Plano de Desenvolvimento Sustentável (PDS), the last document inside the Programa de Aceleração do Crescimento na comunidade (PAC), which tried to develop a top down approach focusing on local inhabitants as promoter of Rocinha transformation. On the other hand, the poverty and the social degradation brought to increase of criminality and development of illegal drug business that label the community as place of criminal actions and violence. After a lot of conflicts against the criminal gangs, the state of Rio de Janeiro reclaimed the occupied territories of Rocinha, starting from November 2011, through the installation of a Pacifying Police Unit, a law enforcement and social services program. The 28a Unidade de Polícia Pacificadora (UPP) was installed in Rocinha on 20th September 2012, through a security operation with hundreds of police and military. After few years of peace a new conflicts to control drug traffic in Rocinha and surroundings had started again on September 2017.
1.4 Social analysis

Social data
The data used below refer to the 2010 IBGE census, that is the last analysis performed especially on Rocinha. These data help to understand the demographic trends, the growth rate of the city and the aging rate of the population. Moreover, they represent an important starting point for deeper considerations.

Rio de Janeiro
According to the 2010 INGE census, Rio de Janeiro has a population of 6 320 446 inhabitants, with an increment of 7.9% in the last ten years. During the 20th century, the cities were invested by a huge and fast growth of the population and nowadays the 20% of the inhabitants (about 1 393 314 people) of Rio de Janeiro lives in informal settlements. These numbers refer to the official data, but unofficial ones demonstrate how the real numbers are higher due to the difficulty to realize an accurate census in favelas. Focusing on the city, the number of women and men is quite balanced. However, it’s possible to notice that the number of female inhabitants is higher than the male one. Furthermore, Rio de Janeiro covers a surface of 1 200.177 km\(^2\) and, consequently, it has a population density of only 5 265.82 inhab/km\(^2\). The 2010 IBGE census also analysed the size of the families through the number of muradores (people) per house and the results showed that the 69.4% of families is composed by 2/4 component, while the 13.1% overcame that number and at least the 17.5% of inhabitants is single. Basing on the number of families of Rio de Janeiro (close to 2 144 020), it is possible to obtain an average number of muradores per house, which is 2.62. The population is now divided into four age groups: children between 0 and 14 years old, young people between 15 and 29 years old, adult population between 30 and 64 years old and elderly people over 64 years old. The first group, with a number of 1 226 388 components, represents the 20% of the total population, a percentage close to the second group’s one, which reaches a 24.1% with 1 523 960 of young people. The largest group is the third one, the group of the adult inhabitants, with its 46%. Elderly people represent the 10.5% of the population, since they are only 661 699 people.

To better understand the age distribution of the city, it is interesting to perform the population pyramid, which is a graphical illustration where the vertical axis represents the age and the horizontal axis represents the number of inhabitants referred to that age. The graph is also divided into two parts: the left side refers to male population and the right side to female one. The age pyramid of Rio de Janeiro is characterized by a trapezoidal shape, which means that in the last years the population is going to decrease. This picture contrasts with the growth that has invested the population of the city in the last 10 years, which is not only related to birth and mortality rate, but also depends on the increment of immigration.
Rocinha

Rocinha is composed by two communities: Vila Parque da Cidade and Rocinha itself. According to the 2010 IBGE census, Rocinha has a population of 69,161 people, which is a number that doesn’t reflect the real situation, since unofficial sources show a higher population, of 200,000 inhabitants or maybe more.

The difference between the two sources is connected to the impossibility to realize a well-structured census in this type of favela. The topography of the site permitted a non-organized urbanization, with narrow streets and buildings that don’t follow an understandable structure. Therefore, it becomes quite impossible to arrange a census that can reach the whole territory, also considering that often the inhabitants don’t collaborate and refuse to be registered.

The following analysis and considerations refer to the official data and that means that consider only the registered population, which represents less that the 50% of the real numbers.

The balance between men and women is also present in Rocinha, where the percentage of men is 49.5% (34,125 people) and the women percentage is 50.3% (35,036 inhabitants); these data can be compared to the very close results obtained on the whole city of Rio de Janeiro.

Rocinha covers 1.4 km² of land and this means that considering the official data, the population density, which is about 48,028.47 inhab/km², appears high, but it is not able to show the real numbers that, according to the unofficial sources, reaches 138,888.89 inhab/km².

Another factor that links Rocinha to its city is the size of the family, since in the favela 68.9% of the families is composed by 2/4 components. As happens in the
whole city, there are also families with 6 or more people. The overall number of families in this community is close to 23,347, referring to the official sources, which means that the average size of families is 2.96 mura-
doress, not so far to the 2.62 of the whole city of Rio de Janeiro. The same division in four groups has been operated on the population of the favela and the results show that the percentage of young people (from 0 to 29 years old) reaches the 57%, higher than the Rio de Janeiro’s one, while the percentage of elderly people (over 64 years old) is lower than in the city (3% instead of 10.5%).

For this reason, the population pyramid of Rocinha appears different from the Rio de Janeiro’s one, since the shape is closer to a triangle and emphasizes the ongoing growth of the population of this community. It is important to remember that the previous data came from the official sources and don’t consider the more realistic unofficial sources.

Economic data

The following analysis focuses on the social-economic data about job and average income of the population of Rio de Janeiro and Rocinha and allow to better understand the economy of the territory and the real-life condition of the population. The main source continues to be the 2010 IBGE census and the target of inhabitants that has been considered is characterized by an age over 10 years old.

Rio de Janeiro. According to the IBGE census, the 47.5% of the population of Rio de Janeiro is unemployed, but this number doesn’t take into account the portion of students (about 15%) and retires (the 10.5% of the inhabitants have more than 64 years old). This leads to a decrease of the percentage of the unemployed population until 22%, that represents a clearer and more realist picture of the job scenario of the city. The number of employed people has to be divided into employees and self-employed, which represent relatively the 29.2% and the 10.2% of the whole percentage. Another important factor is the monthly income per capita because it can show significant information about life condition of the families, but also their wealth and poverty rate. According to the 2010 INGE census, there are ten different income brackets, based on the minimum salary of R$ 510.00, which are:

- Until 1/8 times of minimum salary (R$ 0 - R$ 63.75);
- From 1/8 to 1/4 times of minimum salary (R$ 63.75 - R$ 127.50);
- From 1/4 to 1/2 times of minimum salary (R$ 127.50 - R$ 255.00);
- From 1/2 to 1 times of minimum salary (R$ 255.00 - R$ 510.00);
- From 1 to 2 times of minimum salary (R$ 510.00 - R$ 1020.00);
- From 2 to 3 times of minimum salary (R$ 1020.00 - R$ 1530.00);
- From 3 to 5 times of minimum salary (R$ 1530.00 - R$ 2550.00);
- From 5 to 10 times of minimum salary (R$ 2550.00 - R$ 5100.00);
- More than 10 times of minimum salary (R$ 5100.00 and more);
- No minimum salary (R$ 0);

However, the IBGE census considers the first two brackets as under poverty line. In according to the official
sources, the 33.9% of families in Rio de Janeiro are placed between the third and the fifth brackets (from $\frac{1}{2}$ to 2 times of minimum salary) and only few people belong to the poor part of the population.

Rocinha

Referring to the IBGE census, the percentage of unemployed people in Rocinha is lower than the one found in the city, since it is the 40.5% of its population. Subtracting the number of students (26%) and the number of retirees (3%), the percentage falls to 11.5%. In other hands, analysing the monthly income in favela, it appears that the 51.7% of these employees belongs to the same pay scale of the whole city of Rio de Janeiro, while only 3% of the inhabitants or Rocinha stays below the poverty line. This means that the official data show a better economical situation in favela instead of Rio de Janeiro. This comparison clearly makes understandable how the official sources aren’t able to describe the real situation of this community and how a large part of the population in not take into account in these statistics.
2 Project framing by IMM Methodology
2.1 The Global scale

The Integrated Modification Methodology (IMM) is a multistage, iterative design process with the purpose of providing a Complex Adaptive System (CAS) and investigating the relationship between urban morphology and energy consumption. In order to define it, IMM follows a multilayer and multiscale approach aimed to identify the weakest point of the urban context. These points will lead to the identification of a set of Design Ordering Principles (DOPs) which guide the design process and the retrofitting transformation. As first phase, the IMM requires the division of the urban system into two-layer analysis:

- The Horizontal analysis, which focuses on four physical characteristics of the urban texture: Volume, Voids, Function and Transportation;
- The Vertical analysis, which studies the relationships between the previous characteristics and defines six categories: Porosity, Proximity, Diversity, Interface, Accessibility and Effectiveness.

The overlap of the defined vertical levels resulted in the determination of four categories: Compactness, Complexity, Connectivity and Management qualified by numerical indexes. The design process developed by choosing two catalysts, one from the horizontal and one from the vertical analysis and by defining the DOPs principles which guide the design process. Once the design is completed, the last phase of the IMM methodology, called retrofitting, is applied on the final product. This phase evaluates the effectiveness of the interventions and check the changes of the numerical indexes.

Pic. 2.1.1: “The core of the methodology is an iterative process comprised of four main phases. Investigation, being the first phase, is basically creating a model out of the urban system” (from: http://www.immdesignlab.com);
IMM is still a developing methodology, but its scientific approach allows the design team to work also in informal urban environments such as Rocinha. “Po-limiParaRocinha” is an on-going project in collaboration with Polytechnic of Milan, UFRJ university and the ONLUS “Il Sorriso dei Miei Bimbi”. The focus of the project is to promote a sustainable environment for the favela and social inclusion. The project started in 2016 by the first team of former students who developed an accurate investigation phase. Their goal was to summarize the main strengths and weaknesses of Rocinha by detecting the transformation’s Horizontal and Vertical Catalysts. In 2017 following the IMM process, the second team of students better evaluated the intervention areas in order to define a list of DOPs and propose more accurate local solutions called Prototypes. The second phase teams included the Prototypes in design process of each area and afterwards, during the retrofitting phase, the teams assessed the feasibility of the proposed solution at the local scale. At first our work is to assess and insert the prototypes in the design process of a new intervention zone and to accomplish the local scale Retrofitting. Our main role is to achieve a global scale Retrofit that includes the design solution proposed by former teams in order to assess the feasibility and define the global benefits of the interventions.

**Phase I: investigation analysis**

The first phase investigates the physical configuration and characteristics of the CAS represented by the urban system of Rocinha. The main goals of the investigation phase are:

- Knowledge of the physical arrangement;
- Evaluation of the roles and value of the key categories;
- Evaluation of the current energy performance.

Pic. 2.1.2: IMM methodology through an interconnected Phasing Design Process (from: http://www.immdesignlab.com);
2.1.1 Horizontal analysis:

The horizontal investigation is divided in 4 sublayers defined by IMM. Each layer is analysed separately to understand the individual characteristic related to urban configuration (Morphology), socio-cultural space (Typology) and incidence of human activity (Technology).

Volume and voids
The Void-Volume Analysis of the urban texture of Rocinha highlights the absence of urban planning, the lack of open spaces and the presence of narrow passages. These phenomes are the direct consequence of the high density of the site. The population of the community is approximately 200,000 inhabitants concentrated in a space of 1.5 km² and the 80% of the area is built. Furthermore, due to the morphology of the site, the density gradually rises closer to the centre of the favela and decreases where the slope increase.

Function
In collaboration with the UFRJ team, it has been possible to define a list of the most important key-functions present on the site which are: health services, education services, sport facilities, food market, shopping, bar and restaurant, police, post office, bank, waste collection and parks. Thanks to the municipality’s maps, the digital mapping tools and the site visits it has been possible to ascertain the presence of these function which are mainly located along the main streets. Anyway, it’s quite difficult to locate them properly due to the dynamic expansion of the favela.

Transportation
The public mobility of Rocinha is based on: Busses, Mini-Busses and Moto-Taxi. The busses network was easily defined by using the bus stops as reference points, while the catchment areas (approximately 5 minutes walking distance) were delimited using the software www.walkalytics.com. The results of the analysis were irregular shaped catchment areas as a consequence of the morphology of the site. Drawing a precise map of the Moto-Taxi network was more difficult due to the informal nature of the service. Therefore, it was defined by site survey. The general overview of the transportation network shows a high presence of public transportation along the main roads where the main functions and services are located. Furthermore, in 2014 on the occasion of the World Cup, Rocinha was integrated in the metro system of the city. This gives a considerably implemented the connectivity between the favela and the rest of the city.
Pic. 2.1.3 IMM analysis, Volume state of art;

Pic. 2.1.4: IMM analysis, Voids state of art;

Pic. 2.1.5: IMM analysis, Functions state of art;

Pic. 2.1.6: IMM analysis, Transportation state of art;

Functions:
- Bank/Atm
- Post office
- Health services
- Education services
- Sport services
- Waste collection
- Shopping
- Market (food)
- Bar/restaurant

Transportation:
- Bus stop
- Bus
- Moto taxi stop
- Moto taxi
- Taxi bus stop
- Taxi bus
- Subway stop
- Subway

Pic. 2.1.6: IMM analysis, Transportation state of art;
2.1.2 Vertical analysis

The main goal of the vertical investigation is to understand how the horizontal layers are interrelated in order to define the morphological, typological and technological features of the city. These features, called Key Categories, are used to understand the current situation and the performances of the urban context in order to achieve a sustainable urban design intervention.

Porosity
Porosity is a superimposition of the Volume and the Void Layers. Using the “Plano diretor socio-espacial da Rocinha” by Luiz Carlos Toledo were highlighted, using different colours, the buildings according to the number of floors. This gives an immediate vision of the difference height of the buildings. The indicator associated with porosity is Density because the built-up space volume ratio of the site and the inhabitant’s ratio to the volume are all considered as density indicators for the IMM methodology. Porosity is meant to have an optimum span which should be based on the relation with the other key categories and that changes according to the context. The optimal span of every KC highly depends on the vertical relation with other KCs.

Proximity
Proximity is the superimposition of the Volume and the Function layers. Proximity is related to the pedestrian fruitions of spaces and the pedestrian accessibility of the key function types. The key functions must be defined in relation of each case study, the Rocinha Key Functions are: Education space, Administrative service, Entertainment facilities and Commercial facilities. The map resulting from the proximity analysis highlights those areas characterized by high level of proximity as the areas where it’s possible to observe a stronger mix colour. Furthermore, the map shows that the most relevant key functions in the favela are bars and shops which are mostly located along the main streets. It’s also possible to notice that the only waste collectors are located in the south part of the community, difficult to be reached by the inhabitants.

Diversity
Diversity is the superimposition of the Voids and the Functions layers. Diversity classifies the space between buildings into three categories: Necessary regular activities, Necessary occasional activities and Optional activities. With the help of the Brazilian partners it was possible to divide the eleven Key Functions between the three activities listed above:
- Necessary regular activities: educational services, health services, waste collection and food market;
Pic 2.1.7 IMM analysis, Porosity state of art;

Pic 2.1.8 IMM analysis, Proximity state of art;

Pic 2.1.9 IMM analysis, Diversity state of art;
• Necessary occasional activities: bank/atm, police, post offices, parks and shopping;
• Optional activities: bar, restaurants and sport facilities.

The result of the diversity analysis showed the range of different function in each zone and highlighted that the southern part of the Favela and Estrada da Gavea are the most attractive, in fact in these areas the three colours are mixed.

Accessibility

Accessibility is the superimposition of the Transportation and the Function layer. Specifically, it is the number of jobs related to key functions reachable within twenty minutes using the public transportation network. The aim of the analysis is to understand the relationship between key-functions and transportation nodes to highlight the less accessible areas in a city. Since the Transportation and the Function map show the major concentration of nodal points around the same areas (Estrada da Gavea and the southern part of Rocinha), this analysis just confirmed the close correlation between Transportation and Function.

Interface

Interface is the superimposition of the Void and the Transportation layers. It is the indicator of the mobility quality provided by the street network and the efficiency of the urban morphology. To develop the interface map it was used the software “UCL Depthmap”, developed by the University College of London which processes a 2d file calculating the number of intersections within a street grid. The results are shown in a “heat scale” with warmer colours representing a better interface zone. Contrary to previous results, it is possible to spot a great interface zone at the centre of the favela representing the great number of intersections of its street network.

Effectiveness

Effectiveness is the superimposition of Transportation and the Volume layers. It defines the capability of producing a desired result, in terms of Transportation, to cover built volumes around it. At the same time, it also defines the potential development by representing as potential an unbuilt area reachable by public transportation. In Rocinha the potential gradient was considered to be zero since it is unfeasible to plan for any future urban development. Areas with built volume that have good transportation homogeneity were highlighted which are the southern part and the building along Estrada da Gavea.
Pic 2.1.11 IMM analysis, Interface state of art;

Pic 2.1.10 IMM analysis, Accessibility state of art;

Pic 2.1.12 IMM analysis, Effectiveness state of art;

1. **Accessibility**
   - Bus stop
   - Bus
   - Catchment
   - Taxi bus stop
   - Taxi bus
   - Catchment
   - Moto taxi stop
   - Moto taxi
   - Catchment
   - Subway stop
   - Subway
   - Catchment

2. **Interface**

3. **Effectiveness**
   - Bank/Atm
   - Post office
   - Health services
   - Education services
   - Sport services
   - Waste collection
   - Shopping
   - Market (food)
   - Bar/restaurant

Pic 2.1.11 IMM analysis, Interface state of art;

Pic 2.1.12 IMM analysis, Effectiveness state of art;
2.1.3 Phase 2: Formulation

The next phase of the IMM process is called “Formulation Phase” and consists of:

- Choosing the Catalysts, one from the horizontal and one from the vertical investigation;
- Defining the DOPs (Design Ordering Principles).

The main goals of the formulation phase are three:

- The hypothesis of the Catalysts, based on the knowledge obtained in the previous phases, as to explain the CAS configuration, its behaviour and performance;
- Understand the role of the Catalysts in each Sub-system and Key categories;
- Preliminary control of the local consequences of the design choices.

The choice of the catalyst:

**Horizontal analysis: Volume and Voids**

The chosen Horizontal Investigation Catalyst was Volume and Voids, since the urban density of Rocinha is the most problematic aspect that influences all the other parameters. The high density caused by an uncontrolled informal urban texture doesn’t cause only safety and health problems, but also it severely restricts social inclusion. In fact, the poor urban network and the lack of quality urban voids generates a dearth of interaction places within the community. This is demonstrated by the fact that the few existing voids are used as social interaction hubs. In conclusion, the informal dense urban texture is an unfavourable environment for:

- The growth of a capillary and useful Voids network;
- The development of a homogenous and widespread Transportation system;
- A more efficient distribution of Functions.

**Vertical analysis: Interface**

The chosen Vertical Investigation Catalyst was Interface, since, unlike other vertical investigations, Interface is only based on objective data related to the mobility network and its nodes. Furthermore, it was decided to give more importance to the relationship between Voids and Transportation, because the presence of functions comes only after the accessibility and the safety of the place. The choice of the Interface as Catalyst reflects how much the voids can improve daily life of the inhabitants if well connected.
2.2 The local scale

The methodology previously exposed has been used to carry out an urban analysis about the project area and its surroundings. The goals and the main set of the analysis are the same of the global one, on the other hand this local analysis has been updated following the improvements set up by senior students team and already been applied to other local analysis, as the ones on area 5 and 6. Non the less this analysis is able to provide a more complex frame about the local scale, providing a deeper understanding both of needs and weaknesses as well as opportunities and strength of the project site.

IMM analysis on the top part of area 3

The Area 3 (top part)

The top part of the area 3 is a crucial node in the IMM strategic masterplan. The low part of the area is directly connected and close to the Estrada da Gavea, which is the core of all the activities as well where all the public and private transportations are located. On the other hand the highest part, which is highly densified, looks almost isolated both due to the topography both due to the lack of connection and functions. Non the less the top part of the favela, since is hardly reachable, suffers from a lack of basic infrastructure and services. Those conclusion were made observing the analysis on the global scale. This local analysis would give a closer sight to how each factor has a truly impact on this specific area, looking deeper in the potentialities of the area to provide a better frame to define precise and effective strategies to apply the IMM dop’s.

Pic: 2.2.1 view from the bottom of Rua 2, ph. Perego Francesca, Oct. 2018;
2.2.1 Horizontal analysis

The four layers analyzed by the horizontal analysis, Volume Voids Functions and Transportations represents the dismantling in to physical components of the CAS. Each of the is analyzed to define their own characteristics and to provide a better understanding of the urban configuration (Morphology), the socio-cultural space (Typology) and the incidence of human activity (Technology).

Volumes and Voids:
The analysis stress put the high density of the neighborhood. In detail the density percentage is equal to the 84%, higher than the 80% in average of the whole favela. The main voids are given by the vehicle accessible cars as the Estrada da Gavea and the Rua 2. Between the volumes is recognizable the shape of the Rua 1 that cross the buildings on the top part connecting them with the Estrada da Gavea. All the other voids are mainly a consequence of the steep topography that characterize the North-East side of the area. In fact the topography is the main actor in defining the urban morphology together with the main roads which are the main catalyst of the urban scenario.

Functions
The function were checked and spotted during the site survey in October 2018. Non the less to spot the main public functions as schools, health services, garbage collecting points etc. the PAC 2 report, published by the municipality of Rio de Janeiro was taken as reference. The analysis highlight how almost any functions is located on the proximity or facing the Estrada da Gavea or the Rua 2. As seen in the global analysis Estrada da Gavea confirms its role in being the main attractive spot for function and services inside the favela leaving the majority of the built area isolated. Moreover the analysis underlines a structural lack of basic public services as schools and health structures on the area.

Transportation
The public and private transportation stops and bus and Moto taxi were checked and spotted during the site survey in October 2018. Once again the PAC 2 report was taken as reference. From each stops was evaluated the catchment area, the area reachable in 5 minutes walking, with the support of a free online demo: Walkanalytics able to take in account the topography of the site. As in the functions case the analysis highlights the principal role Estrada da Gavea to host main and vital activities of the favela. Non the less this analysis underlines as seen before the isolation of the vast majority of the area and also the exclusion form public transportation of the Rua 2 despite it is accessible by vehicles.
Functions:
- Bank/Atm
- Post office
- Health services
- Education services
- Sport services
- Waste collection
- Shopping
- Market (food)
- Bar/restaurant

Transportation:
- Bus stop
- Bus
- Catchment
- Taxi bus stop
- Taxi bus
- Catchment
- Moto taxi bus
- Moto taxi
- Catchment

Pic. 2.2.3 IMM analysis, Volume state of art;  
Pic. 2.2.4: IMM analysis, Voids state of art;  
Pic. 2.2.5 IMM analysis, Function state of art;  
Pic. 2.2.6: IMM analysis, Transportation state of art;
2.2.2 Vertical analysis

Diversity
Diversity is the superimposition of the Voids and the Functions layers. The key functions previously spotted were subdivided in three key categories: Necessary regular activities: health services, waste collection and food market (NR); Necessary occasional activities: bank/atm, post offices and shopping(NO); Optional activities: bar, restaurants and sport facilities(OP);
The Walkalytics demo was used once again to define the catchment area. The diversity highlight which category of function is the most diffused and the reachable by the majority of the area. In the case of the top par of the area 3 is visible how the most diffuse function are the ones belonging to the category 2, NO, and that the regular activities are lacking. Moreover the majority of them are food market. Once again the is clear and critical the isolation of the North-East part of the area, that is far away from accessible roads.

Accessibly:
Accessibility is the superimposition of the Transportation and the Functions layers. This analysis is focused on evaluating the degree of accessibility of the area spotting the less accessible areas to improve them. This specific analysis obtained by overlapping the horizontal layers, confirms previous statement about how both transportations and functions are located on the main roads and this one are well connected among each other.

Interface
Interface is obtained by the superposition of Transportation and voids. Interface is an indicator of the quality of the network and a clever tool to observe the urban morphology highlighting the efficiency of the connections between voids and urban flow network. In other words, Interface is an indicator of the quality of movement provided by the street networks. On the global scale it was one of the most important indicator, on the other hand at the local scale it has few impact since is largely affected by changes on the whole network rather than by local ones. To evaluate the interface quality was employed the software for the University College of London “UCL Depthmap” The color scale is proportional to the quality of the connection link: a warm color indicates a well-connected and safe street network; meanwhile, a cold color indicates a bad connected street. The Analysis show how the Estrada da Gavea is well connected as the Rua 2. On the other hand the residential North-East part is badly connected, in detail it is visible the path of the Rua 1 which is the main spine of all this residential area. Focusing on the top part of the area 3 is clear how connecting the top part of the Rua 2 with the Rua 1 could be useful to improve the scarce level of connection of this whole neighborhood.
Pic 2.2.7 IMM analysis, Diversity state of art;

Pic 2.2.8 IMM analysis, Accessibility state of art;

Pic. 2.2.9: IMM analysis, Interface state of art;
Effectiveness
As for the analysis on the global scale it was considered the potential gradient of the Effectiveness Key category to be zero since it is unrealistic to plan for any future urban development in such dense area. Despite global analysis the reference grid was reduced to 20 x 20 meters. The highest level of effectiveness are located on the Estrada da Gavea. Moreover, the level of effectiveness along the Rua 2 is still hight thanks to the bus stop at the beginning of Rua 2 on Estrada da Gavea. Once again, in according to previous investigations the Rua 1 and the North/East area have no capability in terms of transportation.

Proximity
Proximity is the superimposition of the Volume and Function layers. Proximity is highly related with the pedestrian fruition of the space and is defined by the number of key functions within a walkable distance. As before the Walkalytics demo was employed to define the catchment area of a 5 minutes walkable distance. The results shows, in coherence with other analysis a great level of superimposition on Estrada da Gavea and a bit lower on Rua 1. On the other hand, once again the majority of the residential area is isolated. Beside the graphical representation an analytical study had been carried out to evaluate with a statistical approach the performance level of the fruition and the walkability of the case study area. This specific analysis have been run only on the project intervention area. Six different indicator were evaluated and quantified to provide a evaluation chart that would be compared with further results in the retrofitting phase. The values analyzed were:

• \( \frac{L_{sw}}{L_{st}} \): Ratio of window shop surface to the total lateral surface on the street level;
• \( \frac{S_{sw}}{S_{st}} \): Ratio of sidewalk surfaces to the total street surface;
• \( \frac{N}{N_t} \): Ratio of number of jobs to the total occupied population;
• \( \frac{S_p}{S_t} \): Ratio of paved surface to the total street surface;
• \( \frac{A_f}{A_t} \): Ratio of functional area to the total built-up area;
• \( \frac{L_{nm}}{L_t} \): The ratio of non-motorized links length to the total street length.

Due to lack of reliable informations about many of the data employed to perform this analysis, on the legacy of porosity analysis performed on the past year the similar approximation have been applied. Nonetheless, this analysis have been performed only on the project area which is smaller than all the IMM analysis area, therefore the precision of parameters evaluation increase.
Effectiveness

Pic. 2.2.10 IMM analysis, Effectiveness state of art;

Proximity:

Intervention area

Pic. 2.2.11a IMM analysis, Proximity state of art;

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSw/LSt</td>
<td>16.67%</td>
</tr>
<tr>
<td>Lnm/Lt</td>
<td>97.45%</td>
</tr>
<tr>
<td>At/At</td>
<td>5.76%</td>
</tr>
<tr>
<td>Sp/St</td>
<td>7.27%</td>
</tr>
<tr>
<td>NJ/Nt</td>
<td>1.12%</td>
</tr>
<tr>
<td>Ssw/St</td>
<td>3.23%</td>
</tr>
</tbody>
</table>

Tab. 2.2.11b IMM analysis, Proximity values;
Porosity

Proximity is the superimposition of the Volume and Voids layers. As for the proximity case an analysis have been performed to evaluate the performance of the Porosity and to compare the obtained results with the Retrofit one. The value anlayzed were:

- **VOLUME**: is given by the ratio between the voids and the volume obtained by the equivalent volum obtained if all the area was built:
  \[ P_s (%) = \frac{V_v}{V_T} = 30.5\% \]
  The value obtained is low, 30.5 due to the high density of Rocinha and consequently of the project area.

- **SURFACE**: This value is obtained taking in consideration only the free lateral surfaces of the buildings. This value was obtained by the 3D model.
  \[ \text{SURF} = \frac{S_v}{(S_v + A_l)} = 62.3\% \]

- **FOOTPRINT**: two parameters are related to the footprint of the area, The coverage:
  \[ \text{COV} = \frac{A_{fp}}{A_T} = 69.5\% \]

- The FAR values is dependent from the number of floors, this value have been normalized with a given coefficient \( n = 5 \):
  \[ \text{FAR} = \frac{A_{fp,\text{floor}} + N_{\text{floor}}^*}{A_T} = 38.9 \]

- **DISTRIBUTION FACTOR**: is influenced by the mutual distances of the buildings in a determined urban context, due to the high density of the urban pattern the value of \( d = 0.5 \) m was taken. With this value was possible to define the number of groups inside the project area. This number describes the site morphology. In fact the distribution factor is close to 1, symptom of high density of the site and of an homogeneous morphology of the urban pattern.
  \[ \text{BDF} = 1 - \frac{(n^* \text{Groups}(d) - 1)}{100} \]

- **NUMBER OF BUILDINGS**: The last value measures the relationship between the site area in hectares with the number of buildings. The factor 150 is given and is defined on the project context:
  \[ \text{NB} = \frac{N_{\text{built}}}{A_T}/150 \]
Porosity:

Intervention area

- 1 floor (3 m height)
- 2 floor (6 m height)
- 3 floor (9 m height)
- 4 floor (12 m height)
- 5 floor (15 m height)
- 6 floor (18 m height)
- 7 floor (21 m height)
- 8 floor (24 m height)

Pic 2.2.12a IMM analysis, Porosity state of art;

Tab 2.2.12b IMM analysis, Porosity values;
2.2.3 Conclusion

As expected the final results don’t differ from the analysis on the global scale. Nonetheless, thanks to this further analysis it was possible to better alphabetize the weakness as well the main opportunities of the CAS on the local scale. The morphology of the urban pattern is the most influent parameter. In fact, a low value of voids and in consequence a weak connection network between the built area and the main streets has brought to the isolation of the residential neighborhood placed on the steepest areas at North-East. This fact was coherently reported by different analysis as accessibility interface, effectiveness and porosity. On the other hand this analysis has also stressed out the potentialities of the area 3 in become a focal nodes to open the access on the Estrada da Gavea at the residential neighborhood now isolated.
2.3 IMM phase II, formulation and assumption

2.3.1 IMM catalyst and pilot projects

The choice of the catalysts
The second phase of the IMM process is called “Formulation Phase”. It was addressed firstly to chose the Catalysts, one from horizontal and vertical investigation. Secondly, to define the DOPs (Design Ordering Principles). During the formulation phase the hypothesis of the Catalysts is made to explain the CAS configuration and its behavior and performance. Afterwards, the role of the Catalysts has to be outlined in each Sub-system and Key categories. Finally a preliminary control on local scale, of consequences due to design choices has to be performed. About horizontal investigation, since density is one on the main problematic and influent aspect of the project the catalyst chosen was Volume (and its complementary Voids). Uncontrolled urban development has negative influence on safety levels, public transportation network and social practices. High volume density and irregular urban texture avoid the growth of a widespread and useful Voids network, needed to develop a transportation system and an efficient distribution of Functions. About vertical investigation Proximity and Interface had been outlined as the weakest. The latter had been considered as a priority since the presence of a better relationship between Voids and Transportation is the base to spur function diffusion. In conclusion, the first team of students was concerned about the Investigation phase, which highlighted all the main strengths and weaknesses of Rocinha summarized by the detection of transformation’s Horizontal and Vertical Catalysts. Thereafter the second team, following IMM methodology principles, focused their studies in revising the project areas and accurately choose the DOPs. On those principles were developed local pilot solutions in coherence with strategies and assets defined on the global scale.

Prototype projects
The prototype projects were developed following Catalysts detection and DOPs choice. Strongly interrelated with global assets, pilot projects are the translation in design of the main principles adapted to local morphology and constraints. Starting from the evaluation of the DOPs, the goal was to develop valuable solutions able to modify and increase the performances levels of the CAS previously evaluated.
Design ordering principles

The DOPs were selected based on the principles suggested by IMM and ordered by importance related to the Catalysts:

1. Create a connected open space system to activate urban metabolism;
2. Implement a water manage system;
3. Prevent the negative impact of waste;
4. Balance the ground use;
5. Promote cycling and reinforce public transportation;
6. Foster the local energy production;
7. Convert the city in a food producer;
8. Foster mixed use spaces;
9. Promote walkability;
10. Change from multi-modality to inter-modality concept;
11. Balance the public transportation potential;
12. Make biodiversity an important part of urban life.

The DOPs were split between four categories: Morphology, Typology, Management and Technology:

Pic. 2.3.1.1 DOP diagram;
The circular diagram shown above illustrates the interrelationships between the DOPs, divided in their classification of morphology, typology, management and technology and their application in the case study of Rocinha:

The main DOP is connected open spaces. Directly related to the Interface catalyst, it creates efficient connections, basic prerequisite to develop other DOPs as balance the public transportation and promote the walkability. Manage public green space is necessary to balance the ground use. In consequence is possible to development biodiversity, and increase the drainage level of the soil. New connections also promote mixed used spaces thanks to the spur of new functions. Among those, vegetable gardens and green equipped areas has to be included to generate biodiversity and transform the complex system in a food producer. One primary issue in Rocinha is the implementation of water management. A proper sewage system is necessary to manage heavy rainfall, especially in the steepest areas of the favela. A better system can also provide potable water and include the reuse of water for cultivations irrigation, indirectly promoting biodiversity. Waste is one of the main problems of Rocinha. The population needs to be supported by an effective system of waste collector based on recycle. This practice can be promoted by implementation of prototype projects such as the biogas plant and the kerosene production. In consequence the production of compost through the biogas plant could support the food production. The promotion of the cyclability is directly related with the IMM Interface Indicators and other DOPs. The implementation of cycle lanes network addresses to, connecting open spaces and balancing the public transportation system. The implementation of proper draining floors to install cycle lane would positively influence the water management DOP. Trough the installation of a PV roof plant could energetically sustain bike sharing system and all other prototype projects, addressing to the local energy production. Managing public lights with renewable self-produced energy can improve safety level and guarantee the connection of the open spaces and indirectly promoting the walkability.
From DOPS to prototypes

By the definition of DOPs, 14 specific prototype projects were selected. These prototypes, once applied in Rocinha would be able to improve the quality of life on the local and global scale.

Below are listed prototype projects and the concerning DOPs:

1. PV panels; DOPs: 6
2. E-Bike sharing; DOPs: 5; 9; 10
3. Public lights; DOPs: 1; 8; 10
4. Biogas plant; DOPs: 3; 6
5. Compost production; DOPs: 3; 7
6. Kerosene production; DOPs: 3; 6
7. Depuration plant; DOPs: 2; 3
8. Detention basin; DOPs: 2
9. Sewage system; DOPs: 2; 3
10. Drainage system; DOPs: 2
11. Downpipes; DOPs: 2
12. Vegetable gardens; DOPs: 1; 4; 7; 12
13. Aquaponics; DOPs: 7; 12
14. Draining floor. DOPs: 2; 4; 9

All the prototype projects work as a combined force with mutual dependencies they have been spitted in 5 different field of intervention: Mobility, Energy, Water, Food and Waste.
2.3.2 Food

Urban agriculture and food education, aquaponic technology

According to the IMM’s DOP: “Convert the city in a food producer” food is one of the main project catalyst. Create local farms and enhance on-site production of healthy food is one of the main asset to improve life quality. Due to the topological and morphological peculiarity of Rocinha, innovative and sustainable strategies of urban agriculture as green roof, vertical farming and aquaponics, had been investigated. Furthermore, to promote this action possible educational politics were studied to foster people engagement and awareness about agricultural production and healthy food consumption. Finally, the promotion of retail of urban farming product could enhance a positive circular economy to support favela and agriculture development.

Urban agriculture, case studies in Rio de Janeiro and rocinha

Urban agriculture is an innovative and sustainable practice the more and more diffused in urban areas. In Rio de Janeiro and Rocinha, urban farming had been widely experimented. Many urban farming projects were studied as inspiration to look for positive and negative aspects able to affect project success. The majority of the project is focused on transform of abandoned or unused urban areas in community gardens, able to sustain locals and eventually be a source of income thank to retail profits. The majority of these projects are founded and supported by ONGs committed to environmental and social issues, as Pro-Natura Association, Air Liquide Foundation and GreenMyFavela. The role of the associations is related to provide basic tools and know-how till locals are able to manage themselves the green spaces. Among different projects the more relevant are:

• Hortas Cariocas: is a community garden managed by the ONG GreenMyFavela and economically supported by Rio de Janeiro’s Municipal Environment Department. The main goal is to provide to the poorest residents both access to healthy food both a small income in return of vegetables retail. In exchange, farmers must donate half of their harvest to public local schools.
• FoodRoof Rio: promotes the use of aquaponic system able to fits on a small roof. The first FoodRoof has been place in the favela of Cantagalo. Unfortunately the project failed due to...
lack of maintenance and indirect effect of solar radiations.

In Rocinha have been experimented different projects as:

• Eco-Parque Vertical Garden is the first vertical garden sponsored by GreenMyFavela project, located in a public space at the entrance of the eco-parque in Rocinha. On a concrete blocks walls local fruit and ornamental plants are grown. Finally the project is managed by volunteers from Rocinha’s community. Eco-Parque Food Garden promoted by GreenMyFavela, is a temporary experiment voted to promote farming and consumption of local vegetable species.

• Rocinha Mais Verde was a children therapeutic garden, close to Rocinha promoted by a partnership between GreenMyFavela and an educational center, Rocinha Mundo da Arte NGO. Despite the project was showcased in 2012 at the United Nations Conference on Sustainable Development, it failed due to safety and management reasons.

• Favela Verde is a non-governmental organisation founded in 2011, which promotes social-environmental friendly projects in the upper part of Rocinha, close to Tijuca National Park. All the projects have been developed promoting participation, people engagement and social innovation through educational activities aiming to foster collective awareness, dialogue, co-creation and action. Due to recent events in Rocinha the association had widely reduced its activity in the community. Although, some projects are still maintained by locals, as the one located in a public school, while a public garden had been abandoned.
Aquaponic technology, UF box

Aquaponic technology is an innovative, circular and integrated system, based on co-habitation and reciprocal support of plants and fish. Fishes’ waste feeds the plants and the latter act as a filter for fishes’ water. The system works thanks to bacteria and microbes, which transform the fish waste in plants nutrients. In details, those bacteria free the water from waste converting ammonia into nitrites and then nitrates. Nitrates are used, combined with water, by plants to grow. Basically, the system goes into this four time stage: firstly, fishes’ waste release ammonia in water, secondly a pump lifts water from the tank to the cultivation growbed, than water drains in the ground and finally plants roots clean the water feeding themselves. Aquaponics is a sustainable solution able to overcome constraints and problem related to traditional systems. It provides an on-site production system able to co-produce fish and plants, meantime avoiding use of pesticides an drastically reducing the amount of water (1/10). Finally, thanks to the small size and simplicity of the system it can be easily placed in dense urban contexts as Rocinha. Seen the benefits, it could be a valuable solution to be applied inside multiple favela’s area. At this purpose, a resilient aquaponics model had been conceived. The reference had been the UFBOX prototype, an independent, compact and movable unit made up of a container and a greenhouse on top. It is able to fit in 20 sqm and to produce 60 kg of fresh fish and 120 kg of fresh vegetables per annum. As seen before, this system had already been applied by VivaRio in Cantalago. Despite the project failure, VivaRio has shown interest in replicate the project. Eventually, displace the empty container of Cantalago could be a first step to introduce Aquaponic in Rocinha’s community. The following section shows aquaponic functioning within the container: This system needs to be adapted to Rocinha constraints, introducing shades to preserve plants and fishes and eventually redesigned to fit future on site spatial issues. Nevertheless, it has economical advantages, since the majority of the expenses are related to the initial purchase and afterwards reduced only to maintenance and fish food. The energy consumption is limited to pump usage and can be supported by alternative energy sources as integrated PV panel. Finally, it is suitable to grow typical Brazilian food as tomatoes, lettuce and beans and Tilapia, a freshwater fish.
Educational path

Since the aquaponic system is an innovative and unknown practice, to ensure project success, it is important for the population to get familiar with the cultivation technique. At this purpose, partnerships with schools and local association has to be promoted to introduce integrated teaching programmes and activities. Firstly population, mainly children, should be educated on general topics like agricultural production, food nutrients, healthy alimentation and disposal of organic waste. In a second time, practical lesson has to take place to introduce new specific themes as aquaponic management.

Community engagement

Meeting and events organized by local association could be the opportunity to promote the aquaponic system implantation. Moreover, politics, similar to those applied in Hertas Cariocas, that involve locals to manage cultivations in exchange of half harvest for local schools, can spur people engagement and foster a circular economy. In this field, this practice could be the starting point for new activities in the community as restaurants and cooking events able to encourage healthy food practices and provide an economical income to those involved. Finally the food waste, obtained from the cultivation, can be used to power the possible biogas systems, supporting a virtuous and sustainable circle inside the community.

Stakeholders

• Il Sorriso dei miei Bimbi;
• Rocinha schools;
• Gastromotiva;
• Baltazar Morgado;
• Edu Figueiredo.
2.3.3 Waste management

Despite Brazil is a high productive country, there is a wide presence of low-income areas, such as favelas, which arise from a social inequality situation. In these informal communities, the inhabitants are often unable or unwilling to pay the taxes for urban services. It is evident that the problem of unpaid taxes plays a key role in the lack of this service. An example is the waste collection management, which accounts for 20-40% of municipal costs (mainly used for collecting and transporting the trash).

In 1993, the inclusion of Rocinha in the neighborhoods of Rio de Janeiro leaded to an introduction of basic services, including health care, education and waste management. Unfortunately, these services don’t satisfy the needs of the community, cause of their partial and inefficient application.

This analysis was focused on the analysis of the waste management, in order to obtain a realistic picture of Rocinha. Thanks to numerous sources, several aspects of the favela have been analysed:

- General context
- Waste quantification and characterization
- Waste management system
- Social aspects

Solid waste management is a basic service, that has a relevant influence on the quality of life in urban environment. The main guidelines used to sort out existing data and identify relevant aspects were UNEP’s ISWM and Wilson’s Wasteaware Benchmark.

Waste flow analysis: quantification and characterisation

Most of the data available on Rocinha came from Comlurb, the official waste management company operating in the Municipality of Rio de Janeiro. Other sources were the “Integrates Solid Waste Management Plan” (PMGIR, 2015), the “Urban, Environmental and Social diagnostic report” for Rocinha (EMOP, 2012) and other reports from EMOP. The Federal University of Rio de Janeiro also performed a study on behalf of the Prefeitura of Rio de Janeiro on waste management in the city (UFRJ, 2015).

The target of the analysis was the identification of the current situation of waste management in Rio de Janeiro, and more deeply in Rocinha. The principal challenge was to separate the different streams of waste:

- Public waste, from street cleaning and sweeping (Comlurb provides bulky waste collectors)
- Household waste
- Construction and demolition waste (RCC)
- Health-care waste (RSS)
Separate collection

In Rio de Janeiro, some type of streams (e.g. waste form industries or big producers) are collected by private actors which covers the 11% of the total amount of collected public waste and the 16% of the total amount of collected households waste. Anyway, information is available only for the final disposal.

Rocinha

Information about Rocinha were only available about public and household waste collected by Comlurb. For this reason, it was necessary to compare the available information about Rio de Janeiro in order to estimate the data about the favela. As assumed before, this estimation was done in relation of a population of 200,000 inhabitants. Results in the following tab.

<table>
<thead>
<tr>
<th>Source</th>
<th>Municipality of Rio de Janeiro</th>
<th>Rocinha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Collected (t/year)</td>
<td>Collected by</td>
</tr>
<tr>
<td>Households</td>
<td>230'805</td>
<td>Private</td>
</tr>
<tr>
<td></td>
<td>1'859'823</td>
<td>Public</td>
</tr>
<tr>
<td>Public</td>
<td>221'547</td>
<td>Private</td>
</tr>
<tr>
<td></td>
<td>105'7047</td>
<td>Public</td>
</tr>
<tr>
<td>PublicGreen</td>
<td>17'679</td>
<td>Public</td>
</tr>
<tr>
<td>FreeRemoval</td>
<td>88'397</td>
<td>Public</td>
</tr>
<tr>
<td>RCC</td>
<td>70'549</td>
<td>Public</td>
</tr>
<tr>
<td>RSS</td>
<td>617</td>
<td>Public</td>
</tr>
<tr>
<td>Separate collection</td>
<td>20'431</td>
<td>Public</td>
</tr>
<tr>
<td>Total MSW</td>
<td><strong>3'566'898</strong></td>
<td></td>
</tr>
</tbody>
</table>

Tab 2.3.3.1 Waste collection per year in Rio de Janeiro and Rocinha;

Households waste production derives by considering the amount collected by Private and Public sector as 58.70% of the total amount of Households waste. Improperly collected Households waste are set to 18870 t/y. Finally, the total produced waste for 2014 is estimated around 60411 t/y (166 t/d), close to the estimate of 152 t/d by EMOP (2012). Considering a population of 200,000 inhabitants, the daily per capita production of total solid waste is estimated in 0.78 kg/d/in., while the daily per capita production of Households waste is estimated in 0.59 kg/d/in.
Characterization of household waste

The waste collection system of Rio de Janeiro was divided in ten areas (Àreas de Planejamento) and Rocinha was part of the AP2 whose data are available from 1994 on. In particular, data referred to Rocinha are only available for 2012, when Comlurb (GPA) performed a survey on 21 favelas in collaboration with the Pacifying Police Unit (UPPs). The households waste covers the 76% of the total solid waste in Rocinha. The following tab presents a comparison of numerical data for Rio de Janeiro and Rocinha. These data will be the basis for further analyses.

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Rio de Janeiro</th>
<th>Rocinha</th>
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</thead>
<tbody>
<tr>
<td>Paper / Cardboard</td>
<td>15.99</td>
<td>11</td>
</tr>
<tr>
<td>Plastic</td>
<td>19.14</td>
<td>21.82</td>
</tr>
<tr>
<td>Glass</td>
<td>3.28</td>
<td>0.5</td>
</tr>
<tr>
<td>Organic matter</td>
<td>53.28</td>
<td>60.67</td>
</tr>
<tr>
<td>Metal</td>
<td>1.57</td>
<td>1.69</td>
</tr>
<tr>
<td>Inert waste</td>
<td>1.81</td>
<td>1.11</td>
</tr>
<tr>
<td>Leaves</td>
<td>1.35</td>
<td>0.32</td>
</tr>
<tr>
<td>Wood</td>
<td>0.34</td>
<td>0</td>
</tr>
<tr>
<td>Rubber &amp; tires</td>
<td>0.22</td>
<td>0.44</td>
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<tr>
<td>Tissues</td>
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<tr>
<td>Leather</td>
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<td>0</td>
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<td>Bones</td>
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<td>0</td>
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<tr>
<td>Coconut</td>
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<td>0</td>
</tr>
<tr>
<td>Paraffin</td>
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<td>0</td>
</tr>
<tr>
<td>E-waste</td>
<td>0.2</td>
<td>1.04</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Specific weight (kg/m3) | 133.02 | 111.17 |
Moisture content (%)    | 36.57  | 39.46  |

Fig. 3.3.3.1 Comparison between Rio de Janeiro, AP2, Rocinha and an average value calculated with its standard deviation;
Waste management in Rocinha

The main source of information for this chapter has been the grey literature published by official authorities (PMGIRS, 2016; EMOP, 2012; UFRJ, 2015), but also the surveys made by Azevedo (2010) which showed a discrepancy between the results of his analysis and the official data published by authorities. The Architect Toledo published a plan for the waste management in Rocinha (Plano de Gerenciamento de Resíduos Sólidos da Comunidade da Rocinha - Plano Diretor de Reurbanização) by arranging a debate with the community, but unfortunately the documents are not available.

Overview of the Waste management system of Rio de Janeiro

Legal framework and existing programs: In Brazil there is a governmental agency responsible for environmental, sanitation and waste management for each administrative level and each of them is touched by the legal framework. At the municipal level, the most important law is the Integrated Solid Waste Management Law, introduced in 2012. Focusing on Rocinha, numerous development programs interested the favela, concerning also the implementation of the separate collection. The aim of these programs was to promote the recycle philosophy through training the population and not only by introducing scavengers of recyclable materials or sorting centres of recyclable materials and scavengers.

Organisation of the WMS: Since 2011, in Rio de Janeiro the logistic system of waste management has been split in three phases: collection (which the main stakeholder is Comlurb), temporary storage (managed by Ciclus) and final disposal. Ciclus is responsible for the construction, operation and maintenance of the Estações de Transferência de Resíduos (ETRs) until 2026. From the ETRs, the waste is delivered to the Waste Treatment Centre (CTR-Rio) in Seropédica which receives waste from other three municipalities.

Collection system in Rocinha

As already mentioned, the collection service of Rocinha is managed by Comlurb, which sends the waste to CTR-Rio Seropédica. Since the company can’t guarantee a full distribution of the service, this leads to huge sanitation problems. The lack of a collection service provokes several negative impacts such as the presence of insects, rodents and snails; the obstruction of the drainage network which causes flood especially in the lower areas of the favela; the obstruction of sidewalks and streets due to the abandoned waste. In 2010, different actors were identified as involved in street cleaning and waste collection. The main actors were Comlurb, SMO (Secretaria Municipal de Obras), SMAC (Secretaria Municipal de Meio Ambiente), which coordinates the two groups of “Guardioes dos Rios” and the Associação dos Moradores that took part in this process. The role assigned to Garis comunitarios, controlled by Associação dos Moradores, has a close relationship with Rocinha, since these street-sweepers are inhabitants of the community. These actors are responsible for door-to-door waste collection, but according to newspapers, this program was interested by several interruption due to safety issues or political events. Furthermore, the lack of regulation and the difficult financial situation led this problem becoming bigger over the time.
The tab below shows the different type of equipment located in Rocinha, according to three different sources: the first is COMLURB1 2016, the second is COMLURB2 2016 and the third is EMOP 2012.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>First source</th>
<th>Second source</th>
<th>Third source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning service employees</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Officers</td>
<td>1</td>
<td>91</td>
<td>100</td>
</tr>
<tr>
<td>Garbage collector</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Community workers</td>
<td>-</td>
<td>46</td>
<td>50</td>
</tr>
<tr>
<td>Vehicles and trucks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mini-tractor</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Tractor loader</td>
<td>2</td>
<td>2</td>
<td>2 (BOBCAT)</td>
</tr>
<tr>
<td>Garbage tricycle</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Garbage compactor (5-7m³)</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Skip loader truck (simple)</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Skip loader truck (double)</td>
<td>2</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Roll-on Roll-off truck</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tipping truck (19m³)</td>
<td>2</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Tipping truck mini</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Container foundations</td>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Compactors containers (15-19m³)</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Compactor containers (6-7m³)</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Skip containers (5-7m³)</td>
<td>11</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Dustbin (0.24m³)</td>
<td>-</td>
<td>78</td>
<td>-</td>
</tr>
<tr>
<td>Dumpster (1.75m³)</td>
<td>-</td>
<td>40</td>
<td>-</td>
</tr>
</tbody>
</table>

Tab. 2.3.3.2 machineries owned by the public waste collection service;
The different numbers pointed out that the actors and the equipment are ever-changing. Moreover, the differences between the dimensions of the equipment are related to the topography of the site and the width of the streets which is a crucial aspect. The collection management is operated by different type of tractors according to the type of vehicles that can reach the collection points, some of whom are only accessible by foot. For this reason, street-sweepings became necessary. Also, the frequency is based on the easy access of the collection points: starting to a frequency of twice per day, it arrives to 4-6 times per week in the most small and remote streets. The map below was realized in 2010 and shows the locations of the collection points and the tractor routes, divided by typology. Through this analyse, it is possible to understand that the most critical points are located on the boundaries and near the forest.

In conclusion, taking into consideration all the data presented below, the results of the two main census, Censo Demográfico 2010 (IBGE, 2010) and the Censo Domiciliar do Rocinha (EMOP, 2010), report that a properly collected waste reaches a value respectively of 93.5% and 98%. Due to the informal data and the site survey is possible to claim that these data can’t describe the real situation in the community. The gap is probably caused by an improper use of the parameters or an incorrect collection of the data. This entails that these results won’t be used as a proper base for the forthcoming analysis.

![Map of waste collection points](image-url)
Assessment of stakeholders and initiatives

A successful waste management system requires the active involvement of the community inhabitants, but one of the main problems is imputable to the lack of trust in the public authorities by the people from the favela. Therefore, it becomes important to involve several actors (public authorities, academy, civil society organisations (CSOs) and non-governmental organisations (NGOs), companies, scavengers from the informal sector); some of them are already engaged in Rocinha. The government have proposed several programmes about waste management, in which Rocinha have been involved. These programs provide not only management plans, but also awareness practical actions and reuse, recycling and energy recovery practical actions. Even though Rocinha appears included as an official neighborhood of Rio de Janeiro, the real application of these programs is not continuous or only mentioned.

A project for Rocinha

Summarizing what previously stated, the issue of waste management in Rocinha is very complex due to the presence of different factors. Even if the Municipality provided to locate collecting point distributed inside the favela, those are insufficient in number and dimension and this leads to several informal deposits of waste along the streets and sidewalks. This behavior is not only implacable to the lack of a qualitative service, but also to inhabitant’s cultural background (related to the rural life style, where the courtyards were also used to dispose of waste).

Due to the previous consideration, it is understandable that creating a new waste management system is not sufficient to solve the situation but sensitize the favelado has an important role in the process.

Proposed strategy

The proposed strategy was to build a collection system parallel to the existing one performed by Comlurb, aiming to divert valuable materials from general waste collection in order to be recycled. The target was introducing the inhabitants that to the recovery and the recycling philosophy with the purpose of teaching them the value of the materials that can be a source of income not only for individuals, but also for the community. This approach considered the involvement of local scavengers, necessary to the success of the program. Another benefit derived by the diversion of recyclable touched the economic point of view because the decrease of collection costs allows the expansion of the project to more areas. Recycling waste on site requires space for storage and treatment processes, which is one of the big constraints in Rocinha; therefore, only a small amount of waste would be interested by the process. The success of the strategy depends on the awareness of the actors and their active participation in the project. To guarantee this point, it will be necessary to engage professional figures, such as sociologist or anthropologist, to raise awareness of this topic in the population of the favela. Furthermore, to obtain high quality secondary raw materials, a separate collection at single household level becomes crucial, and that points out how the environmental awareness of the favelado is basic to the success of the entire strategy.
The main steps of the proposed strategy were the following:

- **Organic waste**: disposed in the existing containers and transformed into compost;
- **Recyclable waste (plastic, paper, metals, e-waste, etc.):** since these fractions have a high potential economic value, the cooperative of scavengers “De Olho no Lixo” should be involved in the collection process. Furthermore, containers for recyclable waste could be installed in strategic places;
- **Awareness programs** will be needed to achieve a good separate collection.

The position of the separate collection points needs to be analysed in relation to each individual case, while the containers could be located along the main streets.

The organic waste could be managed through anaerobic digestion and composting plants, but the application of these methods involves the participation of local population, considering also the availability of land. Concerning recyclable waste, local treatment depends on several factors, as well as the willingness and ability of the cooperative to collaborate.

![Pic. 2.3.3.3 Waste management strategy;](image-url)
2.3.4 Energy and smart grid

Since the 1990s Brazil’s energy demand has been steadily increasing, Brazilian energy market is radically changed. The main energy companies of the country have been forced to review their pricing policy and to increase the energy costs. These financial measures have caused to difficulties in supporting energy expenditure for the most vulnerable social groups, despite the presence of cross-subsidies. The favela has responded to this situation with the use of informal and individual connections (called gato) to the public distribution system as a way to keep electricity bills affordable. The gato spread to wealthy families of the favela, to formal areas and to other public services. This practice has only worsened the problem: the gato are often improvised and precarious connections to the public power grid and they frequently cause fires in low-income areas of shantytowns. The purposes are to fulfill basic electrical needs of low-income households and to establish PV energy as a viable distributed resource to keep the electricity bills affordable, to make legal electrical connections and to serve the smart grid. The abundance of solar radiation and the frequent clear sky conditions can be used to produce solar energy to improve the energy conditions in Rocinha.

Brazilian energy context

The Balanço Energético Nacional (BEN) is an annual energy balance written by Ministério de Minas, MM, and Empresa de Pesquisa Energética (EPE); it represents an essential tool for planning activities and monitoring the national energy sector. The BEN 2016, referred to 2015 datas, analyses the main energy exploited in Brazil and the rate of this energy coming from renewable sources. In 2015, the overall energy generated in Brazil was 299.2 Mtoe (million tons of oil equivalent) of whom 41.2 % from renewable sources, whereas the total energy consumption was 260.7 Mtoe. Brazil is one of the countries with the highest contribution in terms of renewable sources in its energy needs, thanks especially to the huge water resources and the considerable availability of biomass. The category “other renewable energy” includes wind, biomass, biodiesel, biogas and solar, whose exploitation has grown considerably over the last years and it is predicted to continue growing from the current 41.2 % to 47 % of the total Brazilian supply in 2030, according to the National Energy Plan. The total electrical energy generation in Brazil in 2015 was 581486 GWh and the participation of renewable energy sources in the generation was 75.5 %. In Brazil, electrical energy is largely supplied by
hydroelectric systems whose share is 61.9% of the total electrical energy produced. The hydroelectric potential in Brazil is among the top five in the world: the country has almost 20% of the planet’s water and it boasts about 11% of global hydro power production. Regarding to solar irradiation, Brazil is a privileged country. However, the exploitation of this resource is still negligible because only 26 MW are installed throughout the country. The average productivity estimated by photovoltaic systems is certainly very interesting: the annual solar irradiation reaches its maximum value, about 2300 kWh/m2, in semi-arid regions of the northeast and the minimum, about 1100 kWh/m2, in the North-West and southeast areas. The electrical energy consumed in Brazil in 2015 was of 522800 GWh, equal to an average yearly consumption of 2547 kWh/inhab/year or to 212 kWh/inhab/month. In particular, the data for Rio de Janeiro are in line with national data and equal to 2481 kWh/inhab/year.

<table>
<thead>
<tr>
<th>Energy indicator</th>
<th>Quantity</th>
<th>Rate from renewable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil total yearly energy consumption per capita</td>
<td>1.27 toe/inhab/year</td>
<td>41.2%</td>
</tr>
<tr>
<td>Brazil yearly electrical energy consumption per capita</td>
<td>2547 kWh/inhab/year</td>
<td>75.5%</td>
</tr>
<tr>
<td>Brazil monthly electrical energy consumption per capita</td>
<td>212 kWh/inhab/month</td>
<td>75.5%</td>
</tr>
<tr>
<td>Southeast region yearly electrical energy consumption per capita</td>
<td>2729 kWh/inhab/year</td>
<td>n.a.</td>
</tr>
<tr>
<td>Southeast region monthly electrical energy consumption per capita</td>
<td>227 kWh/inhab/month</td>
<td>n.a.</td>
</tr>
<tr>
<td>Southeast region monthly electrical energy consumption per household</td>
<td>243 kWh/household/month</td>
<td>n.a.</td>
</tr>
<tr>
<td>Rio de Janeiro yearly electrical energy consumption per capita</td>
<td>2481 kWh/inhab/year</td>
<td>n.a.</td>
</tr>
<tr>
<td>Rio de Janeiro monthly electrical energy consumption per household</td>
<td>207 kWh/inhab/month</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Tab. 2.3.4.1 Yearly and monthly electric consumption;
**Rocinha energy context**

In response to the increasing energy costs, the solution of the population of the favela has been the practice of the gato, which has caused several problems. Indeed, these precarious and improvised connections cause fires in low-income area of the favela and the subsequent electrical losses to the public and private systems. Light (Rio’s local company), privately owned since 1996, distributes electricity to four million people in the State of Rio de Janeiro and this makes it the fourth largest Brazilian power company in terms of client base. The company has estimated the non-technical and default losses between the 64.1% and 90.4% due to Gato. This situation is aggravated by several factors, like the presence of defected wiring, which increases the energy consumption, the use of second hand and old energy inefficient appliances, the precarious electrical installations and at least the serious lack of information about the right use of this type of energy. In the early years of 2000s, Brazil adopted a performance-based regulation to ensure that fair and reasonable tariffs were paid by all the electricity customers. For households, the discounts is measured according to the consumption level: the discount declines to zero if the consume is more than 220 kWh per month, while it is applied for lower consumes in according to the previous value. The criteria used to define a low-income consumer are based on consumption levels, but there is also a large part of the population that is, despite being clearly considered low income, unable to receive a benefit from the subsidized tariff because of their high consumption; this is demonstrated by high rates of unpaid bills.

**Case studies in Brazil**

The previous tab shows some projects and initiatives on the installation of PV systems, which are measures to contain electricity consumption of low-income households, applied in Brazil. Some of these projects involve the installation of photovoltaic panels and the substitution of old meter, second-hand or old energy inefficient appliances to reduce energy consumption and leakages. All projects include information and training initiatives to educate the population about the social, economic and environmental benefits of solar energy and the opportunity of energy savings. Among the all reported projects the RevuSolar project deserves a particular attention, for similar features to the Rocinha context. RevuSolar is a cooperative that deals with production and management of renewable energy in the community of Babilônia, a favela located in the Leme region of the city of Rio de Janeiro. The no profit organization was founded in 2015 by a group of six local residents aiming to bring sustainable power to the people of the favela in response to the rising value of the bills. Through volunteer work, involving community leaders, electricians and entrepreneurs of the “Association of inhabitants of Babilônia”, the residents themselves, as well as external supporters, have been created the project for this favela. The goal of RevoluSolar is the creation of the first renewable energy production cooperative in Brazil. The cooperative already receives the interest and support of the Organization of Brazilian Cooperatives (OCB). It also receives support from Viva Rio, the Frente para uma nova Política Energética do Brasil, the Fundação Heinrich Boell and the GIZ.
<table>
<thead>
<tr>
<th>Project or initiative</th>
<th>What?</th>
<th>Where?</th>
<th>Project Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>RevoluSolar</td>
<td>PV panels installation</td>
<td>Rio de Janeiro, favela Morro da Babilônia</td>
<td>Ongoing</td>
</tr>
<tr>
<td>Parque Madureira-ENGIE</td>
<td>PV panels installation</td>
<td>Rio de Janeiro, Madureira Park</td>
<td>Completed</td>
</tr>
<tr>
<td>LPT - Luz para Todos</td>
<td>PV panels installation</td>
<td>Brazil</td>
<td>Ongoing</td>
</tr>
<tr>
<td>Smart Microgrid project</td>
<td>PV panels and storage system</td>
<td>Fortaleza, Brazil</td>
<td>Ongoing</td>
</tr>
<tr>
<td>Low-Income Energy Efficiency programs</td>
<td>Old appliances substitution</td>
<td>Brazil</td>
<td>Completed</td>
</tr>
<tr>
<td>Program for the transformation of consumers into client</td>
<td>Slum electrification and electricity loss reduction</td>
<td>São Paulo, Brazil</td>
<td>Completed</td>
</tr>
<tr>
<td>COELBA Agent Project</td>
<td>Old appliances substitution</td>
<td>Salvador de Bahia, Brazil</td>
<td>Completed</td>
</tr>
</tbody>
</table>

Tab. 2.3.4.2 Energy project comparison;

The project for Rocinha

The proposed project requires the design of PV systems to be installed on the rooftop of the favela’s buildings, in order to keep electricity bills affordable for low-income households but at the same time to create the opportunity of regular, secure, more stable, and economically advantageous connections to the power grid. PV systems can be further equipped with batteries connected to the power grid, in order to cover the electrical energy consumption of household but also to fulfill electrical needs of city’s services as public lighting, electrical vehicles for urban transportation... An important key of the proposal is the education. For the success of the project in Rocinha, as shown in the case study of the favela Babilônia, the community involvement plays a fundamental role. Information campaigns, workshops and professional courses will be offered to the inhabitants of the favela, in order to make them aware of the solar energy potential for the favela’s energy business.
Stakeholder and financing

In order to deal with the situation of Rocinha, several actors as Energy companies, public authorities, university, non-governmental organizations (NGOs) have to be identified. A short overview of stakeholders, identified by the analysis of the energy companies and a previous project held in Brazil and in Rio de Janeiro is presented:

- ABSOLAR: Associação Brasileira de Energia Solar Fotovoltaica;
- Light: Energy company present in Rio de Janeiro;
- Enel Distribuição: Energy company in the state of Rio de Janeiro;
- ANEEL: Agência Nacional de Energia Elétrica;
- ENGIE: Leading independent private power generator in the country;
- OCB: Organização de Cooperativas do Brasil;
- Viva Rio: Social enterprise that builds peace, inclusion and justice with innovative projects in areas marked by poverty and violence;
- FNPE: Fronte para uma nova Política Energeticas do Brasil;
- Heinrich Boell Foundation: Legally independent political foundation, Part of the global Green political movement;
- Axis Renovaveis: Company specializing in photovoltaic solar energy;
- ABGD: Associaçao de Geracao Distribuida;
- Catavento Consultoria: Energy consulting company;
- FGV Energia: Energy research center within Fundação Getúlio Vargas.

Pic. 2.3.4.3 The energy flow chart;
2.3.5 Mobility

A feeling of “spacial segregation” is perceived by the inhabitants of the communities due to the lack of efficient connections and transport systems between the formal and the informal city, spread throughout the metropolitan region. In the last years multiple projects had been proposed to foster this interconnections; the main goal of these programs were to engaging the inhabitants of the favelas into the social tissue of the city, but all of them due to political and economic reasons.

Documentation

“Favela-bairro”

The Favela-Bairro program, idealized by architect and city Secretary of Urbanism Luiz Paulo Conde and approved by the city government in 1994, was coordinated by the newly established Municipal Housing Secretariat (Secretária Municipal de Habitação). The program’s charter planned for infrastructure upgrades, social services, real estate regularization and a crèche in every urbanized favela, to deal with the problem of the lack of affordable houses. For the entire program, the Municipality invested about R$1,2 billion reaching 168 communities in 16 years all around Rio de Janeiro. This program was largely administrated with a top down process, without a proper engagement of the inhabitants of the favelas. Moreover, the project didn’t solve the main issues that forced people to live in informal settlements.

Pic. 2.3.5.1 The cable-car project in Complexo do Alemão;
“Morar carioca” programs

With the imminent 2014 Football World Cup and the Olympic Games hosted in Rio in 2016, in 2010 the administration of Rio de Janeiro presented the Morar Carioca program. This R$9 billion plan tried to address the critical issues of the favelas with strategies based on the direct participation of the communities and the fostering of educational and social services in order to physically and socially connect the informal settlements with the formal city. Accessibility was the keyword of the entire program, which had an international resonance thanks to the fact that Brazil was under the spotlight during that period. The Municipality of Rio de Janeiro, with the economic support of Bloomberg Philanthropies, instructed Embarq Brasil to draw up a manual of projects and best practices for the implementation and the use of bicycles inside the favelas with the help of Alta Planning + Design, an American designing team specialized in theory and application of bike-oriented systems.

The manual shows a strategic vision based not only on technical solutions and guidelines for the implementation of the use of the bicycle in the favelas, but also on the political aspects of the program and systems to educate and engage the communities to avoid a top down process. Four keywords drive the entire program: safety, human scale, community engagement and integration. Moreover different aspect are take in account: education (for example “Ganha uma bicicleta” program, that recycles discarded pieces and uses them to make “new” bicycles.), incentive (link between the use of the bike with a possibility of a job), equality (regard all the actions strictly connected with bike sharing systems and bike repair shops), street, slope and stairs.

“Transportation in the favela of Rio de Janeiro”, Lincoln institute of land policy, 2013

It was written and realized by Jacob Koch, Luis Antonio Lindau and Carlos David Nassi for the Lincoln Institute of Land Policy in 2013. The research project was motivated by the lack of data available about transportation in favelas, while the Morar Carioca program was strongly focused on investments in mobility with the objective of creating an “Integrated city”. The first phase consisted in designing a research survey which could compare results taken from the favelas and the metropolitan region of Rio de Janeiro which could answer two main issues: the travels within the favela and the travels outside the favela in the formal city, in order to understand people habits on a daily basis.

The second phase consisted in the sample selection, which was particularly difficult because of the uniqueness of each settlement in terms of history, age, geography and topography. In the end, over the course of five weeks, data taken from over 2000 interviews were collected and analysed. The main difference detected in the data is focused on the trips made by foot, as inside the favelas it is the most common way to travel, while in the formal city buses are common such as the use of private car. Moreover, the habitants of favelas move inside the area for shopping reasons and during the free time; unlike outside the favelas the people mainly
move for job reasons. The documentation phase brought positive results in terms of potential implementation of a bicycle system inside the favelas. Therefore, a deeper investigation could point out the possible pros and cons about the possibility to enhance the use of bicycles inside the community of Rocinha.

Analysis phase

The “Rio conecta” program

It is a program proposed recently by the local administration to answer two important questions:

• How to improve streets for the pedestrians in Rio de Janeiro?
• How to enhance the accessibility in the city?

With this program the Municipality of Rio de Janeiro is willing to invest about R$675 million to foster micro and interconnections and improve the safety level of the entire mobility system with projects applied on small and big scale. Different levels of investments are applied based on the importance of the connection places to upgrade: Rocinha is considered one of the most important interconnections at a large scale, with a total budget of R$250/m2 for interventions referred to:

• Enlargement and improvement of the sidewalks;
• Implementation of bicycle systems;
• Projects of new squares;
• Upgrading of the areas around the stations;
• Creation of bicycle racks and bike repair shops.

Topography analysis

This type of analysis permits to understand the slope values of the different areas and the general level of usability of a bike, also in terms of width of the streets. Working with a GIS file made possible to highlight the main streets, the “becos” (narrow streets used by the inhabitants to move through different neighborhoods) and the different slope levels in Rocinha. The neighbourhoods located in the lowest part of the favela (Bairro do Barcelos, Largo do Boiadero) are generally flat, while Caminho do Boiadero and Rua do Canal are the most important streets with good possibilities of bike implementation. Another flat area situated is located in the highest part of neighborhood Rua Nova, but it is not linked with the rest of the highlighted zones. The majority of the principal streets of Rocinha have a slope value between 10% and 20%, a percentage that can guarantee the use of bicycles integrated with a steel sliding shoe system (presented in the Embarq manual). Moreover E-Bicycles could be useful to ignore high values of slope level. The analysis of the second parameter chosen (width of the streets) it stands out that the vast majority of the “becos” widths in Rocinha have a lower value than the minimum allowed. Looking at the topography of the favela, it is possible to
highlight some preferential routes which could be useful to connect different and distant areas. Those routes need to be verified with the second analysis based on the local context, but it could be seen a pattern that links four of the six zones selected for the “PolimiparaRocinha” project and, most importantly, a possible vertical connection between the lower and the higher part linked to the entrance of the “Parque Nacional da Tijuca” located in the neighborhood Vila Laboriaux.

Context analysis

It is important to understand the current situation of Rocinha not only in terms of morphology and internal mobility system, but also in terms of habits of the inhabitants. The present critical issues which could affect the life of the community are drastically changing their custom. The analysis is more focused on the lower part of the favela because of the presence of most of the connection points between the community and the rest of the city and several critical issues are referred to them:

Estrada da Gavea: It is the main carriageable street inside Rocinha, used on a daily base by COMLURB’s trucks for garbage collection, buses lines 537, 538 and 539 and all the moto-taxis operating inside the favela. It is subject to intense traffic every day, with a not sufficient overall width to design a safe cycle lane next to the great number of vehicles that usually takes this road. Estrada da Gavea is a constraint which needs to be avoided for security reasons as well.

Rua Nova: The old Rua 4 was renewed and enlarged during 2010’s PAC renovations, which have interested big parts of Rocinha, granting open spaces and an alternative to Estrada da Gavea in terms of mobility inside the favela. It is one of the fewest spot in Rocinha with the presence of vegetation. Today it is principally used by pedestrians and it has a tolerable slope level, which represent some potentials in terms of implementation of a bicycle-based-system.

Caminho do Boiadero: It’s conformation suggest a possible renovation for mobility purposes.

Largo do Boiadero: It represents the historical square of Rocinha and on a daily base hosts a fair with typical goods from the Northeast of Brazil. The square is entirely occupied by stands which are open every day and take part every Sunday at the historical “Feira”. While the “Feira” is an important part of the life of the community and needs to be preserved, during the other days of the week it could be possible to move the stands from the square in order to create an open space useful to social aggregation or to concentrate other leisure activities linked to the bike-oriented system. The Largo do Boiadero could become an opportunity to exploit.

Rua do Valão: Situated in the lower part of the Favela, Rua do Valão is considered one of the main flat streets of Rocinha. It is directly linked to Largo do Boiadero and Caminho do Boiadero, creating a sort of track
that has a good potential of being implemented with a bicycle system. There is an important critical issue to face: the presence of the canal which gives the name to the street. The inhabitants normally use those canals as an informal garbage collector. In conclusion, it is possible to design a lower track which links the vast majority of the flat “bairros” and a vertical connection in Rua Nova in order to interrelate the Portão Vermelho neighborhood with the more vibrant lower part of Rocinha. Estrada da Gavea is impossible to use because is considered too risky in terms of safety for the inhabitants and the cyclists.

Project phase

Draining pavement

During the design session, it was decided to refer to a specific product currently on the market which responds to the minimum technical requirements. The idea is focused on the implementation of the Aquastone© solution, which is a solution solely based on a special epoxy resin and river stones, sandor recycled glass to enhance the draining performance of the favela soil. The product takes the colour depending on the type of stone used; for this reason, there is a wide range of choice which permits to differentiate the routes and to signal the presence of a bicycle lane. There are two main phases: the preparation and verification of the base and the preparation and application of the aggregates. It is important to consider an alternative solution due to logistic problems (the steep and narrow streets of the intervention areas are inaccessible for the common means used to apply a liquid aggregate) because the cycle/pedestrian network interest not only the principal roads of the favela but also the narrow descendant streets of the case study areas. It is fundamental to study an easier to install panel system. It was decided to implement the Limestone© solution. The panels chosen are made by pebbles, fibres, cement, additives and specific dyes and grant a 95% of permeability. The application phase is similar to the Aquastone© solution for the preparation and verification of the base part.

Demographic data and project of a cycle/pedestrian network

Furthermore, in order to understand the internal divisions inside the community and the possible general level of engagement reached by this kind of mobility system, it is very important to make a demographic study of the favela. The tool made available by the IBGE (Instituto Brasileiro de Geografia e Estatistica) was useful to collect data taken from the 2010 national census dividing sector by sector. The geoportal was useful to study different and geographically divided aspects of the population of Rocinha (age ranges, gender, literacy level, employment, ...). In order to avoid an excessive dispersion of the reference sample (according to the Census, Rocinha is divided in 79 different sectors), it was necessary a union operation, obtaining at the end the 21 popular neighborhoods in which the favela is divided. This kind of operation was possible only thanks to the website memoriarocinha.com.br, a web portal which collects historical documentations and photographs of Rocinha and includes a digital map showing all the names and the borders of the 21 neighborhoods.
Crossing the samples regarding the physical characteristics and the people living in the favela who are potential users of the system is useful in order to understand the best places to include in the cycle/pedestrian network. The graph (page 153) shows which neighborhoods of the 18 included in the design process are the most favorable for the implementation of the system: 13 of them have a sufficient level of morphological characteristics, while the remaining 5 areas (Cachopa, Campo Da Esperança, Rua 3, Vila Vermelha E Setor 199), which are included in the cycle/pedestrian network, have a high level of average slope. It is impossible to expect that the bicycle will be used inside those neighborhoods, therefore the implementation of bike racks and hypothetical bike sharing station will be done on the borders of the areas.

The informal nature of the sample area (the entire favela of Rocinha) does not allow to have a correct estimation of the people living inside the Community: the 2010 national census counted more or less 70000 residents, but further studies and polls conducted by the Associations of Residents and non-official estimates made by other public authorities reported a much higher number of inhabitants, at least 200000. The principal aim of the entire project is to design different systems in order to give services to the people living inside the favela. Due to the clear difference between the two results, it is necessary to multiply the official value three time in order to reach the most realistic number, but assuming the distribution of the population (taken by the IBGE geoportal) unchanged.

To collect more data on the resident population in Rocinha different platforms have been used: the public data given by IBGE and the web portal data.rio to study demographic trends; the 2013 paper published by the Lincoln University named “Transportation in the Favelas of Rio de Janeiro” in order to understand better the mobility habits of the sample taken into account. Starting from the collection of demographic data it is possible to subdivide the population of Rocinha living in each one of the 18 neighborhoods considered for the system in different categories based on gender and age ranges. It is possible to highlight a major presence of a relatively young part of the population (under 30 years). It is important now to answer directly to different questions given by the designing process of a cycle/pedestrian network: How the residents in the favela move; when they make a trip considering a normal daily routine; WHY they move, (basically the motivations that push the residents to make a trip).

The study was conducted using a survey on a sample of 2000 inhabitants of 3 different favelas of Rio de Janeiro chosen for their morphological differences and for the availability of the residents. The main motives, which provoke the movement of Rocinha’s inhabitants, are: Leisure, Work, Study, Shopping. Moreover, to make the analysis more realistic, they are divided in inside and outside trips: that is because inside Rocinha it is possible to find only primary or first grade secondary schools, which guarantee education for children until the age of 14; for those who wish to continue their studies until 19, or to enroll in university, the only way is to move outside the favela. In order to transfer the data from the number of people involved to the number of daily trips, it is necessary to introduce the mobility index value, a special coefficient calculated differently.
for the inside and the outside trips that shows the average number of daily trips made by a single person. The mobility index value is divided between motorized and non-motorized trips: the Lincoln University’s paper shows that inside favela settlements the vast majority of the trips are made on foot and that bicycles are used very poorly because of the morphology of Rio de Janeiro. Considering the outside trips, the situation is overturned, with the vast majority of trips made using motorized vehicles, while the bicycle usage still remains low. Another limit which is necessary to take in account is the lack of education of riding the bicycle: only 80% of favela residents can ride a bike. Currently, this project could involve about 20,40% of the total. These results show that the implementation of educational programs based on boosting the bicycle usage could be useful in order to increase the potential poll of Rocinha and design a system for a larger number of persons.

All the previous analysis takes to a first estimate of the bike sharing system sizing. After the choice of the locations of the 12 hypothesized stations, the analysis proceeds with the calculation of the correct number of bicycles to implement inside Rocinha using the reference sample refined by: the application of different coefficients for each neighborhood: the mobility index equals to 0,01 for the inside trips and equals to 0,02 for the outside trips (the actual trends); the different coefficients concerning the various habits of the Rocinha population subdivisions. In order to transfer the data from the number of daily trips to the effective number of bicycle to implement in the system, it is necessary to consult the guidelines written in the “Bike sharing planning guide”, published by the ITPD (Institute for Transportation and Development Policy), an American institution which deals with the implementation inside the cities of slow mobility programs and systems. In the end, it was possible to have a first estimate of 120 bicycle located in 12 stations (with a photovoltaic system), for a total amount of 240 parking spaces (a 2,0 per bike coefficient). This first sizing could be further refined with the hypothesis of a 100% poll (it means that everyone in Rocinha can ride the bicycle), which increases the total number of vehicles up to 180, for a total amount of 360 parking spaces. In Rocinha there are four possible limit conditions:

- Schools in Rocinha have double time, morning and afternoon. The entrance is at 7:00 am, while the exit is at 1:00 pm or 5:00 pm;
- The garbage collection starts between 7:00 am and 1:00 pm;
- The provisioning of the businesses starts in the morning, between 7:00 am and 1:00 pm;
- On Sunday, in the lower part of the favela, the historical “Feira” of Rocinha is held.

Using the table of the coefficients related to the habits of the population resident in favelas it is possible to predict WHEN the different kind of trips are made, highlighting the overlays. In the end, it is easy to realize a proper “Bio-clock” of the entire system. In order to safeguard the weakest part of the population (children above all), and to avoid overlays during the rush hours. Finally have been sized also the photovoltaic system of the station and have been showed the data about the element, which compound it and the e-bike.
Pic. 2.3.5.1 Bike sharing station
2.3.6 Water

Rocinha analysis emerged that water management, both wastewater both rainwater, is one of the most relevant issue. All kid of water produced by the urban agglomeration of Rocinha can be divided as:

- Foul water: all waste water from toilets of house or common meeting places;
- Greywater: all waste water generated by households or office buildings without fecal contamination;
- Water generated by rainfalls.

All those should be collected in the sewer to convey in the downstream pipe network.

Wastewater treatment

By the time, in the favela there are two water collecting system:

- Combined sewer: In only one channels convey both urban waste water as well as rainfall water. This solution has several advantages as reduction of production and maintenance cost. On the other hand the overall flux speed is reduced, with the consequence of sediments accumulation on the channels.
- Separate sewerage: Different flux of water are divided avoiding mixing of rainfall with relatively little polluted surfaces from the municipal wastewater. Therefore, only the foul water and the greywater are leaded to treatment stations. The main advantage is an higher flux speed without sediments problems, vice versa the system overall cost increases.
- The current sewerage has been implemented several times due the significant demographic growth of Rocinha in the last decade. According to the 2010 IBGE census, 86% of the building have a proper access to the sewer system. The last 14%, is mainly located in the favela’s area where too narrow street made impossible to implement a proper system.

Nowadays the favela is divided in two basins, the São Conrado basin and the Gávea basin, that respectively collect 80% and 20% of sewage. The São Conrado basin brings the waste waters to the pumping station that leads sewage from São Conrado to l’EE di Leblon. Instead, in the Gávea basin, there are two pumping station located in Rua Sergio Porto and in estrada da Gávea, that bring the waste waters to Elevatória Saturnino de Brito. The current network is developed on the concept of “condomínios”. Each groups of house is a “condomínios” served by a small secondary network, realized with 100-150 mm PVC tubes. Finally, the all waters collected by each secondary network convey in the principal one. The latter has from 150 to 6000 mm PVC tubes for a 29,2 overall length.
System’ problem

After analysis on current system had been carried out, the main problems in the field of water collection in Rocinha are:

• No efficient connection between houses and neighborhood with existing waste collection network. That’s mainly due to topological and morphological layout of some areas
• In case of combined sewer system, it is downsized and overcharged leading to overflow. Moreover, the system performances are reduced due to population’s habits to throw waste in talvegue.
• Lack of maintenance on current water collection network.

These problems, together with lack of an effective waste collection system and the tropical climate of Rio de Janeiro engender healthy problems and consequently a decrease of life expectations.

Intervention

The water management issue can be solved with the installation of separate sewerages, update with Brazil’s standard, and extending and improving the current sewage network for all the favela. The new system must connect both all the houses to sewerage both all the secondary networks to the principal one. About the new sewage design it has to take in account topography of the site as well as possible obstacles due to the high urban density. The hydraulic sections have to be designed taking in account nowadays and future demands avoiding occlusion. The pipes must be easy to install and move, remove and inspect, and they must be protected from damages, impacts, and sunlight. The outfall of the developed network should be the treatment plant, before the discharge of waters in the environment. This project answers to DOPs number 3 (implement water management) and 4 (prevent the negative impact of waste).
Drainage system introduction

As water management systems are one of the main critical issues of Rocinha, which lead to sanitation, healthy and runoff problems. This situation get worse during summer, that is the heavy rain season in Rocinha. Flooding phenomenas are also in consequence of absence of vegetation and resilient drainage areas.

The Talvegues system

Talvegues, open air channels made with waterproof stone layers, are part of the pre-existent heavy rains mitigation system. In São Conrado side of the favela are present the majority of talvegues. Many of them are close to Campo Esperança, converting in a unique flow that reaches the Treatment Unit before falling in São

Pic. 2.3.6.2 Rua do Valão;
Conrado beach. The São Conrado basin three main drainage basins:

- Basin 2 has an approximated area of 48 ha and it includes the following talvegues: Morro do Laboriaux, Alto da Dioneia e Vila Verde.
- Basin 3 has an approximated area of 62 ha and it includes tributary ‘talvegues’ of the main Rocinha canal, the Valão.
- Basin 4 has an approximated area of 16 ha and it includes the ‘talvegue Goerio’ artificially created at the bottom of the stone massif Morro Dois Irmãos.

The talvegue system of Rocinha acts as a possible solution to concentrate heavy rainfalls, but it is not sufficient due to obstruction caused by waste management and sewage problems. In the end, the talvegues are overloaded and do not act as a proper solution. In consequence an effective drainage system can be implemented exploiting the presence of the ‘talvegues’ with the additional support of simple technological solutions to slow down the runoff phenomena. The interventions had been designed starting from the statistical data and basins of the Rocinha valley shown below:
Stormwater management

Unmanaged stormwater runoff, during and after intense rainstorms, is one of the most significant direct risks for people life and an important source of environmental pollution and health hazard. In Rocinha rainstorms produce flash floods and the runoff is mainly conveyed by streets. In most cases, the absence of street gutters and even of sidewalks, combined with high street slopes, makes walking or moving dangerous for people. To manage stormwater effect, two flux had been considered: the internal one and the external one due to contributions from natural vegetated slopes surrounding the urbanized area.

Management of external stormwater runoff

To achieve a proper stormwater management, reducing the risk of flooding, is mandatory to limit external component of runoff as much as possible. That goal can be achieved building open channels along the borders of urbanized area, to convey the external fluxes entirely downstream. The map below shows the actual “talvegues” network: the evaluation of the effectiveness of the non-obstructed channels is crucial to design proper solutions. Management of internal stormwater runoff

Traditional solutions to internal stormwater management, mainly based on complete coupling of street gutters and underground piped networks, were evaluated as not suitable for Rocinha. An effective strategy for stormwater management should address these issues in the simplest way, in order to be further adapted to urban changes and incrementally implemented. Thanks to the collaboration of the DICA department of Politecnico di Milano, three different levels of intervention based on the width of the streets were spotlighted:

- First level: In large streets, coupling of street gutters and buried pipes and channels are the best solution. The two systems are coupled by inlets along the street sides or by transverse grates, according to slopes and flow paths.

- Second level: In secondary streets (less than 5m of width) flows are to be directed, also by street reshaping, to one or both street sides and then conveyed downstream to the main streets. Sidewalks and gutters have to be realized where they are absent.

- Third level: In the rest of streets, too narrow and generally too steep to limit the surface runoff, flows are not specifically managed. To improve present conditions, however, sidewalks at least on one side have to be realized where possible and house inlets have to be modified in order to make them floodproof. Downstream of narrow streets, whose runoff is conveyed by street surface and/or gutters, before crossing of main streets with underground drainage pipes, cross grated inlets along all the street width have to be used.
3 IMM Phase II modification
3.1 On site survey

The project site is located between the top part of Rua 2 and Rua 1. Both are connected with Estrada da Gavea, the main car-accessible road crossing the whole community of Rocinha. The area is on the south-east part of the favela, built on the hillside of the Tow Twins mountain. The Rua 2 is accessible by car and is connected on the top part with the Estrada da Gavea. Meanwhile, Rua 1 is narrow and accessible only by foot, it serves the vast majority of the residential buildings of the high south east part of the settlement. The area was firstly outlined by previous studies on Rocinha as potential spot where implement new connections and social poles between Estrada da Gavea, thought Rua 2 till Rua 1.

Pic. 3.1.1 Map of Rocinha’s favela, scale 1:10 000;
3.1.1 From Rua 1

At the top of Rocinha, almost on the highest spot on Estrada da Gavea is located the entrance of the Rua 1. Estrada da Gavea is the only road accessible by car and public bus that cross the whole settlement, in consequence the majority of the functions are located on its path. The large part of basic and social structures as schools, banks and workplaces are located on the lowest part of the favela since the area is reachable by metro, bus and moto taxi. As far Estrada da Gavea becomes steeper and it goes up on the mountains the less it becomes accessible and consequently less functions are located on it. Although, the top of the favela is reachable by car, bus and moto taxi, it has an high altitude difference with the lowest part. On the lowest part is settled the biggest economic center of the community and it a node of the transportation network of Rio de Janeiro. Due to the overall distance, the altitude and the tropical warm climate the entrance of Rua 1 and also 2 is reachable from the lowest part only by moto taxi or by bus. The entrance of Rua 1 is full of small shops among them the majority are food and construction materials retails shops (Pic 3.1.2). At the entrance is also located a Moto taxi stop, where for 5 R$ could be purchase one single way for any taxi accessible sites in Rocinha (Pic 3.1.3). Once taken Rua 1 the shops disappear rapidly and there are only residential building. The path has a variable width, around 2 and 1.5 meters, and is mostly planar (Pic 3.1.4). From it different small secondary paths depart, the majority only serves few groups of buildings. In about 10 minutes walks the path start a slowly downhill following the shape of the mountain. At this point it cross in two point the tavlegue, the rainwater collecting channels that are located on the top of the project area (Pic 3.1.5). There is partially visible, a large green area hided by a brick wall on the left. Since this area is exceptionally hidden and unreachable is mainly used, as testified by Julio the guide from Il sorriso dei miei Bimbi, for illegal drug traffic. It takes other five minutes’ walk to reach the first path that connects Rua 1 with Rua 2. Once there a sharp downhill starts and takes from ten to fifteen minutes to reach Rua 2. This last path is more narrow than Rua 1 with picks of 70 cm width (Pic 3.1.6). The majority of the buildings have maximum three floors and among them there are some old wooden shacks that were built when bricks were not diffused in Rocinha and many unfinished or abandoned structures. In fact due to topography and morphology conditions, the area is mostly unreachable. It would takes 10 more walkings minutes in downhill to reach the Rua 2.
Pic. 3.1.2: Shops between Estrada da Gavea and Rua 1; Pic. 3.1.3: Moto taxi stop at the beginning of Rua 1; Pic. 3.1.4: Narrow street in Rua 1; Pic. 3.1.5: Talvegue on Rua 1; Pic. 3.1.6: Narrow street connecting Rua 1 and Rua 2; Pic. 3.1.7: Unfinished building; Pic. 3.1.8: Map of the project area;
3.1.2 From Rua 2

The project area is located on the top of Rua 2. The road is secondary to Estrada da Gavea from which it begins ending 1 km downhill in a residential area without reconnecting to any vehicle accessible roads. On the road are located few shops, one school and a police station and a garbage collecting point. The road is not large enough to fit two cars, which can cross each other in only few spots (Pic 3.1.8). At the beginning, close to Estrada da Gavea are located two Bus stations. The majority of the functions are located on Estrada da Gavea and their number decreases as far as Rua 2 gets in the residential neighborhood. The project area begins where a small path almost invisible goes up between few buildings following the Talvegue trace. On the corner are located two construction materials shops, outside the sidewalks are full of bricks and other merchandise, probably the most common way to advertise the products (Pic 3.1.9,10). After only two buildings, following the road, is visible an unusual void between two building. Once again it is used as stockage site for construction materials (Pic 3.1.11). Both at the beginning of Rua 1 and 2 many construction materials shops are located, probably due to the privileged position. From Rua 2 a small narrow path goes up following the talvegue and reaching a small group of house (Pic 3.1.12). On the path is visible how the rain water collecting system is used as sewage too for the settlement facing on it, on the other hand the path rise few meters before stopping in front of the talvegue (Pic 3.1.13). From that point is partially visible the green area that face on one side Rua 1.
Below: Pic. 3.1.8: View in Rua 2; Pic. 3.1.9: Construction material shops in Rua 2; Pic. 3.1.10: Construction material shops in Rua 2; Pic. 3.1.11: Void on Rua 2 used as material deposit; Pic. 3.1.12: Small path along the Talvegue; Pic. 3.1.13: End on the path on the Talvegue;

Left: Pic. 3.1.14: View on the top part of Rocinha, the area 3 is located on the left side of the photo, ph. Perego Francesca, Rocinha, Oct. 2018;

Project area
3.2 Definition of project area on pilot project effectiveness

In the first phase of the project, after the analysis on the global scale, it was defined a common strategies for all the project’s areas. Secondly, pilot projects solutions were developed to address to the project DOP's in order to improve the quality of life both on the local and global scale. Fourteen different solutions, divided in 5 key categories were chosen. The project site was spotted in the first phase as a strategic node for Rocinha’s further development. On the other hand, the physical delimitation of the project area has been obtained thanks to the application of the 14 pilot projects. In detail, these pilot project have been set in 5 keys categories and for each of them it was defined a project area. The superposition of these areas gives the final project area for the top part of area 3.

Food

Due to the projects site slope, to the high building density and to the narrow and pedestrian only paths it is possible to implement only some solutions for urban farming. In detail, it was not possible to implement an aquaponics system due to a physical lack of voids on the vehicle accessible roads. On the other hand, no other voids could not be exploited due to the physical inability to bring aquaponics equipment. Few green areas, suitable to be converted in terraces or vertical walls for urban farming have been spotted. Urban farming have been conceived to create a microeconomic system based on own produced healthy food. In detail, this urban farming terraces, placed on the top of the area 3, could be an opportunities for old or young people which are unable to pay themselves a daily public or private transportation to reach the main economic centers. The area identified would be sufficient to provide vegetables and fruit s for an average of 5 people in one year. Nonetheless, this green area is going to be exploited also to other purposes as reduction of runoff effect as a resilient area for rain water drainage.
Energy
Along the different pilots projects regarding energy, it was chose to develop the PV panel smart grid in order to provide low cost and sustainable energy for the public buildings and for the public lightening of the roads. A preliminary solar analysis was carried out, and as would be further explained, the PV panels have been installed on new buildings defined by project design and on existing selected buildings. The latter have been chosen because both they benefit of the best yearly radiations, both because they are more than four floor higher, therefore the possibility that they would be enlarged is reduced.

Mobility
The mobility issue can’t be faced only focusing on the area 3. Nevertheless the Bike-sharing project refers to a network of connections in which is included the area 3. Moreover a close stop of public bus line to the area 3 makes it a privilege spot to install a bike-sharing stop creating a transportation node in which the interurban network and the extra-urban network meet each other.

Waste
The introduction of waste collection points is one of the main assets to the IMM project to ensure health. In detail, in the project area two new garbage collection points have been added. A main collection point is placed on the Rua 2 to be easily picked up by the public service or by the “De OlhoNo Lixo”. One more have been placed on the top of the area 3, facing the Rua 1 to supply the neighborhood and to be easily transported to the one of Rua 2 below.
Water

The water issue concerns two topics: the drainage and sewerage issues. The drainage is about discharge the rain water. In detail the area is crossed by the talvegue, which is an existing rainwater channel. The analysis on water flow have shown that the talvegue is normal in average full for the 35% of its course. Non the less the area is subjected to flooding phenomena due to the topography and to the high building density. Therefore the talvegue system have been implemented, increasing its coverage area and adding new pipes. Moreover, the existing green area have been improved to act as resilient surfaces against water flooding. About the sewage system, today the area is lacking if this basic service. In consequence, black waters are discharged on the Talvegue. To improve the health conditions a new sewer system, which follow mainly the same path of the drainage system, have been implemented to serve the majority of the building on the area and it has been connected to the existing main sewer system on the Rua 2. Moreover, to supply to the demands of potable, that is an important issue due to low water quality of accessible water in the favlea, two water-house, one on top and one on the bottom of the area have been placed. The one on the bottom has a bigger catchment area meanwhile the one on top supplies the residential neighborhood on top.

Project Area

The superposition of all the areas defined previously defined gives the final project area.

Pic: 3.2.5, Drainage project area;
Pic: 3.2.6, Sewer project area;
Pic: 3.2.7, Project area;
In the chapter 2 were set the base for the masterplan development on the top part of area 3. On chapter 2 both the favela and the project area were analyzed thanks to the IMM methodology approach. In fact, is was possible to deeply study the urban context to better recognize the opportunities as well as the weakness and threats hidden in the project area. In this specific context, where necessities and needs are almost countless, it is important to optimize and choose the most effective interventions due to limited project budget. Moreover, one of the main goal of IMM action in Rocinha is to limit as much as possible the physical intervention on the area. As already happened in the favela, for the Rua Nova refurbishment, many buildings had been demolished and massive relocations of their inhabitants had been pursued by the municipality. Families were displaced far away from their original neighborhood. This fact was not well perceived by the community of Rocinha which now tends to mistrust any foreign help. Therefore, it has been a matter of primary importance to reduce the displacements and eventually to move people close to their original position.

The project design at urban scale must address to two main goals

• To introduce, whether is possible, in the master plan design the IMM pilot projects.
• To design, thanks to changes in the neighborhood a favorable context for the introduction of a new building technology inside the community of Rocinha.

At this purpose an OSA matrix have been developed to define, once analyzed the projects goals and strategies, the actions to implement om the project area and consequently to draw a concept-plan.

• The OSA matrix is defined by three levels: The goals: They define the main assets of the project intervention. In detail, the majority of them are defined by the IMM DOPs application on the project area;
• The strategies: are consequently developed to satisfy the project goals and they refer to the project area;
• Actions: they are explicit intervention to implement on the project area and one action could eventually address to one or more strategies, belonging also to different goals.
<table>
<thead>
<tr>
<th>GOAL</th>
<th>STRATEGY</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Create a connected open space system to activate urban metabolism</td>
<td>Create new connections between high attractive spots and urban voids</td>
<td>Partial demolition of existing buildings and walls to enlarge the access from Rua 2;</td>
</tr>
<tr>
<td>8) Foster mixed use spaces</td>
<td></td>
<td>Create a new connection between Rua 2 (Estrada da Gavea) and Rua 1;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Re-qualify the area around the talvelgue;</td>
</tr>
<tr>
<td></td>
<td>Re-conversion and re-qualification of urban voids;</td>
<td>Introduction of social-functions as meeting spots in the urban voids;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Introduction of an NRA function;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Design adaptable and resilient public spaces in Rua 2 and Rua 1;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Devote spaces for public activities as Sunday markets in Rua 2;</td>
</tr>
<tr>
<td></td>
<td>Re-conversion of green areas</td>
<td>Exploit green and steepest areas close to Rua 1 for green parks and urban farming;</td>
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<tr>
<td></td>
<td></td>
<td>Employ the steepest and reduced spaced along the talvelgue for vertical farming practices;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Introduce positive practices, supported by ONG, to manage the public gardens</td>
</tr>
</tbody>
</table>
The action defined in the OSA matrix have been translated in practice on the concept-plan. A new social center have been placed on the bottom of the area 3. In detail, two buildings have been demolished and the families moved in a new structure, built few meters below. A new plaza have been designed to be the most resilient possible and equipped to host different activities such as the Sunday market that now could take place more often or eventually become permanent. The building would host at the ground floor a restaurant or a commercial activity meanwhile the top floors are devoted to host a NRA activity, necessary regular activity, for example a school or an education center. The two roads, Rua 1 and Rua 2 have been connected and a satellite function have been placed on the top of the area to manage the green spaces.
<table>
<thead>
<tr>
<th>GOAL</th>
<th>STRATEGY</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>2) Implement a water management system</td>
<td>Create distinct sewer systems (drainage and sewer);</td>
<td>Implement a new sewage system parallel to the talvegue;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implement a new system of condominos for the houses;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Refurbish the existing talvegue Introduction of social-functions as</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Avoid waste to fall in the talvegue</td>
</tr>
<tr>
<td></td>
<td>Introduce resilient areas to reduce runoff phenomena;</td>
<td>Surround the talvegue path with green resilient areas;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implement resilient green areas with a water basin;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implement a drainage pavement;</td>
</tr>
<tr>
<td></td>
<td>Purify water</td>
<td>Install waterhouses to purify water and provide free potable water;</td>
</tr>
<tr>
<td>5) Promote cycling and reinforce public transportation 9) Promote walkability 11) Balance the public transportation potential</td>
<td>Promote a new bike sharing system inside the favela</td>
<td>Insert a bike sharing station in Rua 2;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Install concrete sput system the connections between Rua 2 and 1 ;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Introduce pedestrian and cyclable path in Rua 2</td>
</tr>
<tr>
<td></td>
<td>Re-qualify the walkable path inside the favela;</td>
<td>Partial demolition of existing buildings and walls to increase accessibility from Rua 1 and 2</td>
</tr>
</tbody>
</table>
To avoid flooding phenomena the existing talvegue have been improved, the water channel has been also surrounded, whether is possible, by resilient green areas. A new sewage system have been designed to avoid waste water to be discharged in the talvegue and Finally a system of two water-houses have been placed to supply the neighborhood of drinkable free water.

The mobility system have been implemented placing a bike sharing station on the Rua 2. Thanks to the proximity with the bus station the area became a transportation node where inter-urban and extra urban networks meet. The Walkability have been improved thanks to new connections and enlarging the Rua 2 and installing sidewalks where were missing.
## GOAL

7) Convert the city in a food producer,

12) Make biodiversity an important part of urban life.

<table>
<thead>
<tr>
<th>STRATEGY</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promote urban farming practices;</td>
<td>Exploit green and steepest areas close to Rua 1 for green parks and urban farming;</td>
</tr>
<tr>
<td></td>
<td>Introduce positive practices, supported by NGO, to manage public gardens;</td>
</tr>
<tr>
<td></td>
<td>Promote workshop and social activities to involve the community in the farm activities;</td>
</tr>
<tr>
<td></td>
<td>Promote outdoor and &quot;indoor&quot; urban farming practices;</td>
</tr>
<tr>
<td></td>
<td>Guarantee an economical income from urban agriculture;</td>
</tr>
<tr>
<td></td>
<td>Build a facility to sell the harvest;</td>
</tr>
<tr>
<td></td>
<td>Introduce the farmer in cooperative to support their work;</td>
</tr>
<tr>
<td>Introduce recycle and reuse practices;</td>
<td>Place new collection spots in Rua 1 and 2 and collect organic and inorganic waste to be further moved on the lowest part of Rua 2;</td>
</tr>
<tr>
<td></td>
<td>Involve people in waste recycle processes in return of benefits;</td>
</tr>
<tr>
<td></td>
<td>Use the organic waste to produce biofertilizer;</td>
</tr>
<tr>
<td>Promote the production of energy from renewable sources;</td>
<td>Implementation of PV panels on houses roof for public use;</td>
</tr>
<tr>
<td></td>
<td>Implement a free public light system;</td>
</tr>
</tbody>
</table>
To guarantee the access to health food two actions have been carried out. Promoting two structures, in Rua 2 and Rua 1 to sell the harvest and to host temporary food markets. Moreover, the green areas on the top of the area have been exploited for urban farming. About the waste management two collection points have been placed. One on Rua 1 to serve the neighborhood and a main collection point is placed on the Rua 2 to be easily collected by the public service or by the "De OlhoNo Lixo".

A smart grid of PV panel have been set to supply public buildings and public lightening. PV panels have been installed on new buildings defined by project design and on existing selected buildings.
<table>
<thead>
<tr>
<th>Introduction of the TRC technology to local construction workers</th>
<th>Creation of a TRC retail hub involving local construction material sellers;</th>
<th>Build a polyvalent building where TRC is produced and retailed;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Involvement of local building materials shops in TRC retail;</td>
</tr>
<tr>
<td>Promote the TRC technology;</td>
<td>Educational project and workshop to promote the technology;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Provide professional and educational teaching activities on the construction field;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Refurbishment of the neighborhood using also the TRC solution (buildings and path)</td>
<td></td>
</tr>
</tbody>
</table>
3.4 Masterplan

The masterplan have been designed based on decisions taken on the concept plan. Moreover all the actions are not supposed to be taken in place simultaneously. In fact many actions as demolishing the buildings and built new ones, as well as the creation of the connection and the sewer system can’t take place on the same time. Furthermore, a phasing time would give the chance to discuss and review changes with the neighborhood inhabitants in order to build a more suitable project. Although, specific actions are easily to put in place others needs both to be discussed with the inhabitants, as the placing of PV panels on private buildings, or needs further verifications as the construction of a sewer system.

Time phasing:
As first action the building to host the production and retail of Argamassa armada would be built. This action would occurs as first since the plot occupied by the building is today empty and is used as construction material warehouse (Phase I). This structure would support, employing the argamassa armada technology, to construction and the displacement of the new projects planned in the masterplan design. In fact the next step would be the elevation of a new floor on an existing building (Phase II). In consequence, the families living in the buildings expected to be demolished by the project, would be relocated in this new apartments, close to the original ones, avoiding roaming. Afterwards, the buildings on the corner could be demolished (Phase 3) and the new path connecting Rua 1 and Rua 2 would be built at the same time with the project building and the new plaza on Rua 2 (Phase 4). Tagheter,with the new path the sewer, the drainage system and the public lighting have to be installed. Finally, once that the social center on the Rua 2 is settled the building on the Rua 1 could be built and the terraces for urban farming arranged.
Pic. 3.4.1: Final masterplan 1:1000;
The plaza on the Rua 2 has been designed to be the most resilient and dynamic as possible. In fact a urban void is very precious in a super dense context as Rocinha. Leaving empty spaces could lead them to be used for different scopes than the designed ones. Moreover, as explained on the OSA matrix, many functions have to be placed in a small space. One of the first project goal is to fulfill a lack of missing structural services. The IMM analysis have spotted a defect of as called NRA (necessary regular activities) on the area. Among those educational services are vital to satisfy basic needs of the neighborhood inhabitants. Therefore and school have been designed on the area and following pilot projects guidelines waste collecting points, bike sharing station for the inter-urban transportation network and the water-house, that address to a lack of potable water inside the favela, have been added. The left space have been conceived as partially open to host temporary activities as market, which already happen every Sunday, and social activities managed by the educational structure built above. The goal is to increase the impact, as economic social and transportation center, of this new node in Rocinha.
### 3.4.1 Energy management: smart grid

Today in Rocinha energy is supplied by the electric company of Rio de Janeiro. On the other hand, due to expensive cost the electricity is mainly "stolen" by favelados that illegally connect electric cables to the existing main network. To enhance the sustainability and reduce the environmental footprint of the project a smart grid of photo-voltaic panels have been designed to supply electric needs of project's building and facilities, included bike-sharing system, public lighting and public market.

#### Electric consumption:

In order to size correctly the electric production in the project area, it was necessary to list all the needs in terms of electric consumption. The project building functions are the followings: a public school, an open-air market, a bike sharing station, a building that host an argamassa armada production and retail point and an office dedicated either to the teaching of this technology or the retail of the TRC elements. For each of those functions, the energy consumption had been evaluated forecasting which and how many electric devices will be used by the final users, included cooling system employed in the summer season. Moreover, one of the project goal is to enhance the life’s quality for the resident through the implementation in the neighborhood of "pilot projects". Those includes a network of public lighting; street lamps have been spread around the main axis of the project’s site especially along the new connection between Rua 2 and Rua 1. Always in the focus of giving services to the community, the bike sharing facilities will offer the possibilities to rent e-bikes. Therefore, it was also necessary to evaluate the electric need in order to charge their batteries.

Below are listed all the designed electric consumption for the project buildings and facilities. Moreover, the building devoted to the argamassa retail, production and teaching, that has been designed in detail in chapter 4 part 2. Therefore, the consumptions have been evaluated with higher precision, included the cooling system that has been designed in chapter 4.4.2 part 2.

<table>
<thead>
<tr>
<th>Building devoted to argamassa armada activities</th>
<th>Power [W]</th>
<th>Number of items</th>
<th>TOTAL Power [W]</th>
<th>Hours [h]</th>
<th>Daily consumption [kWh/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamps / m²</td>
<td>11.00</td>
<td>153.09</td>
<td>1684.0</td>
<td>8</td>
<td>13.5</td>
</tr>
<tr>
<td>Computer Floor 1</td>
<td>100.00</td>
<td>2</td>
<td>200.0</td>
<td>8</td>
<td>1.6</td>
</tr>
<tr>
<td>Computer Floor 2</td>
<td>100.00</td>
<td>10</td>
<td>1000.0</td>
<td>8</td>
<td>8.0</td>
</tr>
<tr>
<td>Printer</td>
<td>175.00</td>
<td>1</td>
<td>175.0</td>
<td>2</td>
<td>0.4</td>
</tr>
</tbody>
</table>
### School and public market

<table>
<thead>
<tr>
<th></th>
<th>Power [W]</th>
<th>Number of items</th>
<th>TOTAL Power [kW]</th>
<th>Hours [h]</th>
<th>Daily consumption [kWh/da]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamps/m²</td>
<td>11.0</td>
<td>270.0</td>
<td>2970.0</td>
<td>8</td>
<td>23.8</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>119.0</td>
<td>7.0</td>
<td>833.0</td>
<td>24</td>
<td>20.0</td>
</tr>
<tr>
<td>Oven</td>
<td>1200.0</td>
<td>7.0</td>
<td>8400.0</td>
<td>3</td>
<td>25.2</td>
</tr>
<tr>
<td>Computer Floor 1</td>
<td>100.0</td>
<td>3.0</td>
<td>300.0</td>
<td>8</td>
<td>2.4</td>
</tr>
<tr>
<td>Computer Floor 2</td>
<td>100.0</td>
<td>3.0</td>
<td>300.0</td>
<td>8</td>
<td>2.4</td>
</tr>
<tr>
<td>Beamer Floor 1</td>
<td>300.0</td>
<td>1.0</td>
<td>300.0</td>
<td>4</td>
<td>1.2</td>
</tr>
<tr>
<td>Beamer Floor 2</td>
<td>300.0</td>
<td>1.0</td>
<td>300.0</td>
<td>4</td>
<td>1.2</td>
</tr>
<tr>
<td>TV Screen</td>
<td>60.0</td>
<td>1.0</td>
<td>60.0</td>
<td>8</td>
<td>0.5</td>
</tr>
<tr>
<td>Ventilation</td>
<td>150.0</td>
<td>2.0</td>
<td>300.0</td>
<td>8</td>
<td>2.4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>13763.0</td>
<td></td>
<td>79.0</td>
</tr>
</tbody>
</table>

### Public lightning

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamps</td>
<td>12.0</td>
<td>23.0</td>
<td>276.00</td>
<td>12.50</td>
<td>3.45</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>12.50</td>
<td></td>
<td>3.45</td>
</tr>
</tbody>
</table>

Tab 3.4.1.1: Electric consumption evaluation for building and public facilities (*Surface m², in detail to evaluate the number of lamps has been considered a comfort ratio of 11W/m²);
Design of PV smart grid

As said before, the new functions implemented in the project area need energy to run. Of course it can’t go totally off-grid, but at least, it is possible to produce a certain amount of electricity using some photovoltaic panels. The first step for the sizing of this renewable energy installation was choosing on which roofs they could be installed. To do so, a simulation was run on DIVA to evaluate which roof are the most irradiated by the sun during the year. This simulation showed where it was logic to install, so the PV wouldn’t be bothered by the shadow of a taller building or even by the topography of the area. The results were useful to select the best candidates. The second criteria was the ownership of those roofs. Indeed, it is not fair to come to the favelas and force everyone to accept this kind of installation on their roofs. The remaining place selected where the ones that are so tall that it is conceivable that there will be no further vertical expansion. Even if the roofs of the new buildings are not on the best spots to produce energy, it has been chose to use them anyway in order to minimize the impact on the neighbors.

Pic: 3.4.1.1: Diva simulation results;
The next step was to set which azimuth and inclination will maximize the on-site energy production. Concerning the azimuth, it was logic to choose 0° because all the selected building’s roofs are flat. About the inclination, to find the best one it has been necessary to run a simulation using the tool provided by National Renewable Energy Laboratory (USA). Different inclinations from 15° to 30° have been tested. The best production results were when the inclination was set to 20°.

<table>
<thead>
<tr>
<th>Incl. 0°</th>
<th>Incl. 5°</th>
<th>Incl. 10°</th>
<th>Incl. 15°</th>
<th>Incl. 20°</th>
<th>Incl. 25°</th>
<th>Incl. 30°</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.11</td>
<td>6.05</td>
<td>5.96</td>
<td>5.84</td>
<td>5.69</td>
<td>5.5</td>
<td>5.28</td>
</tr>
<tr>
<td>6.26</td>
<td>6.28</td>
<td>6.27</td>
<td>6.21</td>
<td>6.12</td>
<td>5.99</td>
<td>5.83</td>
</tr>
<tr>
<td>5.35</td>
<td>5.47</td>
<td>5.55</td>
<td>5.59</td>
<td>5.61</td>
<td>5.59</td>
<td>5.54</td>
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<tr>
<td>4.78</td>
<td>4.99</td>
<td>5.17</td>
<td>5.32</td>
<td>5.43</td>
<td>5.51</td>
<td>5.56</td>
</tr>
<tr>
<td>4.04</td>
<td>4.3</td>
<td>4.53</td>
<td>4.73</td>
<td>4.91</td>
<td>5.05</td>
<td>5.17</td>
</tr>
<tr>
<td>3.75</td>
<td>4.05</td>
<td>4.32</td>
<td>4.56</td>
<td>4.77</td>
<td>4.96</td>
<td>5.11</td>
</tr>
<tr>
<td>3.87</td>
<td>4.16</td>
<td>4.42</td>
<td>4.66</td>
<td>4.87</td>
<td>5.04</td>
<td>5.19</td>
</tr>
<tr>
<td>4.94</td>
<td>5.22</td>
<td>5.46</td>
<td>5.68</td>
<td>5.85</td>
<td>5.99</td>
<td>6.09</td>
</tr>
<tr>
<td>5.05</td>
<td>5.19</td>
<td>5.31</td>
<td>5.39</td>
<td>5.44</td>
<td>5.45</td>
<td>5.43</td>
</tr>
<tr>
<td>5.31</td>
<td>5.35</td>
<td>5.35</td>
<td>5.33</td>
<td>5.27</td>
<td>5.18</td>
<td>5.07</td>
</tr>
<tr>
<td>5.34</td>
<td>5.31</td>
<td>5.24</td>
<td>5.15</td>
<td>5.03</td>
<td>4.88</td>
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</tr>
<tr>
<td>5.92</td>
<td>5.84</td>
<td>5.73</td>
<td>5.59</td>
<td>5.42</td>
<td>5.21</td>
<td>4.98</td>
</tr>
<tr>
<td>5.06</td>
<td>5.18</td>
<td>5.28</td>
<td>5.34</td>
<td>5.37</td>
<td>5.36</td>
<td>5.33</td>
</tr>
</tbody>
</table>

Tab 3.4.1.2: daily solar radiation for inclination in Rio de Janeiro;

The final step was to figure out how many of the selected spots would be needed to cover, the consumption of the new functions. The production capacity of each of the chosen spot were calculated. It was then possible to figure out how many buildings would be needed to cover 30, 50 or 100% of the energy needs.
<table>
<thead>
<tr>
<th>Building</th>
<th>Building 2</th>
<th>Building 3</th>
<th>Building 4</th>
<th>Building 5</th>
<th>Building 6</th>
<th>Building 7</th>
<th>Building 8</th>
<th>Building 9</th>
<th>Building 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>kWh</td>
<td>kWh</td>
<td>kWh</td>
<td>kWh</td>
<td>kWh</td>
<td>kWh</td>
<td>kWh</td>
<td>kWh</td>
<td>kWh</td>
<td>kWh</td>
</tr>
<tr>
<td>Month</td>
<td>January</td>
<td>February</td>
<td>March</td>
<td>April</td>
<td>May</td>
<td>June</td>
<td>July</td>
<td>August</td>
<td>September</td>
</tr>
<tr>
<td>273</td>
<td>294</td>
<td>269</td>
<td>261</td>
<td>236</td>
<td>229</td>
<td>234</td>
<td>281</td>
<td>261</td>
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</tr>
<tr>
<td>208</td>
<td>224</td>
<td>205</td>
<td>199</td>
<td>180</td>
<td>175</td>
<td>178</td>
<td>214</td>
<td>199</td>
<td>193</td>
</tr>
<tr>
<td>1075</td>
<td>1157</td>
<td>1060</td>
<td>1026</td>
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<td>902</td>
<td>920</td>
<td>1106</td>
<td>1028</td>
<td>996</td>
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<td>109</td>
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</tr>
<tr>
<td>939</td>
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<td>810</td>
<td>787</td>
<td>804</td>
<td>965</td>
<td>898</td>
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</tr>
<tr>
<td>302</td>
<td>324</td>
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<td>597</td>
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<td>501</td>
<td>511</td>
<td>614</td>
<td>571</td>
<td>553</td>
</tr>
<tr>
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<td>447</td>
<td>410</td>
<td>396</td>
<td>358</td>
<td>348</td>
<td>356</td>
<td>427</td>
<td>397</td>
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</tr>
<tr>
<td>825</td>
<td>887</td>
<td>813</td>
<td>787</td>
<td>712</td>
<td>692</td>
<td>706</td>
<td>848</td>
<td>789</td>
<td>764</td>
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<tr>
<td>ANN.</td>
<td>3349</td>
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<td>13188</td>
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<td>11513</td>
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<td>6629</td>
<td>7327</td>
<td>5094</td>
</tr>
</tbody>
</table>

Tab 3.4.1.3: Annual production for PV located on each buildings;

Legend:
- 30%
- 50%
- 100%

Previous page: Pic: 3.4.1.2: Building location;
Above: Pic: 3.4.1.3: PV panel design for 30%, 50% and 100% configuration;
3.4.2 Water management

3.4.2.1 Sewer system

The top part of the area 3 is served by the sewage system only on the bottom part. Indeed a sewage channel is reported along the Rua 2 and, thanks to sometime visible connection pipes, during the site inspection was possible to verify that buildings close to the Rua 2 were relaying on the existing sewage system. Nevertheless, for those who are not facing the main road the Talvegue, rain water channel, had became an alternative to discharge all the black water causing health and drainage problems.

To improve the health and hygiene conditions of the area a new sewage system, parallel to the talvegue, was designed to divert the black water from the rainwater channel to the existing main sewerage pipe on the Rua 2. In consequence, a new line of “condomí-nios “, system of pipes which serves a small number of houses, had been traced along the new connection, defined in the project masterplan, between Rua 1 and Rua 2. The main issue related to the design of a sewer system in this neighborhood is the topography. In detail due to high slope the velocity in the pipes increases and exceed the design admissible value. On the other hand is extremely complicated to excavate deep to decrease slope. Firstly the narrow path don’t allow the transportation of heavy machineries. Secondly it is not possible to guarantee the stability and avoid damage to the surroundings foundations, since they were built in a precarious way without pre design and structural verification.

Pic: 3.4.2.1: Existing talvegue on area 3, Rocinha, ph. Perego Francesca, Oct 2018;
Design data

A draft of the sewer system path has been made taking into account that due to low budget, the same path would be employed both for drainage and sewer system. As would be shown on the next chapter or the drainage system, the existing talvegue path has been exploited and improved with secondary connections. Therefore, the talvegue path has been employed for the sewer system too.

Between each node had been calculated the slope defined by the elevation of the nodes. In detail, all the pipes had been placed at 1.20 m underground, to protect them from sunlight and impacts.

Moreover to evaluate the flow a value of daily medium discharge equal to 150 l/inhabitant day was adopted to design all the future intervention about the sewer system in the favela. This data was obtained according to the assumptions made by professors S. Mambretti and G. Becciu. Thereafter, this data has been reduced to 120 L/inhabitant day considering that only the 80% of available water is collected by the sewer.

Moreover, for the design the maximum values have been obtained by multiplying the daily average values of discharge by 1.5. The results are shown in the following table, together with the elevation of the nodes and their depth.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</table>

Pic: 3.4.2.2: designed sewer system;
Design verification

Velocity, flow and filling of the pipes were verified in this preliminary phase.
The water velocity has been calculated with the Chezy formula assuming the full pipe conditions:

\[ V_r = K_s \cdot R^{2/3} \cdot i^{1/2} \quad \text{and} \quad 0.5 \, \text{m/s} \leq V_r \leq 5 \, \text{m/s} \]

Where:
- \( V_r \) is the uniform motion velocity in full pipe condition [m/s];
- \( K_s \) is the section roughness [m^{-1/3}];
- \( R \) is the hydraulic radius of the section;
- \( i \) is the pipe average slope [%].

Once the water velocity is calculated, it is possible to calculate the flow in full pipe conditions for each section with the following formula:

\[ Q_r = V_r \cdot A \quad \text{and} \quad Q_r \leq 83.7\% \cdot Q \]

Where:
- \( Q_r \) is the uniform motion flow in full pipe condition [m^3/s];
- \( V_r \) is the uniform motion velocity in full pipe condition [m/s];
- \( A \) is the area of the section pipe [m^2].

In particular, as explained before due to the high slope of the site and the low accessibility of the worksite as well as the instability of the surroundings foundation few values of \( V_r \) are not verified.

The results are reported in the following table.

<table>
<thead>
<tr>
<th>No</th>
<th>Node Ground Height (m)</th>
<th>Pipe Height (m)</th>
<th>Path No</th>
<th>Building Surface (m²)</th>
<th>No. People</th>
<th>Medium Flow (l/s)</th>
<th>Maximum Flow (l/s)</th>
<th>Medium Total Flow (l/s)</th>
<th>Maximum Total Flow (l/s)</th>
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<td>DN (PN10) [mm]</td>
<td>Diameter [m]</td>
<td>Hydraulic radius [m]</td>
<td>Length path [m]</td>
<td>Nodes height [m]</td>
<td>Slope</td>
<td>Vr [m/s]</td>
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</table>

Tab. 3.4.2.2: Design and verification of the sewage system;
3.4.2.2 Rainwater management: Drainage system

The drainage system design consists in the verification of the existing rainwater collecting system and the implementation of the latter with secondary systems that flows into the talvegue. Based on pluvimetrical data the values obtained and calculated by previous researches on other IMM areas have been taken. In detail they are depending on the chosen return time. As in previous analysis a return time of 10 years has been taken in consideration for morphological reasons.

Legend:
- Path
- Talveques
- Nodes
- Buildings connected
- Surfaces connected

Pic: 3.4.2.3: designed drainage downpipes system;

Design data

To size the downpipes and verify the talvegue section the analysis had been performed with a duration time of 5 minutes. This timing has been employed also in previous design on other IMM areas due to the high slopes rates and high level of impermeability of the soil due to densification and lack of resilient green area. In consequence a general short adduction time is the most likely scenario. Given this values considering a $T_r = 10$ years and a $t = 5$ minutes, the rain intensity is equal to $133.93$ mm/h. This value has been multiplied for the area of each roof. Moreover a coefficient to take in account of surfaces characteristics has been applied. According to Brazilian law: ASN 565.010 the considered values of $K$ are:

- $K = 0.8$: coefficient for concrete surfaces;
- $K = 0.3$: coefficient for green surfaces, included green roofs;
### Tab. 3.4.2.3: Design data collected per each line of the drainage system;

<table>
<thead>
<tr>
<th>Node</th>
<th>Ground height (m)</th>
<th>Pipes height (m)</th>
<th>Path</th>
<th>n° Buildings</th>
<th>Surface [m²]</th>
<th>Green roof surface [m²]</th>
<th>Concrete ground [m²]</th>
<th>Green ground [m²]</th>
<th>No-draining surfaces [m²]</th>
<th>Green surfaces [m²]</th>
</tr>
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**Design verification**

As for the sewer case the design section has been verified both for the velocity parameter as well for the flow.

In detail, the system new pipes has been designed and verified. Meanwhile, hand the existing talvegue has been verified. The section results are verified, on the other hand the weakest sections, that corresponds to the smallest ones are also the ones where it is not possible to intervene due to buildings proximity. In particular, for the talvegue verification it has been employed an area equivalent hydraulic radius.

Velocity, flow and filling of the pipes were verified in this preliminary phase.

The water velocity has been calculated with the Chezy formula assuming the full pipe conditions:

\[ V_r = K_s \times R^{2/3} \times i^{1/2} \text{ and } 0.5 \text{ m/s} \leq V_r \leq 5 \text{ m/s} \]

Where:
- \( V_r \) is the uniform motion velocity in full pipe condition [m/s];
- \( K_s \) is the section roughness [m\(^{-1/3}\)s];
- \( R \) is the hydraulic radius of the section;
- \( i \) is the pipe average slope [%].
In detail for the verification of design pipes the evaluation of the flow has been carried out by the Rational Method:

\[ Q = 2.78 \times \Phi \times S \times a \times T_o \times n^{-1} \]

\[ Q_r = V_r \times A \text{ and } Q_r \leq 83.7\% \times Q \]

Where:
- \( Q \): water flow \([\text{L/s}]\);
- \( \Phi \): inflow coefficient taken equal to 0.9;
- \( S \): collecting surface area \([\text{m}^2]\);
- \( a \): characteristic parameter of intensity curve \([\text{mm/hn}]\);
- \( T_o \): concentration time \([\text{h}]\);
- \( n \): characteristic parameter of intensity curve \(n = 1.29\);

In detail the value of \( n = 1.29 \) has been obtained by Rocinha’s pluvionometrical data, available on www.data.rio. Meanwhile, the data of “a” and “n” had been obtained by previous researches on Rocinha’s IMM area analyzing the intensity-time curve considering a return time of 10 years.

<table>
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<th>Ks [m1/3/s]</th>
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Tab. 3.4.2.5: Design and verification of the drainage system, flow;
4 O ateliê

4.1 Architectural design

The issue of introducing a technology that is designed on peculiar necessity of Rocinha finds its key point in a structure that supports and promotes this innovative solution inside the favela. At this purpose, an empty plot, today employed as warehouse for construction materials, had been used to build a structure where at the same time elements in argamassa armada are retailed and craft on a small scale. Nonetheless, this structure is also meant to introduce Rocinha’s construction workers not only to the argamassa armada practice, but also to the overall issues about the architectural and construction practice. The main question in conceiving a workshop inside such dense settlement where space is basically lacking has its purpose in showing, thorough the evidence of facts, that this technology is tailored and is meant to be used in Rocinha. Today construction materials are taken form the exterior and employed in the favela by construction workers that lack in knowledge about how to deploy them. The goal is not only to introduce the technology on the worksite to be easily put in place. The key point is to directly involve the construction workers from Rocinha, unskilled low-class workforce, from the production till the deployment to get a deeper understanding not only on the argamassa armada but also on the mains architectural matters. This structure, even in such small scale, embodies the difference between an architecture able to involve on the worksite a low cost unskilled craftmanship perpetuated by Lelè and the idea to provide a know-how. This concept was translated in a space were raw material as concrete and textile reinforcement are taken and in face of anybody crossing the road are transformed in construction prefabricated elements. History had made favela’s inhabitants doubting about anything that would come from the exterior. The simplest and easiest way to gain trust is merely bring in Rocinha the technology. Would be difficult in the favela to explain how the element works once the concrete is casted and the reinforced is not visible anymore. Commonly in the favelas construction workers learn the practice on the worksite. In consequence, to introduce a new the technology wishing that would be used and handled by favelados, is necessary to get through the empirical understanding of the system behavior. The purpose is to show the elements and employ the materials when and where favelados can see, touch and understand how they works and at the same time to integrate this practical learning providing technical and architectural support that is basically lacking in all this informal settlements, especially in Rocinha. Due to the size of the building it is not conceived to eventually satisfy the overall demands of the whole favela, in this project is supposed that there is a reference prefabrication factory, meanwhile this structure in the favela solve the function of promoter and a supporter of the argamassa armada, a place where not only people can learn how to use the technology but also exchange and create a more favela-friendly product.
4.1.1 Strategic location

As seen in chapter 3.1 part 2 On site survey, the building is placed in a strategic position. It faces Rua 2 and is close to the Estrada da Gavea. Moreover, the neighborhood is one of few spots inside the favela where are located few construction material sellers. Although is easy to reach the project site by car it is located close to the summit of the favela. This part of the favela, at exception of building facing main vehicle accessible roads, is left for the poorest. In fact, it is more difficult and more expensive to reach these buildings due to high slopes and narrow paths. On the other hands, this is a valuable reason to place a spot for argamassa armada retail. Moreover as seen in chapter 3.2 the concept plan, this building plays a strategic role in carrying out multiple urban strategies meant to revitalize and open this new strategic node both to the Estrada da Gavea both and mostly to the neighborhood above.

Pic 4.1.1 project site;
4.1.2 Functions and architectural design

This building was designed to host two main separate functions: a space where the argamassa armada is retailed and craft and on the top floor, a space for an architectural studio that works for the promotion and for the teaching of architectural practices, included the use of argamassa armada, inside the favela.

The workshop: ground floor and second floor:
This place was studied in order to fit in 90 meter square the retailing and the production of the argamassa armada. To defines the main function needed to accomplish the production task a research of similar workshops and precast concrete factories was carried out. Among all possible examples the main reference were the factories built buy Lelè. In detail, Lelè factories are well described by the literature. Moreover, since the ALICE and I-béton researchers went to Slavador da Bahia to study Lelè work they also had the possibility to visit the fabrica de equipamentos comunitarios (FAEC) a ferrocement or argamassa armada prefabrication center built in Salvador da Bahia in the 1889. During their visit they had the chance assist to the casting of different elements.

Lelè built a total of 12 factories on the country among them one in Rio de Janeiro which contributes to build more than two hundreds schools in poor settlement as Rocinha. On the other hand literature reports also that others transitional factories were raised and dismantled for a specific worksite. In this case the factories were used only to precast the elements once the molds were provided on place.
The project aims is to create a dialog between the construction workers in the favela through a more handcraft creative approach to prefabrication of argamassa armada. At this purpose it is necessary to host in the building all the phases of the prefabrication process from the preliminary mold construction till the final finishing on the elements. In consequence spaces and machines employed in Lelé factory had been studied and eventually introduced in the small structure. The space had been designed to host a fix number of 4 employee. Since the building has only one free side that faces the road, it was necessary to place the stockage area on this side. All the preliminary activities as cut and arrange the textile fabrics or set up the materials for formworks are placed both, when is possible on the first floor or at the ground floor. The first floor is devoted to preliminary activities as formwork and elements design or modification. In comparison to Lelé factories a large part of the total space is left for all this activities to highlight the craft hand activities. The main challenge to face was to combine the different timing and workforce needed to accomplish different tasks with the lack of space inside the workshop. About the pouring stations, knowing that argamassa armada elements need to be demolded at least two or three days after the pouring, it was essential to set up multiple elements at the same time and keeping the casting platform free. Inspired by pouring machines employed by Lelé the vertical casting platform was conceived to cantilever the molds during the pouring phase and after move them, thanks to rails, to free the area and to let them drying. Once the molds are sufficiently dried they could be moved and displaced to horizontal demolding stations. After the demolding phase whether is needed the elements could be finished to care imperfections and finally stocked.

Pic. 4.1.6: Ground floor; Pic. 4.1.7: First floor;
The architectural studio:

Combine the empirical activities carried out on the workshop with teaching activities to provide a solid know-how inside the favela is a key point of this project. At this purpose the second floor has been conceived as a large and dynamic open space where multiple activities are carried out. This part of the project have been inspired by an NGO that was present inside the favela of Rocinha, called InovaUrbis. This NGO used to offer both teaching courses about architectural and construction matters both architectural and construction projects at fair price for the favelados. Inside informal settlement as the favela the architectural practice is not diffused because there is no rule that impose it and because the majority of favelados can’t afford it. The goal of this association was to democratize architecture and construction practice introducing it to the less favorite and poorest people living in marginalized settlements as the favela. Moreover the other issue related to the construction practice is the structural lack of knowledge and education about construction issues. This association promotes architectural courses open to construction workers and common people, women and men, interest in the subject. Construction market in the favela is a big source of revenues for construction workers as well for common people since is a safe and rentable investment. On this reason the role played by Inova Urbis was fundamental. The primary goal of the project is to promote and introduce to Rocinha inhabitants the argamassa armada and in general the value of design and architecture. Therefore, the support of an activity as Inova Urbis is central. This place would be a unique space inside the favela to give a chance for a dialog between a the marginalized and topics as architecture and design that has always been a matter of privileged.
Materials and Facades design

The final layout of the building plays a very important role in showing the building purpose: the argamassa armada. In Rocinha, it is common to advertise the merchandise putting it on the streets or close to the building where is visible by everybody. As said before, this building wants to create a dialog with the favelados speaking the same direct and genuine language of the favela. This building has a very privileged position in the neighborhood since it faces one of the main and large car accessible roads, the Rua 2. Therefore, this opportunity has to be exploited as much as possible to advertise the argamassa armada. The North-West façade has a double height open space designed to host the vertical pouring station. In consequence the exterior façade have been designed to show the skeleton of the structure that bear the building. The second floor, which host the architects studio has been equipped with a large and open glass façade. This one has been designed to benefit as much as possible of the natural light, that comes mostly from this façade. On the other hand, due to the building orientation, this façade is also one of the most exposed to sunlight and needs to be shaded. In the rural construction tradition is common to use hollowed bricks to shadow windows and to guarantee ventilation. Today those bricks are widely employed in the favela. In consequence, the same principle have been used to shadow the façade, on the other hand, to remark the purpose of the building construction bricks were employed. Commonly two typology of bricks are used in the favela, the common 8/9 cm depth and 30/19 centimeter width hollow bricks or semi-hollowed bricks of 12 centimeters depth and 5.5/25 cm width. The latter are bit more expensive, increasing of 20% , but they guarantee a

Pic.4.1.10: Construction material shop, ph. Perego Francesca, Rocinha, Oct 2018;
better thermal inertia. This specific bricks, since they are not too depth and with many holes have been used to shade the facades of all the building as alternative to the common hollowed bricks. Unfortunately, the other facades don’t benefit of the same visibility as the North-West. In fact all of them are close to other building. The South-West façade is the one which among the three has more visibility since faces the stairs that brings to the buildings behind. On of the other important element, not so visible from the Rua 2 façade, are the exterior TRC panels. Those panels are thin to address spaces necessities and since they don’t have a relevant thermal mass, the exterior panel have been designed to be molded in different shapes for self-shading to reduce the overall radiation acting on the façade. The facades have been made employing those panels. In detail, the North-East and South-West façades, in the part that faces the workshop are blind to avoid noise, pollution and dust to reach the close building. On the other hand, the panel texture have been employed to give rhythm and dynamism to the façade playing with variables geometric patterns and concrete texture. Moreover due to proximity with residential building the window have been shaded once again with the hollow bricks. In consequence diffused and sufficient light is guarantee in the internal spaces as well as privacy for the close neighborhood. Few texture have been used on this building, the most important one are the concrete and the bricks. Both of them are common and widely diffused in Rocinha. Moreover, both of them are produced locally: concrete comes from local product as grain sand and water, the same is for the bricks. This building, through its architecture wants to enhance local and poor materials that commonly are a symbol of poverty and low class.

Pic.4.1.11: South-East facade detail;
Pic.4.1.12: North-East facade;

Pic.4.1.13: South-East facade;
Pic. 4.1.14: North-West facade;

Pic. 4.1.15: South-West facade;
4.2 Technological design

The overall design of the building had been carried out with a careful regard on details, elements texture and perception as space generators. In consequence, the choice of materials, building elements and crossing details had been taken from the early begin addressing not only to performance and technical requirements but also to architectural concepts too. This research had been carried out addressing to the question of sustainable building solutions in Rocinha involving both technical and performance requirements as well as peculiar necessities of such dense and unique context.

Pic: 4.2.1, North West facade detail;
4.2.1 Rocinha context

The choice of materials and construction techniques have been taken after a deep analysis on the construction field. Rocinha isn’t an isolated community where construction materials are limited and inaccessible. The favela shares the same construction market with the City of Rio de Janeiro, in consequence different solutions are accessible but on the other hand, common and cheap materials as bricks and concrete are privileged since construction workers inside the community know how to deploy them. As said by the construction seller on an interview “(Construction materials) are changing a lot, thorough more “technological direction” more resistant and lighter”. Therefore, the introduction in the favela of a new technological solution is possible as far as it meets basic requirements such:

• Thickness: Space is the mostly lacking in common houses and structure inside the favela and this issue explains also why commonly walls and slabs are extremely thin inside the settlement. Many of the houses have structural problems as unaligned pillars due to the attempt by the owner to enlarge as much as possible the house building rough cantilevers. Therefore, space had been considered as a main requirement stressing out the question of how much a wall should be thick to be built and adopted in Rocinha, especially whether compared to the employed 8/9 cm wall solution.

• Cost: Rocinha is not a extremely poor settlement, instead as many cities, the purchasing power is different depending on social status. Anyway the budget issue has to be taken in account reducing the overall cost also due to the TRC employment.

• Transportation: transportation and stockage are fundamental issue inside Rocinha. Although the building is facing one of the main road accessible to cars the technological solutions had been designed to be repeated in the majority of the Favela, included no-car accessible sites.

• Easy deployment: no need of high specialized employers and massive machineries as heavy cranes to build the technical solution.

Energy performances and technical requirements in Rio de Janeiro’s Tropical climate.

One of the main factor that influence building performances are location, orientation and climate conditions. As already mentioned, Rocinha and Rio de Janeiro are characterized by high temperatures during the year with an average of 29°C from October to March and 23°C from April to September. In consequence, both in the architectural and technical design the main efforts are focused in develop solutions to guarantee internal comfort through the reduction of heat gains and the increasing of natural cooling performances. Firstly the local law had been taken in account to define the minimum level of performance requested to each techno-
logical system. Currently the norm employed in Brazil is the “ABNT NBR 15575 2013 normas de desenpenho”, made by 6 different sections that define the minimum requirements for each technological solution. These values are defined by the climate zone where the project is located, Rio de Janeiro, as the majority of the Brazil, is grouped in this Zone 8.

Pic: 4.2.2, Zonas Bioclimaticas (from: ABNT NBR 15575 2013 normas de desenpenho);

**Thermal transmittance requirements:**

Designing the technical solutions is important to grant a thermal transmittance and thermal capacity that satisfy the minimum requirements defined:

- **Walls:** in tabela “Tabela 13 Transmissância térmica de paredes externas” is defined the The maximum value for the thermal transmittance (U) of the external walls:

<table>
<thead>
<tr>
<th>Zonas 1 e 2</th>
<th>Zonas 3, 4, 5, 6, 7 e 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U \leq 2.5$</td>
<td>$U \leq 2.7$</td>
</tr>
<tr>
<td>$\alpha^* \leq 0.6$</td>
<td>$\alpha^* &gt; 0.6$</td>
</tr>
<tr>
<td>$U \leq 2.5$</td>
<td></td>
</tr>
</tbody>
</table>

Pic: 4.2.3, Minimum thermal transmittance requirements for vertical walls (from: Transmissância térmica de paredes externas, ABNT NBR 15575 2013 normas de desenpenho);

- **Roof:** in tabela “Tabela 3 Critérios de coberturas quanto à transmissância térmica” is defined the The maximum value for the thermal transmittance (U) of the external walls

<table>
<thead>
<tr>
<th>Zonas 1 e 2</th>
<th>Zonas 3 e 6</th>
<th>Zonas 7 e 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U \leq 2.0$</td>
<td>$\alpha \leq 0.8$</td>
<td>$\alpha \leq 0.4$</td>
</tr>
<tr>
<td>$U \leq 2.3$</td>
<td>$U \leq 1.5$</td>
<td>$U \leq 2.3$ PV</td>
</tr>
<tr>
<td></td>
<td>$\alpha &gt; 0.8$</td>
<td>$\alpha &gt; 0.4$</td>
</tr>
</tbody>
</table>

Pic: 4.2.4, Minimum thermal transmittance requirements for roof (from: “Tabela 3 Critérios de coberturas quanto à transmissância térmica”, ABNT NBR 15575 2013 normas de desenpenho);
4.2.2 Technological solutions compendium

The minimum requirements imposed by Brazilian laws are easily fulfilled. There thermal performance as well as different secondary requirements previously listed as transportation, displacement on site, employment of local materials and techniques have been employed to define the technological solutions. The vertical technological solution have been equipped with sound proofing layers and services layer thanks to the use of counter-wall pasteboard. This technology may not be the most diffused one in the favela. But as said in chapter 2.1 part 1, Buildings techniques today, Rocinha has as reference Rio de Janeiro’s market of construction material. Therefore, as was verified during the site survey in different shopping buildings, is not uncommon to find other technological solutions than the bricks-concrete traditional ones. Finally for each technical solution different analysis have been carried out to verify performances and guarantee that each solution is not subjected to mold or condensations phenomena. The principal technological solutions are exposed in the following pages.
H.C 02: Slab on cold spaces

1: Colored self-levelling floor finishing in concrete based mixing, thk. 1 cm;
2: Leaning and service layer in portland concrete lighted thanks to expanded polystyrene sphere (Ø2mm), \( \lambda = 0.104 \) W/mK, \( \rho = 515 \) kg/m³, \( c = 1000 \) J/kgK, thk. 5 cm;
3: Acoustic insulation layer in felt sheets for floating floors, thk. 0.6 cm;
4: Thermal and acoustic insulation layer in high density glass-fiber, \( \lambda = 0.037 \) W/mK, \( \rho = 97 \) kg/m³, \( c = 1030 \) J/kgK, thk. 5.0 cm;
6: Protecting and anti-defect base in water based bitumen primer, thk. 0.5 cm;
7: Floor slab in textile reinforcement concrete, \( \rho = 2500 \) kg/m³, \( c = 780 \) J/kgK, thk. 2 cm/7 cm;

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<table>
<thead>
<tr>
<th>H.C 02: Slab on cold spaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal transmittance U</td>
</tr>
<tr>
<td>Thermal resistance R_t</td>
</tr>
<tr>
<td>Thickness thk</td>
</tr>
<tr>
<td>Decrement factor t_0</td>
</tr>
<tr>
<td>Thermal shift ( \Phi )</td>
</tr>
<tr>
<td>Thermal mass ( m )</td>
</tr>
<tr>
<td>Mold/Condensation</td>
</tr>
</tbody>
</table>
**H.C 02: flat roof**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>λ (W/mK)</th>
<th>ρ (kg/m³)</th>
<th>c (J/kgK)</th>
<th>thk (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Finishing layer in ceramic tiles, dim. 30x30 cm, thk. 0.7 cm;</td>
<td>2.3</td>
<td>2400</td>
<td>780</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Grout filling for ceramic tiles, thk. 0.4 cm;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Cement adhesive for ceramic tiles, λ = 2.3 W/mK, ρ = 2400 kg/m³, c = 780 J/kgK, thk. 1 cm;</td>
<td>2.3</td>
<td>2400</td>
<td>780</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Leaning layer in concrete, λ = 2.3 W/mK, ρ = 2400 kg/m³, c = 780 J/kgK, thk. 3 cm;</td>
<td>2.3</td>
<td>2400</td>
<td>780</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Protection layer in sand, λ = 0.35 W/mK, ρ = 1400 kg/m³, c = 800 J/kgK, thk. 1 cm;</td>
<td>0.35</td>
<td>1400</td>
<td>800</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Nonwoven fabric layer, thk. 0.2 cm;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Water proof membrane root-proof in polymer-bitumen, thk. 0.5 cm;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Thermal and acoustic insulation layer in high density glass-fiber, λ = 0.037 W/mK, ρ = 97 kg/m³, c = 1030 J/kgK, thk. 5.0 cm;</td>
<td>0.037</td>
<td>97</td>
<td>1030</td>
<td>5.0</td>
</tr>
<tr>
<td>9</td>
<td>Vapor resistant membrane in elastoplastomeric with aluminum reinforcement, thk. 0.4 cm;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Protecting and anti-defect base in water based bitumen primer, thk. 0.5 cm;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Leaning and service layer in portland concrete lighted thanks to expanded polystyrene sphere (Ø2mm), λ = 0.104 W/mK, ρ = 515 kg/m³, c = 1000 J/kgK, thk. 8.4 cm;</td>
<td>0.104</td>
<td>515</td>
<td>1000</td>
<td>8.4</td>
</tr>
<tr>
<td>12</td>
<td>Floor slab in textile reinforcement concrete, λ = 2500 kg/m³, c = 780 J/kgK, thk. 2cm/7 cm;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**H.C 02: flat roof**

<table>
<thead>
<tr>
<th>Thermal transmittance</th>
<th>U</th>
<th>W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal resistance</td>
<td>Rₜ</td>
<td>m²K/W</td>
</tr>
<tr>
<td>Thickness</td>
<td>thk</td>
<td>cm</td>
</tr>
<tr>
<td>Decrement factor</td>
<td>fₙ</td>
<td></td>
</tr>
<tr>
<td>Thermal shift</td>
<td>Φ</td>
<td>h</td>
</tr>
<tr>
<td>Thermal mass</td>
<td>m</td>
<td>kg/m³</td>
</tr>
</tbody>
</table>

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
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<tbody>
<tr>
<td>2</td>
<td></td>
<td>23.3</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>slope 1%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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244
H.C 03: green roof

1: Cultivation soil with expanded clay, $\lambda = 0.300 \text{ W/mK}$, $\varrho = 750 \text{ (1200) kg/m}^3$, $c = 1.840 \text{ J/kgK}$, thk. 10 cm;
2: Nonwoven fabric layer, tck. 0.2 cm;
3: Drainage layer in expanded clay, $\lambda = 0.12 \text{ W/mK}$, $\varrho = 380\text{kg/m}^3$, $c = 1000 \text{ J/kgK}$, thk. 5 cm;
4: Nonwoven fabric layer, tck. 0.2 cm;
5: Water-accumulating drainage sheet in ashlar membrane of high density polyethylene, thk. 0.8 cm;
6: Water proof membrane root-proof in polymer-bitumen, thk. 0.5 cm;
7: Thermal and acoustic insulation layer in high density glass-fiber, $\lambda = 0.037 \text{ W/mK}$, $\varrho = 97 \text{ kg/m}^3$, $c = 1030 \text{ J/kgK}$, thk. 5.0 cm;
8: Vapor resistant membrane in elastoplastomeric with aluminum reinforcement, thk. 0.4 cm;
9: Protecting and anti-defect base in water based bitumen primer, thk. 0.5 cm;
10: Leaning and service layer in portland concrete lighted thanks to expanded polystyrene sphere (Ø2mm), $\lambda = 0.104 \text{ W/mK}$, $\varrho = 515 \text{ kg/m}^3$, $c = 1000 \text{ J/kgK}$, thk. 8-4 cm;
11: Floor slab in textile reinforcement concrete, $\varrho = 2500 \text{ kg/m}^3$, thk. 2cm/7 cm;

<table>
<thead>
<tr>
<th>H.C 03: green roof</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal transmittance</strong></td>
</tr>
<tr>
<td><strong>Thermal resistance</strong></td>
</tr>
<tr>
<td><strong>Thickness</strong></td>
</tr>
<tr>
<td><strong>Decrement factor</strong></td>
</tr>
<tr>
<td><strong>Thermal shift</strong></td>
</tr>
<tr>
<td><strong>Thermal mass</strong></td>
</tr>
<tr>
<td><strong>Mold/Condensation</strong></td>
</tr>
</tbody>
</table>

Decrement factor $f_a = 0.06$ - 

Thermal shift $\Phi = 19.1$ h

Thermal mass $m = 321.6$ kg/m²

Mold/Condensation NO
V.C 01: TRC insulated wall

1: Double layer of plasterboard with lime finishing, $\lambda = 0.21$ W/mK, $\rho = 900$ kg/m³, $c = 1000$ J/kgK, thk. 2.5 cm,
2: Vapor resistant membrane in elastoplastomeric with aluminum reinforcement, thk. 0.4 cm;
3: C. aluminum guide profile, 50x75x50, thk 6 mm.
4: Thermal and acoustic insulation layer in high density glass-fiber, $\lambda = 0.034$ W/mK, $\rho = 80$ kg/m³, $c = 1030$ J/kgK, thk. 4.0 cm;
5: Air cavity, $\lambda = 0.1$ W/mK, thk. 3.5 cm;
6: Wall panel (interior face sandwich panel) in textile reinforced concrete, $\rho = 2500$ kg/m³, thk. 2 cm;
7: Cast on site joint fill with concrete and reinforced with steel bars $\varnothing$ 6 mm;
8: Neoprene dilatation joint, thk. 2.5 mm;
9: Polyurethane insulation layer, $\lambda = 0.028$ W/mK, $\rho = 38$ kg/m³, $c = 1450$ J/kgK, thk. 6 cm;
10: Wall panel (exterior face sandwich panel) in textile reinforced concrete, $\rho = 2500$ kg/m³, thk. 2.5 cm;

<table>
<thead>
<tr>
<th>V.C 01: TRC insulated wall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal transmittance</strong></td>
</tr>
<tr>
<td><strong>Thermal resistance</strong></td>
</tr>
<tr>
<td><strong>Thickness</strong></td>
</tr>
<tr>
<td><strong>Decrement factor</strong></td>
</tr>
<tr>
<td><strong>Thermal shift</strong></td>
</tr>
<tr>
<td><strong>Thermal mass</strong></td>
</tr>
</tbody>
</table>

Mold/Condensation | NO
V.C 03: Hollow bricks wall

1: Double layer of plasterboard with lime finishing, $\lambda = 0.21$ W/mK, $\rho = 900$ kg/m³, $c = 1000$ J/kgK, thk. 2.5 cm;
2: Vapor resistant membrane in elastoplastomeric with aluminum reinforcement, thk. 0.4 cm;
3: C aluminum guide profile, 50x50x50, thk 6 mm.
4: Thermal and acoustic insulation layer in high density glass-fiber, $\lambda = 0.034$ W/mK, $\rho = 80$ kg/m³, $c = 1030$ J/kgK, thk. 4.0 cm;
5: Air cavity, $\lambda = 0.1$ W/mK, thk. 1 cm;
6: Bearing layer in hollow bricks, $\lambda = 0.350$ W/mK, $\rho = 800$ kg/m³, $c = 840$ J/kgK, dim. 5 x 11.5 x 24.5 cm, thk. (11.5+5 cm) joined by cement mortar, thk. 1 cm;

<table>
<thead>
<tr>
<th>Thermal transmittance</th>
<th>U</th>
<th>0.41</th>
<th>W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal resistance</td>
<td>$R_t$</td>
<td>2.43</td>
<td>m²K/W</td>
</tr>
<tr>
<td>Thickness</td>
<td>thk</td>
<td>25.4</td>
<td>cm</td>
</tr>
<tr>
<td>Decrement factor</td>
<td>$f_a$</td>
<td>0.23</td>
<td>-</td>
</tr>
<tr>
<td>Thermal shift</td>
<td>$\Phi$</td>
<td>10.3</td>
<td>h</td>
</tr>
<tr>
<td>Thermal mass</td>
<td>$m$</td>
<td>253</td>
<td>kg/m²</td>
</tr>
</tbody>
</table>
4.3 Structural design

In the first part, the research one, at chapter 4 “Structural system pre-design” were defined the typology of concrete matrix and reinforcement. Nevertheless, the slabs were verified for generic load cases (internal slab and flat roof and small gangway). This chapter is focused on:

• Verify the reinforcement an section of the slab element defined at chapter 4 part 1 (ULS, SLS) for the building load cases;
• Verify the beam section and design the beam reinforcement for bending, shear-force and torsion (due to variable loads combinations) (ULS, SLS);
• Verify the pillars sections (ULS, SLS);
• Verify and design the bracing wall reinforcement (ULS).

The reference A3 board are the number 2 4.3 1-8.
4.3.1 Method of work and Legislation references

For the structural analysis was assumed that the basis of simple material laws and well-established assumptions generally employed in ordinary reinforced concrete structural works could be employed, under specific hypothesis for the TRC slab analysis.

The structural analysis and verification had been performed taking as references:

- ABNT NBR 6118 “Projeto de estruturas de concreto - Procedimento”;
- ABNT NBR 6120 “Cargas para o calculo de estruturas de edificacoes”;
- ABNT NBR 15421 “Projecto de estructuras resistentes a sismos”;
- ABNT NBR 6123 “Cargas para o calculo de viento”;
- D.M. 14.01.2018 “Norme Tecniche per le costruzioni”;
- EuroCode 2 Design of concrete structures;

Work method:

Work method: The Brasilian norms had been employed for the definition of loads and actions and minimum requirements that employed materials as concrete and reinforcement have to satisfy. On the other hand the EuroCode 2 had been employed to perform an analytical structural analysis and verification of the chosen solutions. The TRC is a developing technology still not regulated by shared laws. In consequence, to the describe the tensile response of the materials behaviour, textile reinforcement and mortar, an analytical model had been defined on previous researches carried out in the I-béton (EPFL) laboratories.

4.3.2 Description of employed materials

Concrete:

For structural verification in chapter 4 part 1, it has been employed a special mortar tailored by CemSuisse for TRC element. In this chapter the other structural elements as pillars and beams, that are not that thin and reinforced with steel bars too have been investigated. In detail the ULS structural verification has been carried out supposing a ductile failure by steel bars and not by brittle textile reinforcement. Therefore it has been made the assumption that less performing mortar, which preserve it ductile behavior and not only a linear one, which was the case of Cemsuisse mortar, could be employed. Following the Brazilian norm ABNT NBR 6118 “Projeto de estruturas de concreto - Procedimento” the mortar has to respect the minimum requirements of:

- The ratio between water and cement has to be less than or equal to 0,55
- The minimum equired class resistance is C30.
- Moreover since steel bars are employed the minimum coverage value is set to 40 mm for pillars and 35 for slabs. In case of slabs covered with no structural as leaning or service layer the minimum coverage is reduced to 15 mm.

The mortar employed is a class resistance C45/55 this has been chosen since it has good resistance and no extra verification are needed once the element is poured.
Pic. 4.3.1 environmental aggressiveness classes (from: ABNT NBR 6118 Tab. 6.1 Classes de agressividade ambiental).

<table>
<thead>
<tr>
<th>Classe de agressividade ambiental</th>
<th>Agressividade</th>
<th>Classificação geral do tipo de ambiente para efeito de projeto</th>
<th>Risco de deterioração da estrutura</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Fraca</td>
<td>Rural, Submersa</td>
<td>Insignificante</td>
</tr>
<tr>
<td>II</td>
<td>Moderada</td>
<td>Urbana(^{1,2})</td>
<td>Pequeno</td>
</tr>
<tr>
<td>III</td>
<td>Forte</td>
<td>Marinha(^1)</td>
<td>Grande</td>
</tr>
<tr>
<td>IV</td>
<td>Muito forte</td>
<td>Industrial(^{1,2})</td>
<td>Elevado</td>
</tr>
</tbody>
</table>

Pic. 4.3.2: Concrete quality minimum requirements (from: ABNT NBR 6118 Tab. 7.1 - Corresponderência entre classe de agressividade e qualidade do concreto).

<table>
<thead>
<tr>
<th>Relação água/cimento em massa</th>
<th>Concreto</th>
<th>Tipo</th>
<th>Classe de agressividade (tab. 6.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>I</td>
</tr>
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</tbody>
</table>

Pic. 4.3.3: Minimum value of concrete cover (from: ABNT NBR 6118 Tab. 7.2 - Corresponderência entre classe de agressividade ambiental e cobrimento nominal).
Reinforcement

According with previous analysis on chapter 4 part 1, the design net is a mixed carbon and glass fiber with a spacing of 20 mm and a single strand area of 0.85 mm. The steel used for the reinforcement bars is B450C.

<table>
<thead>
<tr>
<th>C 45/55</th>
<th>Textile reinforcement</th>
<th>B 450C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value</td>
<td>Unit</td>
</tr>
<tr>
<td>Fck</td>
<td>45</td>
<td>Mpa</td>
</tr>
<tr>
<td>fck,cube</td>
<td>55</td>
<td>Mpa</td>
</tr>
<tr>
<td>fcm</td>
<td>53</td>
<td>Mpa</td>
</tr>
<tr>
<td>fctk,0.05</td>
<td>2.7</td>
<td>Mpa</td>
</tr>
<tr>
<td>fctk,0.95</td>
<td>4.9</td>
<td>Mpa</td>
</tr>
<tr>
<td>Ec</td>
<td>36</td>
<td>Gpa</td>
</tr>
<tr>
<td>Fcd*</td>
<td>30.0</td>
<td>Mpa</td>
</tr>
<tr>
<td>Fcd**</td>
<td>1.80</td>
<td>Mpa</td>
</tr>
<tr>
<td>ec1 %0</td>
<td>2.4</td>
<td>-</td>
</tr>
<tr>
<td>ec1 %0</td>
<td>3.5</td>
<td>-</td>
</tr>
<tr>
<td>ec2 %0</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>ecu2 %0</td>
<td>3.5</td>
<td>-</td>
</tr>
<tr>
<td>n</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>ec3 %0</td>
<td>1.75</td>
<td>-</td>
</tr>
<tr>
<td>ecu3 %0</td>
<td>3.5</td>
<td>-</td>
</tr>
</tbody>
</table>

*Ec2 fcd = acc fck / gc with acc=1 and gc=1.5

<table>
<thead>
<tr>
<th>Textile reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
</tr>
<tr>
<td>ftk,0</td>
</tr>
<tr>
<td>ftk*,0</td>
</tr>
<tr>
<td>ftk,90</td>
</tr>
<tr>
<td>ftk*,90</td>
</tr>
<tr>
<td>E</td>
</tr>
<tr>
<td>Atk*,0.90</td>
</tr>
<tr>
<td>e,0.90</td>
</tr>
</tbody>
</table>

Tab. 4.3.1, Design concrete matrix proprieties, textile reinforcement proprieties and steel reinforcement proprieties

4.3.3 Load analysis

The actions acting on the structures can be various and they are classified as:

- **Permanent (f_{g})**: actions that act throughout the nominal life of the building, whose intensity variation in time is so small that can be considered as a constant.
  They are divided into:
  - Structural elements own weight, \( f_{g1} \);
  - Non-structural elements own weight, \( f_{g2} \).

- **Variable (f_{q})**: actions that act on the structure with variables values that may differ from one another over time. They are divided into:
  - long term actions: they act with a significant intensity for not a negligible period. They are the variable loads related to the planned use of the buildings, \( f_{q1} \).
small term actions: they act for a limited period of time compared to the whole life of the structure; they can be divided into:
- variable loads by wind action, \( f_{q} \);
- Exceptional (A): actions that occur exceptionally during the nominal life of the structure, such as explosions, impacts and fires;
- Seismic (E): actions deriving from the earthquakes.

### 4.3.3.1 Structural elements own weight (\( f_{g1} \)):

This value is provided by the weight of only structural elements employed in the structure. The value density considered to quantify the structural weight (\( f_{g1} \)) was 2.500 \( \text{kg/m}^3 \) (reinforced concrete value). The values for slab equivalent section, beam and column are reported on the following table 5.3.2

<table>
<thead>
<tr>
<th>Area [( \text{m}^2 )]</th>
<th>Density [( \text{kN/m}^3 )]</th>
<th>Lin. Load [( \text{kN/m} )]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab 0.022</td>
<td>25.00</td>
<td>0.56</td>
</tr>
<tr>
<td>beam 0.029</td>
<td>25.00</td>
<td>0.71</td>
</tr>
<tr>
<td>Column 0.011</td>
<td>25.00</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Tab. 4.3.2 values of \( f_{g1} \), structural elements own weight.

### 4.3.3.2 Non-structural elements own weight:

<table>
<thead>
<tr>
<th>( f_{g2} ) Non structural own weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal elements</td>
</tr>
<tr>
<td>Element</td>
</tr>
<tr>
<td>H.C.04 Intensive green roof</td>
</tr>
<tr>
<td>H.C.03 Flat roof</td>
</tr>
<tr>
<td>H.C.02 Slab on cold spaces</td>
</tr>
<tr>
<td>Vertical elements</td>
</tr>
<tr>
<td>Element</td>
</tr>
<tr>
<td>V.C.01/02: TRC insulated wall</td>
</tr>
<tr>
<td>V.C.04/v.p. 01: TRC non insulated wall</td>
</tr>
<tr>
<td>V.C.03: Brick wall</td>
</tr>
</tbody>
</table>

Tab. 4.3.3 values of \( f_{g2} \), non structural elements own weight.
4.3.3.3 Variables loads, Operative loads:
Variable loads are defined in Table 2 of ABNT NBR 6120. The table 4.1.6 is based on the intended use of the building and shows the values considered for the structural analysis.

<table>
<thead>
<tr>
<th>Technical element</th>
<th>Srf Load [kN/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>Office*</td>
<td>2</td>
</tr>
<tr>
<td>Shop*</td>
<td>3</td>
</tr>
<tr>
<td>Teaching room*</td>
<td>3</td>
</tr>
<tr>
<td>Terrace</td>
<td>3</td>
</tr>
</tbody>
</table>

Tab. 4.3.4 values of \( q_1 \), variable loads, * all uses supposed for the second floor, in consequence the worst one 3 kN/m² was considered (from: Table 2 of ABNT NBR 6120).

4.3.3.4 Wind loads
As defined by norms, the simple architecture and the regular shape of the analyzed structure admit to adopt a simplification on the winds loads analysis. The wind action had been studied considering an equivalent action, that applied through a static analysis, performs the maximum effect of the wind dynamic action.

The wind actions depends on:
- The site context to define the maximum wind speed and pick pression
- The shape and dimensions as well as orientation of the building to evaluate the maximum wind actions acting on the structure

Speed: the value of the wind velocity is defined by the ABNT NBR 6123

\[ V_k = V_0 \times S_1 \times S_2 \times S_3 \]

Where:
- \( V_0 \) : defined as the base speed of the wind [m/s], equal to 37 m/s according to picture 4.3.4
- \( S_1 \) : coefficient that depends on topography \( Z \) is the average height of the building \( ( Z_2 = 6, Z_3 = 9 \text{ m}) \) and \( d \) the difference between the base and the summit of the hills \( d = 100 \text{ m} \). Assuming \( \theta > 45° \), with \( \theta > 45° \) topography slope angle, The value \( S_1 \) is defined as:
  \[ S_1 = 1 + (2.5 - z/d) \times 0.31 \geq 1 \]
- \( S_2 \): coefficient defined by roughness of the ground and dimensions of the building. According to the Brazilian law, the roughness of the ground is in the IV Category (that includes high densified urban areas) and the building is class A (All buildings with less than 20 meters of vertical and horizontal span). Once those value had been set it is possible to define the value of \( S_2 \) through the table 2 of ABNT NBR 6123, reported on picture 4.3.5: \( S_2 = 0.86 \);
- S3: Safe coefficient that include the possibility of increasing of wind speed during the building life-cycle. This value is defined in table 3 of ABNT NBR 6123: S3 = 1.0.

Pic. 4.3.4: base speed of the wind (-from: ABNT NBR 6123: Figura 1- isopletas da velocidade básica V₀(m/s));

Pic. 4.3.5: topography coefficient (from ABNT NBR 6123: Figura 2 - Factor topográfico S₁(z));

Pic. 4.3.6: S₂ factor depending on roughness of the ground and building class (from ABNT NBR 6123: Tabela 2- Factor S₂);

Pic. 4.3.7: S₃ factor inimum value (from ABNT NBR 6123: Tabela 3- valores mínimos do factor estatístico S₃);
Once the wind speed has been defined it is possible to evaluate the action of the wind on the building (ABNT NBR 6123, 4.2 Determinação das forças estáticas devidas ao vento):

The dynamic pressure is defined as:

\[ q = 0.613 V_k \]

- The wind pressure is defined by the Brazilian norm as:

\[ \Delta p = (C_{pe} - C_{pi}) q \]

- The force acting on the façade of a planar building is defined as:

\[ F = (C_{pe} - C_{pi}) A q \]

Where:

- \( C_{pi} \): Internal pressure coefficient, \( C_{pi} = 0.2 \) (ABNT NBR 6123, 6.2.5 Coeficientes de pressão interna)
- \( C_{pe} \): External pressure coefficient is defined by height of the building and wind direction on table 4 in pic. 4.3.8.

<table>
<thead>
<tr>
<th>Floor</th>
<th>( h ) [m]</th>
<th>( V_0 ) [m/s]</th>
<th>( S_1 )</th>
<th>( S_2 )</th>
<th>( S_3 )</th>
<th>( V_k ) [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>37</td>
<td>1.76</td>
<td>0.86</td>
<td>1</td>
<td>55.89</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>37</td>
<td>1.75</td>
<td>0.86</td>
<td>1</td>
<td>55.59</td>
</tr>
</tbody>
</table>

Tab. 4.3.5: Values of \( S_1, S_2, S_3 \) factor for first and second floor and value of wind velocity \( V_k \). In detail the wind action were not evaluated for the ground floor since it is open and there is no pressure difference between interior and exterior.

Once the wind speed has been defined it is possible to evaluate the action of the wind on the building (ABNT NBR 6123, 4.2 Determinação das forças estáticas devidas ao vento):

The dynamic pressure is defined as:

\[ q = 0.613 V_k \]

- The wind pressure is defined by the Brazilian norm as:

\[ \Delta p = (C_{pe} - C_{pi}) q \]

- The force acting on the façade of a planar building is defined as:

\[ F = (C_{pe} - C_{pi}) A q \]

Where:

- \( C_{pi} \): Internal pressure coefficient, \( C_{pi} = 0.2 \) (ABNT NBR 6123, 6.2.5 Coeficientes de pressão interna)
- \( C_{pe} \): External pressure coefficient is defined by height of the building and wind direction on table 4 in pic. 4.3.8.

![Diagram](image)

Pic. 4.3.8: Value of \( C_{pe} \) (from: ABNT NBR 6123 Tabela 4 - Coeficientes de pressão e de forma, externos, para paredes de edificações de planta retangular);
4.3.3.5 Seismic Loads

To verify the building structure under seismic action the reference is the ABNT NBR 15421 norm, that establishes the criteria for quantifying the earthquake actions and building structure resistance. According to the ABNT NBR 15421 the area of Rio de Janeiro is located in the seismic zone 0, as the majority of the country, picture 4.3.9, at which corresponds value of acceleration $a_g = 0.025$ g. The ABNT NBR 15421 defines that for buildings in seismic zone 0 it is not necessary to consider the seismic actions during structure verification. In consequence the seismic resistance of the building wasn’t analyzed.

4.3.3.6 Load combinations factors:

To verify the limit states, the following combinations of actions are defined:

- **Fundamental combination**, generally used for the ultimate limit states (ULS):
  \[
  \gamma_{G1}G_1 + \gamma_{G2}G_2 + \gamma_P + \gamma_{Q1}Q_{k1} + \gamma_{Q2}Q_{k2} + \gamma_{Q3}Q_{k3} + \ldots
  \]

- **Characteristic combination**, generally used for the irreversible serviceability limit state (SLS):
  \[
  G_1 + G_2 + P + Q_{k1} + \psi_{Q1}Q_{k2} + \psi_{Q3}Q_{k3} + \ldots
  \]

Tab. 4.3.6: Values of pressure and wind actions on the building.

Pic. 4.3.9: Seismic zone in Brazil (from: ABNT NBR 15421 Figura 1);
• Frequent load combination, generally used for reversible serviceability limit state (SLS):
  \[ G_1 + G_2 + P + \psi_{11} Q_{k1} + \psi_{22} Q_{k2} + \psi_{23} Q_{k3} + \ldots \]

• Quasi permanent load combination, generally used for reversible serviceability limit state (SLS):
  \[ G_1 + G_2 + P + \psi_{21} Q_{k1} + \psi_{22} Q_{k2} + \psi_{23} Q_{k3} + \ldots \]

Those combinations are multiplied by the coefficients of combination \( \gamma_{0i}, \psi_{i1}, \psi_{2i} \) and \( \gamma_{G1}, \gamma_{G2} \)

<table>
<thead>
<tr>
<th>Combinações de ações</th>
<th>Permanentes (g)</th>
<th>Variáveis (q)</th>
<th>Protensão (p)</th>
<th>Recalques de apoio e retração</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>F</td>
<td>G</td>
<td>T</td>
</tr>
<tr>
<td>Normais</td>
<td>1,4(^{1)}</td>
<td>1,0</td>
<td>1,4</td>
<td>1,2</td>
</tr>
<tr>
<td>Especiais ou de construção</td>
<td>1,3</td>
<td>1,0</td>
<td>1,2</td>
<td>1,0</td>
</tr>
<tr>
<td>Excepcionais</td>
<td>1,2</td>
<td>1,0</td>
<td>1,0</td>
<td>0</td>
</tr>
</tbody>
</table>

Pic 4.3.10: Combination factors \( \psi_{ij} \) (from: ABNT NBR 6120 tabela 2);

<table>
<thead>
<tr>
<th>Ações</th>
<th>( \gamma_{0} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \psi_{x} )</td>
<td>( \psi_{11} )</td>
</tr>
<tr>
<td>Cargas acidentais de edifícios</td>
<td>( \gamma_{0x} )</td>
</tr>
<tr>
<td>Locais em que não há predominância de pesos de equipamentos que permanecem fixos por longos períodos de tempo, nem de elevadas concentrações de pessoas (^2))</td>
<td>0,5</td>
</tr>
<tr>
<td>Locais em que há predominância de pesos de equipamentos que permanecem fixos por longos períodos de tempo, ou de elevada concentração de pessoas (^3))</td>
<td>0,7</td>
</tr>
<tr>
<td>Biblioteca, arquivos, oficinas e garagens</td>
<td>0,8</td>
</tr>
<tr>
<td>Vento</td>
<td>( \gamma_{0v} )</td>
</tr>
<tr>
<td>Pressão dinâmica do vento nas estruturas em geral</td>
<td>0,6</td>
</tr>
<tr>
<td>Temperatura</td>
<td>( \gamma_{0t} )</td>
</tr>
<tr>
<td>Variações uniformes de temperatura em relação à média anual local</td>
<td>0,6</td>
</tr>
</tbody>
</table>

Pic 4.3.11: Combination factors \( \gamma_{0} \) (from: ABNT NBR 6120 tabela 11.2);
4.3.4 Slab verification

According to the chapter 4, part 1 a preliminary design of slab reinforcement had been carried out on generic load cases analyzing a generic isolated “single spam”. In detail, the preliminary shape had been kept and the reinforcement as well as the concrete matrix had been properly chosen depending on the more relevant efforts guaranteeing that the failure is carried out on the tensile reinforcement rather than concrete bittering. The main difference between the generic case analyzed in chapter 4 part 1:

- Non structural loads ($g_2$):
  The structural loads depends on the technical solution employed on the slab. In this specific case the main difference between generic solutions employed at chapter 4 part 1 and the ones employed in the building is the Green roof, which has a relevant non structural weight.

ULS Fundamental loads combinations:

**Variable loads:**

<table>
<thead>
<tr>
<th>Action</th>
<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_g1$</td>
<td>0.56</td>
<td>-</td>
<td>1.4</td>
<td>-</td>
<td>0.78</td>
</tr>
<tr>
<td>$f_g2$</td>
<td>2.92</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>4.08</td>
</tr>
<tr>
<td>$f_q1$</td>
<td>3.00</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>4.20</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>9.07</strong></td>
</tr>
</tbody>
</table>

**H.C.04 Intensive green roof**

**H.C.03 Flat roof**

<table>
<thead>
<tr>
<th>Action</th>
<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_g1$</td>
<td>0.56</td>
<td>-</td>
<td>1.4</td>
<td>-</td>
<td>0.78</td>
</tr>
<tr>
<td>$f_g2$</td>
<td>2.25</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>3.15</td>
</tr>
<tr>
<td>$f_q1$</td>
<td>3.00</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>4.20</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>8.13</strong></td>
</tr>
</tbody>
</table>

**H.C.02 Slab on cold spaces**

<table>
<thead>
<tr>
<th>Action</th>
<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_g1$</td>
<td>0.56</td>
<td>-</td>
<td>1.4</td>
<td>-</td>
<td>0.78</td>
</tr>
<tr>
<td>$f_g2$</td>
<td>1.53</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>2.15</td>
</tr>
<tr>
<td>$f_q1$</td>
<td>3.00</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>4.20</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>7.13</strong></td>
</tr>
</tbody>
</table>

**Absence of variable loads:**

**H.C.04 Intensive green roof**

<table>
<thead>
<tr>
<th>Action</th>
<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_g1$</td>
<td>0.56</td>
<td>-</td>
<td>1.4</td>
<td>-</td>
<td>0.78</td>
</tr>
<tr>
<td>$f_g2$</td>
<td>2.92</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>4.08</td>
</tr>
<tr>
<td>$f_q1$</td>
<td>0.00</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>4.87</strong></td>
</tr>
</tbody>
</table>

**H.C.03 Flat roof**

<table>
<thead>
<tr>
<th>Action</th>
<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_g1$</td>
<td>0.56</td>
<td>-</td>
<td>1.4</td>
<td>-</td>
<td>0.78</td>
</tr>
<tr>
<td>$f_g2$</td>
<td>2.25</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>3.15</td>
</tr>
<tr>
<td>$f_q1$</td>
<td>0.00</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>3.93</strong></td>
</tr>
</tbody>
</table>

**H.C.02 Slab on cold spaces**

<table>
<thead>
<tr>
<th>Action</th>
<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_g1$</td>
<td>0.56</td>
<td>-</td>
<td>1.4</td>
<td>-</td>
<td>0.78</td>
</tr>
<tr>
<td>$f_g2$</td>
<td>1.53</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>2.15</td>
</tr>
<tr>
<td>$f_q1$</td>
<td>0.00</td>
<td>1</td>
<td>1.4</td>
<td>-</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>2.93</strong></td>
</tr>
</tbody>
</table>

Tab. 4.3.7 ULS Fundamental loads combinations;
### ELS Characteristic loads combinations:

#### Variable loads:

<table>
<thead>
<tr>
<th>Action</th>
<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.C.04 Slab on cold spaces</td>
<td>fg1</td>
<td>0.56</td>
<td>-</td>
<td>1</td>
<td>0.56</td>
</tr>
<tr>
<td>H.C.03 Flat roof</td>
<td>fg2</td>
<td>2.92</td>
<td>1</td>
<td>1</td>
<td>2.92</td>
</tr>
<tr>
<td>H.C.02 Slab on cold spaces</td>
<td>fg1</td>
<td>3.00</td>
<td>1</td>
<td>1</td>
<td>3.00</td>
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<tr>
<td>TOTAL</td>
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<td></td>
<td></td>
<td>6.48</td>
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</tbody>
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<table>
<thead>
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<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.C.04 Intensive green roof</td>
<td>fg1</td>
<td>0.56</td>
<td>-</td>
<td>1</td>
<td>0.56</td>
</tr>
<tr>
<td>H.C.03 Flat roof</td>
<td>fg2</td>
<td>2.25</td>
<td>1</td>
<td>1</td>
<td>2.25</td>
</tr>
<tr>
<td>H.C.02 Slab on cold spaces</td>
<td>fg1</td>
<td>3.00</td>
<td>1</td>
<td>1</td>
<td>3.00</td>
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<tr>
<td>TOTAL</td>
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<td></td>
<td></td>
<td>5.81</td>
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<table>
<thead>
<tr>
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<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.C.04 Intensive green roof</td>
<td>fg1</td>
<td>0.56</td>
<td>-</td>
<td>1</td>
<td>0.56</td>
</tr>
<tr>
<td>H.C.03 Flat roof</td>
<td>fg2</td>
<td>2.25</td>
<td>1</td>
<td>1</td>
<td>2.25</td>
</tr>
<tr>
<td>H.C.02 Slab on cold spaces</td>
<td>fg1</td>
<td>3.00</td>
<td>1</td>
<td>1</td>
<td>3.00</td>
</tr>
<tr>
<td>TOTAL</td>
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Tab. 4.3.8 ELS Characteristic loads combinations;

#### Absence of variable loads:

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<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
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</thead>
<tbody>
<tr>
<td>H.C.04 Intensive green roof</td>
<td>fg1</td>
<td>0.56</td>
<td>-</td>
<td>1</td>
<td>0.56</td>
</tr>
<tr>
<td>H.C.03 Flat roof</td>
<td>fg2</td>
<td>2.25</td>
<td>1</td>
<td>1</td>
<td>2.25</td>
</tr>
<tr>
<td>H.C.02 Slab on cold spaces</td>
<td>fg1</td>
<td>0.00</td>
<td>1</td>
<td>1</td>
<td>0.00</td>
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<tr>
<td>TOTAL</td>
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<table>
<thead>
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<th>Action</th>
<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.C.04 Intensive green roof</td>
<td>fg1</td>
<td>0.56</td>
<td>-</td>
<td>1</td>
<td>0.56</td>
</tr>
<tr>
<td>H.C.03 Flat roof</td>
<td>fg2</td>
<td>2.25</td>
<td>1</td>
<td>1</td>
<td>2.25</td>
</tr>
<tr>
<td>H.C.02 Slab on cold spaces</td>
<td>fg1</td>
<td>0.00</td>
<td>1</td>
<td>1</td>
<td>0.00</td>
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<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.81</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Action</th>
<th>Load</th>
<th>Section [m]</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.C.04 Intensive green roof</td>
<td>fg1</td>
<td>0.56</td>
<td>-</td>
<td>1</td>
<td>0.56</td>
</tr>
<tr>
<td>H.C.03 Flat roof</td>
<td>fg2</td>
<td>2.25</td>
<td>1</td>
<td>1</td>
<td>2.25</td>
</tr>
<tr>
<td>H.C.02 Slab on cold spaces</td>
<td>fg1</td>
<td>0.00</td>
<td>1</td>
<td>1</td>
<td>0.00</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.09</td>
</tr>
</tbody>
</table>
The transversal behavior of the slab changes since each span is connected one to the other to guarantee uniform displacement under horizontal loads. In detail, the slabs are connected by a tie, made possible by a simple cast on site joint. As consequence, the moment on the joint is equal to 0. The transversal section had been verified both on the terrace case, both for the intermediate slab case. In fact, not only no structural loads change between floor but also, in the case of intermediate slab, the effect of exterior walls have to be considered.

<table>
<thead>
<tr>
<th>Action</th>
<th>Load [m]</th>
<th>Section</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{g1}$</td>
<td>0.56</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>0.56</td>
</tr>
<tr>
<td>$f_{g2}$</td>
<td>2.25</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>2.25</td>
</tr>
<tr>
<td>$f_{q1}$</td>
<td>3.00</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>3.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>5.81</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Action</th>
<th>Load [m]</th>
<th>Section</th>
<th>$\gamma_f$</th>
<th>$\psi_f$</th>
<th>Lin. Load [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{g1}$</td>
<td>0.56</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>0.56</td>
</tr>
<tr>
<td>$f_{g2}$</td>
<td>2.25</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>2.25</td>
</tr>
<tr>
<td>$f_{q1}$</td>
<td>0.00</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>2.81</strong></td>
</tr>
</tbody>
</table>

**Tab. 4.3.9 SLS Quasi permanent loads combination;**

- The static scheme:
  The transversal behavior of the slab changes since each span is connected one to the other to guarantee uniform displacement under horizontal loads. In detail, the slabs are connected by a tie, made possible by a simple cast on site joint. As consequence, the moment on the joint is equal to 0. The transversal section had been verified both on the terrace case, both for the intermediate slab case. In fact, not only no structural loads change between floor but also, in the case of intermediate slab, the effect of exterior walls have to be considered.

**Pic 4.3.12: Static scheme of generic slab elements;**
Combination of loads cases:

Case 1

Case 2

Case 3

Case 4

Case 5

Case 6

For the genetic case of the intermediate slab the non structural loads due to vertical elements has to be considered \((q_{2,v} = 5.5 \text{ kN})\)

Resulting diagrams for bending moment and shear force, Third floor slab:

ULS: bending moment diagrams;

ELS: bending moment diagrams;

ULS: Shear force diagrams;

ELS: Shear force diagrams;
According with chapter 4, part 1 the designed slab is verified under the building loads conditions:

- ULS Foundamental combination:

<table>
<thead>
<tr>
<th>Bending moment</th>
<th>Shear force</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEd [kNm]</td>
<td>MRd [kNm]</td>
</tr>
<tr>
<td>Third floor, terrace</td>
<td>12.11</td>
</tr>
<tr>
<td>First and second floor, intermediate slab</td>
<td>10.39</td>
</tr>
</tbody>
</table>

Tab. 4.3.10 Maximum value of bending moment and shear-force at ULS Fundamental loads combinations and verification in reference with results obtained in chapter 4 part 1;
• ELS Characteristic and Quasi permanent loads combination, Stress limitation:
The verification of the stress limitation is carried out following the Ec2 § 7.2 Stress limitation. The maximum tension had to be verified with:
• $\sigma_c = 0.6 f_{ck}$ (characteristic combination)
• $\sigma_{tx} = 0.8 f_{tx}$ (characteristic combination)
• $\sigma_c = 0.45 f_{ck}$ (quasi-permanent loads combination)

<table>
<thead>
<tr>
<th></th>
<th>m</th>
<th>bw [mm]</th>
<th>d [mm]</th>
<th>x [mm]</th>
<th>Med [kNm] (Ch.)</th>
<th>Med [kNm] (Qu. P.)</th>
<th>$\sigma_c, Ch$ [Mpa]</th>
<th>$\sigma_c, Qu.$ [Mpa]</th>
<th>$\sigma_c, max, Qu.$ [Mpa]</th>
<th>$\sigma_{tx}$, Ch [Mpa]</th>
<th>$\sigma_{tx}$, max, Ch [Mpa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third floor</td>
<td>15</td>
<td>30</td>
<td>230</td>
<td>83.1</td>
<td>6.5363</td>
<td>4.5</td>
<td>25.9</td>
<td>27.0</td>
<td>17.9</td>
<td>20.3</td>
<td>687.4</td>
</tr>
<tr>
<td>First and second floor</td>
<td>15</td>
<td>30</td>
<td>230</td>
<td>83.1</td>
<td>6.4</td>
<td>5.5</td>
<td>25.6</td>
<td>27.0</td>
<td>18.8</td>
<td>20.3</td>
<td>677.8</td>
</tr>
</tbody>
</table>

Tab. 4.3.11 Maximum value of bending moment at ELS Characteristic and Quasi permanent loads combinations, stress limitation verification;
4.3.5 Beam verification and reinforcement design

According to the system design defined in the first part, chapter 3 part 1, the beam element is made of two part:

- The precast part, reinforced with two layer of composite net;
- The cast on site part, to join the slab elements with the beam. Moreover, the beam was designed to locate both textile reinforcement, to cope with both shear and torsion actions and longitudinal steel bars reinforcement located guaranteeing minimum coverage limits defined by norms to address bending moments.

Bending, section behavior:

The reinforcement layout is made both of composite fabric in carbon-glass fibers and steel reinforcement bars. About the textile reinforcement the same assumptions made in chapter 4 part 1 remain relevant. Nevertheless, since the reinforcement layout is obtained combining both metallic and textile reinforcement, failure has to be calculated accounting for the contribution of each reinforcement. On the other hand, it shall be noted that the deformation capacity for high strength steel is higher than the carbon textile reinforcement one. Seen the purpose of adding ductile reinforcement thought the use of steel bars the ultimate limit state shall be attained by failure of the ductile reinforcement. Therefore, at failure, whether a sufficient metallic reinforcement is provided, fabric should have already attained their ultimate strain and the contribution of the longitudinal carbon strands may be neglected.
Therefore the main hypothesis about longitudinal reinforcement design to satisfy are the followings:

\[ M_{rd} > M_{cd} \]

And

\[ M_{rd} > M_{r} \] (reistant moment at first crack)

Where:
- \( M_{rd} = A_s f_y d_m \)
- \( x_{pl} = A_s f_y / f_{cd} 0.8 \)

For each beam analyzed significant section for positive or negative bending moment were outlined. For each case were calculated the minimum reinforcement area needed, neglecting the contribute of textile reinforcement:

\[ A_{s,min} = \frac{M_{Ed}}{f_{yd} z} \]

Where:
- \( z = 0.9 d \)
- \( f_{yd} = \) design resistance for steel bars reinforcement (B450C)

Once the minimum area of reinforcement was evaluated the number and diameter of steel bars were properly chosen addressing also to the hypothesis previously made. In detail, the contribution of textile reinforcement could be evaluated, under hypothesis that the section behave with a linear response:

\[ M_{rd, tex,u} = (\sigma_y A_y) z_y + (\sigma_t A_t) z_t \]

The moment is evaluated imposing the textile fabric \( \varepsilon_{tx} = 1\% \).
Shear force reinforcement design:
The shear reinforcement design had been carried out under the same hypothesis made in chapter 4 part 1. The shear reinforcement is provided by a textile fabric which means, for all the beam length, a constant spacing between strands of equal area and resistance. In consequence, the first design hypothesis was to add, once the joint is cast on site, a single layer of textile fabric, considering that extra double layer of textile reinforcement is located on the pre-casted beam part. Once the maximum values of shear-force were calculated the resistance of reinforcement and the one of compressive struts have been verified. The verification to the shear resistance was carried out following the Ec2 § 6.2.3 Members requiring design shear reinforcement. The angle of the compression struts had been considered $\theta = 45^\circ$; the shear resistance $V_{rd}$ is the smaller value of:

Shear reinforcement:

$$V_{rd,s} = (A_{sw}/s)*z*f_{tx,d} * \cot \theta$$

Where:
- $A_{sw}$: area of vertical shear reinforcement
- $z = d*0.9$

Compression struts:

$$V_{rd,max} = \alpha_{cw} * b * \nu_i * f_{cd} / (\cot \theta + \tan \theta)$$

Where:
- $\nu_i = 0.6$ for $f_{cd} \leq 60$ Mpa
- $\alpha_{cw}$:
  - $\alpha_{cw} = (1 + \sigma_{cp} / f_{cd})$ for $0 < \sigma_{cp} \leq 0.25 f_{cd}$
  - $\alpha_{cw} = 1.25$ for $0.25 f_{cd} < \sigma_{cp} \leq 0.5 f_{cd}$
  - $\alpha_{cw} = 2.5*(1 - \sigma_{cp} / f_{cd})$ for $0.5 f_{cd} < \sigma_{cp} \leq f_{cd}$

Beams reinforcement design and verification:
The beams at each floor on axes 3 have been analyzed and the reinforcement designed:

Combination of loads, B3, third floor:

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q_1$</td>
<td>$q_1$</td>
</tr>
<tr>
<td>$g_2$</td>
<td>$g_2$</td>
</tr>
<tr>
<td>$g_1$</td>
<td>$g_1$</td>
</tr>
</tbody>
</table>
Diagrams for bending moment and shear force, B3, Third floor:

- **ULS:** Bending moment diagrams;
- **ULS:** Shear force diagrams;
- **ELS:** Bending moment diagrams;
- **ELS:** Shear force diagrams;

<table>
<thead>
<tr>
<th>Section</th>
<th>distance [mm]</th>
<th>As,min [mm²]</th>
<th>∅</th>
<th>As [mm²]</th>
<th>Mrd [kNm]</th>
<th>Med [kNm]</th>
<th>MRd [kNm]</th>
<th>MRd,tx,u [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-</td>
<td>-0.79;0.5</td>
<td>224.6</td>
<td>2X12</td>
<td>226</td>
<td>4.4</td>
<td>18.10</td>
<td>26.4</td>
<td>26.4</td>
</tr>
<tr>
<td>B-</td>
<td>2.5;3.5</td>
<td>281.3</td>
<td>2X14</td>
<td>308</td>
<td>4.4</td>
<td>23.99</td>
<td>33.4</td>
<td>33.4</td>
</tr>
<tr>
<td>C-</td>
<td>3.5;5.5</td>
<td>101.7</td>
<td>2x10</td>
<td>157</td>
<td>4.4</td>
<td>12.86</td>
<td>18.9</td>
<td>18.9</td>
</tr>
<tr>
<td>D-</td>
<td>5.5;6.5</td>
<td>302.4</td>
<td>2X16</td>
<td>402</td>
<td>4.4</td>
<td>30.31</td>
<td>41.1</td>
<td>41.1</td>
</tr>
<tr>
<td>E-</td>
<td>7.5;9</td>
<td>247.5</td>
<td>2X14</td>
<td>308</td>
<td>4.4</td>
<td>23.99</td>
<td>33.4</td>
<td>19.2</td>
</tr>
<tr>
<td>---</td>
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<tr>
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<td>As,min [mm²]</td>
<td>ϕ</td>
<td>As [mm²]</td>
<td>Mrd [kNm]</td>
<td>MRd [kNm]</td>
<td>MRd,tX,u [kNm]</td>
<td>Med [kNm]</td>
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<tr>
<td>A-+</td>
<td>0;2.5</td>
<td>247.5</td>
<td>2X14</td>
<td>308</td>
<td>2.8</td>
<td>25.43</td>
<td>27.3</td>
<td>19.2</td>
</tr>
<tr>
<td>B+-</td>
<td>3.5; 5.5</td>
<td>127.9</td>
<td>2X10</td>
<td>157</td>
<td>2.8</td>
<td>13.23</td>
<td>14.5</td>
<td>9.9</td>
</tr>
<tr>
<td>C+-</td>
<td>6.5;9</td>
<td>273.5</td>
<td>2x14</td>
<td>308</td>
<td>2.8</td>
<td>25.43</td>
<td>27.3</td>
<td>21.2</td>
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</table>

Tab. 4.3.12 Longitudinal reinforcement design for bending moment on B3, third floor;

<table>
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<th></th>
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<tbody>
<tr>
<td>39.97</td>
<td>77.41</td>
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<td>77.41</td>
<td>80.00</td>
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<td>206.65</td>
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</tr>
</tbody>
</table>

Tab. 4.3.13 Shear force verification, B3, third floor;

Combination of loads, B3, second floor:

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2/case 4 (symmetric distribution)</th>
</tr>
</thead>
</table>

Case 3

Case 5

Diagrams for bending moment and shear force, B3, third floor:

ULS: bending moment diagrams;

ULS: Shear force diagrams;
ELS: bending moment diagrams;  
ELS: Shear force diagrams;

<table>
<thead>
<tr>
<th>Section</th>
<th>distance [mm]</th>
<th>As,min [mm²]</th>
<th>Ø</th>
<th>As [mm²]</th>
<th>Mrd [kNm]</th>
<th>MRd [kNm]</th>
<th>MRd,tx,u [kNm]</th>
<th>Med [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-</td>
<td>0,5</td>
<td>302.8</td>
<td>2X14</td>
<td>308</td>
<td>4.4</td>
<td>23.99</td>
<td>33.4</td>
<td>23.5</td>
</tr>
<tr>
<td>B-</td>
<td>2.5,4</td>
<td>351.6</td>
<td>2X16</td>
<td>402</td>
<td>4.4</td>
<td>30.31</td>
<td>41.1</td>
<td>27.2</td>
</tr>
<tr>
<td>C-</td>
<td>4,5,5</td>
<td>98.3</td>
<td>2X10</td>
<td>157</td>
<td>4.4</td>
<td>12.86</td>
<td>18.9</td>
<td>7.6</td>
</tr>
<tr>
<td>D-</td>
<td>5.5,6.75</td>
<td>315.9</td>
<td>2X16</td>
<td>402</td>
<td>4.4</td>
<td>30.31</td>
<td>41.1</td>
<td>24.5</td>
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<tr>
<td>E-</td>
<td>6.75,9</td>
<td>258.0</td>
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<td>308</td>
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<td>23.99</td>
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Negative moments

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<th>Ø</th>
<th>As [mm²]</th>
<th>Mrd [kNm]</th>
<th>MRd [kNm]</th>
<th>MRd,tx,u [kNm]</th>
<th>Med [kNm]</th>
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<td>C+</td>
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Positive moments

Tab. 4.3.14 Longitudinal reinforcement design for bending moment on B3, second floor;

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Tab. 4.3.15 Shear force verification, B3, first floor;

Combination of loads, B3, first floor:

Case 1  
Case 2
Diagrams for bending moment and shear force, B3, Third floor:

ULS: bending moment diagrams;

ULS: Shear force diagrams;

ELS: bending moment diagrams;

ELS: Shear force diagrams;

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<thead>
<tr>
<th>Negative moments</th>
<th>Section</th>
<th>distance [mm]</th>
<th>As,min [mm²]</th>
<th>Ø</th>
<th>As [mm²]</th>
<th>Mrd [kNm]</th>
<th>MRd [kNm]</th>
<th>MRd,tx,u [kNm]</th>
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<td>41.1</td>
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<td>325.6</td>
<td>2X16</td>
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<th>As,min [mm²]</th>
<th>Ø</th>
<th>As [mm²]</th>
<th>Mrd [kNm]</th>
<th>MRd [kNm]</th>
<th>MRd,tx,u [kNm]</th>
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Tab. 4.3.16 Longitudinal reinforcement design for bending moment on B3, first floor;

Tab. 4.3.17 Shear force verification, B3, first floor;
Torsion:

Due to variable loads the beams could be subjected to torsional moments. The analysis of the torsional resistance has been carried out through the simplification of the beam in tubular reticular isostatic system (Traliccio di Raush) where the compression struts are inclined of 45°-degree. The torsion resistance had been calculated following the Ec2 § 6.3.2 (torsion, design procedure). The torsional resistance of the section had been calculated as the torsional resistance of a thin-walled closed sections, in which equilibrium is satisfied by a closed shear flow.

The shear stress of a section subject to a pure torsional moment may be calculated from:

\[ \tau_{t,i} \cdot t_{ef,i} = \frac{T_{Ed}}{2A_k} \]

and the shear force \( V_{Ed,i} \) due to torsion is given by:

\[ V_{Ed,i} = \tau_{t,i} \cdot t_{ef,i} \cdot z_i \]

Where:

- \( A_k \): the area enclosed by the centre-lines of the connecting walls, including inner hollow areas;
- \( \tau_{t,i} \): the torsional shear stress;
- \( t_{ef,i} \): is the effective wall thickness;
- \( z_i \): is the side length of wall \( i \) defined by the distance between the intersection points with the adjacent rectangular sections.

Minimum reinforcement:

The required cross-sectional area of the longitudinal reinforcement for torsion \( \Sigma A_{sl} \) may be calculated from expression:

\[ \Sigma A_{sl} = \frac{T_{Ed} \cdot \cot \theta \cdot U_k}{2 \cdot (A_k \cdot f_{y,d} + A_s \cdot f_{y,d})} \]

Where:

- \( U_k \): is the perimeter of the area \( A_k \).
The maximum resistance of a member subjected to torsion and shear is limited by the capacity of the concrete struts. In order not to exceed this resistance the following condition should be satisfied:

\[ \frac{T_{Ed}}{T_{Rd,\text{max}}} + \frac{V_{Ed}}{V_{Rd,\text{max}}} \leq 1 \]

\[ T_{Rd,\text{max}} = 2 \cdot \nu^* \cdot \alpha_{cw} \cdot A_k^* \cdot t_{ef,i} \cdot \sin \theta \cdot \cos \theta \]

Where:

- \( \nu = 0.6 \cdot (1 - f_{ck}/250) \)

\[ V_{sl,\text{max}} = \theta \cdot \nu^* \cdot b_w^* \cdot f_{cd}/(\cot \theta + \tan \theta) \]

Where:

- \( \nu = 0.6 \) for \( f_{ck} \leq 60 \text{ Mpa} \)
- \( \alpha_{cw} \):
  - \( \alpha_{cw} = (1 + \sigma_{cp}/f_{cd}) \) for \( 0 < \sigma_{cp} \leq 0.25 f_{cd} \)
  - \( \alpha_{cw} = 1.25 \) for \( 0.25 f_{cd} < \sigma_{cp} \leq 0.5 f_{cd} \)
  - \( \alpha_{cw} = 2.5 \cdot (1 - \sigma_{cp}/f_{cd}) \) for \( 0.5 f_{cd} < \sigma_{cp} \leq f_{cd} \)

The section had been verified on the most critical case obtained by obtained by ULS combination on the slabs. The section verified, for each beam at each floor was the one with the lowest ratio of reinforcement.

<table>
<thead>
<tr>
<th>B3, third floor section A-</th>
<th>TEd [kNm]</th>
<th>uk [mm]</th>
<th>Ak [mm²]</th>
<th>tef,x [mm]</th>
<th>t(\tau),x [Mpa]</th>
<th>zx [mm]</th>
<th>Ved x [kN]</th>
<th>tef,y [mm]</th>
<th>t(\tau),y [Mpa]</th>
<th>zy [mm]</th>
<th>Ved y [kN]</th>
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<td>574.0</td>
<td>16560</td>
<td>40</td>
<td>5.13</td>
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<td>3.54</td>
<td>80.00</td>
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<table>
<thead>
<tr>
<th>B3, second floor section A+</th>
<th>TEd [kNm]</th>
<th>uk [mm]</th>
<th>Ak [mm²]</th>
<th>tef,x [mm]</th>
<th>t(\tau),x [Mpa]</th>
<th>zx [mm]</th>
<th>Ved x [kN]</th>
<th>tef,y [mm]</th>
<th>t(\tau),y [Mpa]</th>
<th>zy [mm]</th>
<th>Ved y [kN]</th>
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<tr>
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<td>16560</td>
<td>40</td>
<td>4.01</td>
<td>206</td>
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<table>
<thead>
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<th>TEd [kNm]</th>
<th>uk [mm]</th>
<th>Ak [mm²]</th>
<th>tef,x [mm]</th>
<th>t(\tau),x [Mpa]</th>
<th>zx [mm]</th>
<th>Ved x [kN]</th>
<th>tef,y [mm]</th>
<th>t(\tau),y [Mpa]</th>
<th>zy [mm]</th>
<th>Ved y [kN]</th>
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Tab. 4.3.21: verification of the torsional resistance of the beam at the lowest reinforcement ratio section;

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<th>Asl,tx</th>
<th>fxd [Mpa]</th>
<th>Asl,s</th>
<th>fy,d [Mpa]</th>
<th>Trd,r [kNm]</th>
<th>TEd [kNm]</th>
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<td>6.80</td>
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<tr>
<td>B3, second floor</td>
<td>47.09</td>
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<td>402</td>
<td>391.3</td>
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Tab. 4.3.22: Verification of the reinforcement;
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<th>v</th>
<th>acw</th>
<th>fcd [Mpa]</th>
<th>Ak [mm²]</th>
<th>tef [mm]</th>
<th>Trd,x,y, max [kNm]</th>
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<td>0.6</td>
<td>1.25</td>
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<td>40</td>
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<th>z[mm]</th>
<th>v</th>
<th>fcd [Mpa]</th>
<th>Vrd,max [kN]</th>
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<td>80</td>
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Tab. 4.3.23: Compression strut verification on the beams, third floor;

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<th>acw</th>
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<th>Ak [mm²]</th>
<th>tef, x [mm]</th>
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<td>1.25</td>
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<td>16560</td>
<td>40</td>
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<tr>
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<td>0.6</td>
<td>1.25</td>
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<th>fcd [Mpa]</th>
<th>Vrd,max [kN]</th>
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Tab. 4.3.24: Compression strut verification on the beams, first and second floor;
SLS, Stress limitation:

The verification of the stress limitation is carried out following the Ec2 § 7.2 Stress limitation. The maximum tension had to be verified with:
- \( \sigma_c = 0.6 \ f_{ck} \) (characteristic combination)
- \( \sigma_y = 0.8 \ f_y \) (characteristic combination)
- \( \sigma_c = 0.45 \ f_{ck} \) (quasi-permanent loads combination)

To guarantee the equilibrium (with \( x \): neutral axis right after the first cracking):

\[
C-Z = 0
\]

Where

In this case the textile reinforcement has been neglected:
- \( C = 0.5 \* \sigma_c \* b \* x + \sigma_s' \* A_s' \)
- \( Z = \sigma_y \* A_s \)

\[
0.5 \* \sigma_c \* b \* x + \sigma_s' \* A_s' - \sigma_s \* A_s = 0
\]

The relationship between \( \sigma_c \) and \( \sigma_y \) can be written as:

\[
\frac{(\sigma_s / m) / (d-x)}{(d-x)/x} = \frac{\sigma_c}{x} \quad \text{and} \quad \frac{(\sigma_s' / m) / (d'-x)}{(d'-x)/x} = \frac{\sigma'_s}{x}
\]

Where:
- \( m = 15 \) represents the homogenization coefficient which takes into account the viscous effects produced by the permanent fraction of loads;
- \( A_s \): Steel bar area depending on the section analyzed in the tensile zone
- \( A_s' \): Steel bar area depending on the section analyzed in the compressive zone

In consequence:

\[
0.5 \* \sigma_c \* b \* x - (m \* \sigma_c \* (d-x)/x) \* A_s + m \* \sigma_c \* (d'-x)/x \* A'_s = 0
\]

Once solved the second degree expression and excluded the non-admissible solution the equilibrium:

\[
0.5 \* \sigma_c \* b \* x + \sigma_s' \* A_s' (d-d') = M_{Ed}
\]

\( \sigma_c \) is obtained both for Characteristic combination and quasi-permanent combination
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Tab. 4.3.25: SLS stress limit verification for Beam B3, Third floor

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<td>229</td>
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<tr>
<td>Section</td>
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<td>308</td>
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<td>220</td>
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Tab. 4.3.26: SLS stress limit verification for Beam B3, Second floor
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<th>A's [mm²]</th>
<th>bw [mm]</th>
<th>d [mm]</th>
<th>x [mm]</th>
<th>Med [kNm] (Ch.)</th>
<th>Med [kNm] (Qu. P.)</th>
<th>(\sigma_{c,Ch})</th>
<th>(\sigma_{c,Qu.P})</th>
<th>(\sigma_{c,max,Ch})</th>
<th>(\sigma_{c,max,Qu.P})</th>
<th>(\sigma_s, C.H.)</th>
<th>(\sigma_s, C.H.)</th>
<th>(\sigma_{s,max,Ch})</th>
<th>(\sigma_{s,max,Qu.P})</th>
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<td>603</td>
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<td>16.0</td>
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<td>27.0</td>
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<td>200.2</td>
<td>200</td>
<td>360</td>
<td></td>
</tr>
<tr>
<td>Section</td>
<td>m</td>
<td>As [mm²]</td>
<td>A's [mm²]</td>
<td>bw [mm]</td>
<td>d [mm]</td>
<td>x [mm]</td>
<td>Med [kNm] (Ch.)</td>
<td>Med [kNm] (Qu. P.)</td>
<td>(\sigma_{c,Ch})</td>
<td>(\sigma_{c,Qu.P})</td>
<td>(\sigma_{c,max,Ch})</td>
<td>(\sigma_{c,max,Qu.P})</td>
<td>(\sigma_s, C.H.)</td>
<td>(\sigma_s, C.H.)</td>
<td>(\sigma_{s,max,Ch})</td>
<td>(\sigma_{s,max,Qu.P})</td>
</tr>
<tr>
<td>Section</td>
<td>15</td>
<td>603</td>
<td>402</td>
<td>120</td>
<td>220</td>
<td>69.7</td>
<td>24.8</td>
<td>19.2</td>
<td>30.1</td>
<td>27.0</td>
<td>23.3</td>
<td>20.3</td>
<td>778.2</td>
<td>778</td>
<td>360</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 4.3.27: SLS stress limit verification for Beam B3, First floor;
4.3.6 Columns verification and reinforcement design:

As seen in chapter 3 part 1 the columns layout had been designed to weigh less than 100 kg, to be easily transported with lightweight and manual tools. Moreover, the pillar has a compressive strength equal to an area-equivalent pillar of few more than 10 cm side. On the other hand, it has an inertia on the most stressed side of 3.4 time bigger.

<table>
<thead>
<tr>
<th>Pillar C3, B3 preliminary design</th>
<th>value</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>28.00</td>
<td>m</td>
</tr>
<tr>
<td>depth</td>
<td>18.00</td>
<td>m</td>
</tr>
<tr>
<td>Atot</td>
<td>11377.60</td>
<td>mm²</td>
</tr>
<tr>
<td>xcg</td>
<td>90.00</td>
<td>mm</td>
</tr>
<tr>
<td>ycg</td>
<td>140.00</td>
<td>mm</td>
</tr>
<tr>
<td>I</td>
<td>38122496</td>
<td>mm⁴</td>
</tr>
</tbody>
</table>

Tab. 4.3.25: preliminary design pillar, geometrical characteristics, weigh 88 kg;

In a preliminary phase the reinforcement layout had been roughly designed with both textile reinforcement to confine concrete and one steel bar in the middle. In detail the number of bar is limited by the necessity to respect the 4 cm coverage imposed by law. As in chapter 3 part 1 the main structural elements were designed after a simple verification in this chapter the previous design would be improved to satisfy structural requirements. Moreover, especially about the column, different hypothesis have to be made since the TRC technology is still on research phase and a little is known about structural behavior when subjected to buckling. Moreover, as already said in chapter 3 part 1 the issues related to fire resistance has not been addressed in this project. In detail, for carbon textile reinforced concrete had been experimentally observed that the resistance decreases depending on temperature and other factors. Consequently, the use of a glass fiber fabric would be suitable.

The design was carried out on the two most critical columns. The column analyzed are the B3 and the C3. The efforts acting on columns had been previously calculated from beams reactions at which it was added the own weight of each column multiplied for the combination factor at ULS and ELS. In detail, about the two column analyzed the C3 was considered because it is subjected to the highest axial efforts (215 kN). The B3 instead is the most loaded column among the ones with a total height of 6 meters (170 kN).

Since the designed element is slender in a previous phase, before proceeding with the structural design, the slenderness ratio had been evaluated to check the necessity of taking in account second order effects for the elements design.
The Ec2 § 5.8.3.1 Slenderness criterion for isolated members, defines the slenderness maximum value. Nevertheless the norms refers to national annex to define the value of $\lambda_{\text{lim}}$, in consequence it was calculated in reference to the NTC 2018 4.1.2.3.9.2 Verifiche di stabilità per elementi snelli.

As seen the slender ratios of the elements, especially of those with a total height of 6 meters, is not verified. In consequence a further analysis, that includes second order effects, had to be carried out to verify structural requirements.

The Ec2 § 12.6.5.2 Simplified design method for walls and columns states that “In absence of a more rigorous approach, the design resistance in terms of axial force for a slender wall or column in plain concrete may be calculated as follows”:

$$N_{rd} = b \cdot h_w \cdot f_{cd,pl} \cdot \phi = A_{pl} \cdot f_{cd,pl} \cdot \phi$$

(Since the pillars has not a rectangular shape the area $A_{pl}$ was used to verify the ultimate compression resistance)

Where:

- $b$: is the overall width of the cross-section
- $h_w$: is the overall depth of the cross-section
- $\phi$: Factor taking into account eccentricity, including second order effects and normal effects of creep

$$\phi = 1.14 \cdot (1 - 2 \cdot e_{vo}/h_w) - 0.02 \cdot l_i/h_w \leq (1 - 2 \cdot e_{vo}/h_w)$$

Where:

- $e_{vo}$: is the first order eccentricity including, where relevant, the effects of floors (e.g. possible clamping moments transmitted to the wall from a slab) and horizontal actions
- $e_i$: is the additional eccentricity covering the effects of geometrical imperfections

The Ec2 § 5.2 defines for isolated members

$$e_i = \theta \cdot l_i/2$$

Where:

$$\theta = \theta_0 \cdot \alpha_h \cdot \alpha_n$$
Where:

- $\theta_0 = 1/200$;
- $\alpha_h = 2(l)^{0.5}$;
- $\alpha_n = 1$

A preliminary analysis had been carried out assuming $e_o = 0$. In detail the beams may be subjected to torsional effects due to variable loads.

The first analysis underlines that in both case of column B3 and C3 the section is verified. Nevertheless the hypothesis excludes any first order eccentricity. In this case either is assumed that all the torsional moments in the beams are taken by bracing walls either further analysis should be carried on.

See the peculiarity of the building, as for the double open-air space of the atelier, bracing wall could be located only on one façade. In consequence, the pillars are supposed to carry at least moments due to torsional effects, meanwhile the horizontal actions would be taken by bracing walls.

Since the design roughly defined in the chapter 3 part 1 doesn’t satisfy the structural requirements two options could be taken in consideration:

- Increasing the section dimensions: a first case considering pillars webs thickness of 3 cm had been analyzed:

<table>
<thead>
<tr>
<th></th>
<th>$A_c$ [mm$^2$]</th>
<th>$l_o$ [m]</th>
<th>$h_w$ [mm]</th>
<th>$e_o$ [mm]</th>
<th>$e_i$ [mm]</th>
<th>$\phi$</th>
<th>$\phi_{max}$</th>
<th>$f_{cd}$ [MPa]</th>
<th>$N_{rd}$ [KN]</th>
<th>$N_{ed}$ [KN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
<td>11378</td>
<td>1918</td>
<td>280</td>
<td>0</td>
<td>4.795</td>
<td>1</td>
<td>1</td>
<td>0.964</td>
<td>0.9658</td>
<td>30</td>
</tr>
<tr>
<td>C3</td>
<td>11378</td>
<td>4018</td>
<td>280</td>
<td>0</td>
<td>8.2017</td>
<td>0.8165</td>
<td>1</td>
<td>0.7862</td>
<td>0.9414</td>
<td>30</td>
</tr>
</tbody>
</table>

Tab 2.3.26: Design resistance verification for column B3 and C3 taking in account second order effect and assuming $e_o = 0$;

<table>
<thead>
<tr>
<th></th>
<th>$A_c$ [mm$^2$]</th>
<th>$l_o$ [m]</th>
<th>$h_w$ [mm]</th>
<th>$e_o$ [mm]</th>
<th>$e_i$ [mm]</th>
<th>$\phi$</th>
<th>$\phi_{max}$</th>
<th>$f_{cd}$ [MPa]</th>
<th>$N_{rd}$ [KN]</th>
<th>$N_{ed}$ [KN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
<td>11378</td>
<td>1918</td>
<td>280</td>
<td>68.003</td>
<td>4.795</td>
<td>1</td>
<td>1</td>
<td>0.4102</td>
<td>0.48</td>
<td>30</td>
</tr>
<tr>
<td>C3</td>
<td>11378</td>
<td>4018</td>
<td>280</td>
<td>88.694</td>
<td>8.2017</td>
<td>0.8165</td>
<td>1</td>
<td>0.064</td>
<td>0.3079</td>
<td>30</td>
</tr>
</tbody>
</table>

Tab 2.3.27: Design resistance verification for column B3 and C3 taking in account second order effect and assuming $e_o = 0$;
Increasing mortar resistance (e.g. C 70/85, fcd=46.7)

The results show that the new section is sufficient for the case of pillar B3 but not for the case of pillar C3. Indeed, this further analysis stress out how a different layout is needed for the C3, and in consequence for C1,2 and D1,2,3.

Since the structural analysis of the beams had been carried out employing a mortar C45/55 the first option had been selected and the section of the pillar had been increased.

Longitudinal reinforcement design:

The Ec2 § 9.5.1 defines that the total amount of longitudinal reinforcement should not be less than:

$$A_{s,min} = (0.1*N_{Ed}/f_{yd}) = 56.4 \text{ mm}^2$$
Moreover technological limits, due to minimum coverage values it is possible to fit only one bar. In consequence a steel bar of Ø 14 mm had been chosen (As = 154 mm²).

**Axial forces verification ULS**

Once the steel reinforcement had been set the overall section resistance under axial efforts is provided by:

\[ N_{rd} = N_{rd,c} + (A_s f_{yd}) = 301.5 \text{ kN} \]

**Transversal reinforcement design:**

The transversal reinforcement is provided by the composite net.

**Redesign of pillar layout (Case B3, 6 m height)**

Seen the peculiarity of the building due to the double height space to host the atelier and the vertical pouring station is reasonable that the pillar layout designed for common uses, with a maximum 3 or 3.5 meters height couldn’t satisfy the structural requirements.

In this specific case it was supposed that the pillar would be cast on site and the reinforcement would be provided using steel bars.

To address architectural and joint issues the shape of the pillar had been designed on the other pillars layout.

<table>
<thead>
<tr>
<th>Pillar B3</th>
<th>value</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>28.00</td>
<td>m</td>
</tr>
<tr>
<td>depth</td>
<td>18.00</td>
<td>m</td>
</tr>
<tr>
<td>A\text{tot}</td>
<td>65428.14</td>
<td>mm²</td>
</tr>
<tr>
<td>x\text{cg}</td>
<td>90.00</td>
<td>cm</td>
</tr>
<tr>
<td>y\text{cg}</td>
<td>140.00</td>
<td>mm</td>
</tr>
<tr>
<td>I</td>
<td>131701875</td>
<td>mm⁴</td>
</tr>
</tbody>
</table>

Tab. 4.3.30: design of B3 pillar, geometrical characteristics;

Firstly the minimum concrete area had been calculated. At the base reaction had been added the overall weight of the pillar multiplied for the combination coefficient (ULS: \( \gamma = 1.4 \)).

As first preliminary verification the minimum concrete area had been calculated:

\[ A_{c,min} = N_{rd} / f_{cd} * \alpha_{cc} = 6231 \text{ mm}^2 < 65428 \text{ mm}^2 \]
Once again the slenderness ration $\lambda_{lim}$, had been calculated according to the NTC 2018 4.1.2.3.9.2 Verifiche di stabilità per elementi snelli.

<table>
<thead>
<tr>
<th>Column</th>
<th>Ac [mm²]</th>
<th>ix [mm]</th>
<th>iy [mm]</th>
<th>$l_o$ [mm]</th>
<th>$\lambda_x$</th>
<th>$\lambda_y$</th>
<th>NEd [kN]</th>
<th>fcd [Mpa]</th>
<th>Ac [mm²]</th>
<th>$\lambda_{lim}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
<td>65428.1</td>
<td>92.748</td>
<td>57.72</td>
<td>1918.00</td>
<td>20.68</td>
<td>33.23</td>
<td>180.47</td>
<td>30.00</td>
<td>11377.60</td>
<td>34.38</td>
</tr>
</tbody>
</table>

Tab 4.3.31: slender value for the column and slender values obtained applying the NTC 2018 4.1.2.3.9.2 Verifiche di stabilità per elementi snelli;

The section is verified and in consequence second order effects could be neglected.

**Longitudinal reinforcement design:**

The Ec2 § 9.5.1 defines that the total amount of longitudinal reinforcement should not be less than:

$$A_{s,min}=(0.1*N_{Ed}/f_{yd})=45 \text{ mm}^2$$

$$A_{s,max}=0.04A_c=2617 \text{ mm}^2$$

Moreover technological limits, due to minimum coverage values it is possible to fit properly a minimum of 4 reinforcement bars. In first hypothesis 4 bars of Ø12 mm were used.

**Axial forces verification: ULS**

Once the steel reinforcement had been set the overall section resistance under axial efforts is provided by:

$$N_{Ed}=(0.8*A_c*f_{cd})+(A_*f_{yd})=2358 \text{ kN}$$

**Buckling verification ULS:**

The ULS buckling verification takes into account the effects that axial forces and bending moments have on the column sections. The verification have been carried out by definition of the breaking domain M-N and graphically verifying the stability thanks to the the software "VcaSlu" developed by professor P. Gelfi. The analysis had been carried assuming that:

- Conservation of flat sections;
- Perfect steel-concrete adhesion;
- Null traction resistance in the concrete;
- Breaking of the concrete caused by the achievement of his ultimate deformation capacity to compression;
- Evaluation of the concrete and steel stresses by strain-deformation diagrams ($\sigma$-$\epsilon$).

The overall results show how the sections is verified to axial and bending combined efforts.
Transversal reinforcement design:

The Ec2 § 9.5.3 states that:

- The diameter of the transverse reinforcement should not be less than 6 mm or one quarter of the maximum diameter of the longitudinal bars.
- The spacing of the transverse reinforcement along the column should not exceed:
  - 20 times the minimum diameter of the longitudinal bars the lesser dimension of the column
  - 400 mm

A transversal reinforcement of 6 mm with a spacing of 120 cm had been chosen.

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ned</td>
<td>101.301</td>
<td>87.9602</td>
<td>101.301</td>
</tr>
<tr>
<td>Med</td>
<td>8.7</td>
<td>2.7</td>
<td>8.7</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>B2</td>
<td>B3</td>
</tr>
<tr>
<td>Ned</td>
<td>180.471</td>
<td>176.758</td>
<td>180.471</td>
</tr>
<tr>
<td>Med</td>
<td>17.4</td>
<td>5.4</td>
<td>17.4</td>
</tr>
</tbody>
</table>

Tab 4.3.32: Maximum axial and bending action on pillars sections.
SLS, Stress limitation:

The verification of the stress limitation is carried out following the Ec2 § 7.2 Stress limitation. The maximum tension had to be verified with:

- $\sigma_c = 0.6 \ f_{ck}$ (characteristic combination)
- $\sigma_y = 0.8 \ f_y$ (characteristic combination)
- $\sigma_c = 0.45 \ f_{ck}$ (quasi-permanent loads combination)

To guarantee the equilibrium:

$$N_{ed} = A_c^* \sigma_c + A_s^* \sigma_s$$

Where

The relationship between $\sigma_c$ and $\sigma_s$ can be written as:

$$\sigma_c = m^* \sigma_s$$

Where:

- $m = 15$ represents the homogenization coefficient which takes into account the viscous effects produced by the permanent fraction of loads;

In consequence:

$$N_{ed} = \sigma_c^* (A_s + m A_s)$$

Once again the two most loaded columns are verified:

<table>
<thead>
<tr>
<th>Column</th>
<th>$A_c$ [mm$^2$]</th>
<th>$A_s$ [mm$^2$]</th>
<th>$N_{ed}$ (Ch) [KN]</th>
<th>$N_{ed}$ (Qp) [KN]</th>
<th>$\sigma_c$,Ch [Mpa]</th>
<th>$\sigma_c$,Max, Ch [Mpa]</th>
<th>$\sigma_c$,Qu. P. [Mpa]</th>
<th>$\sigma_c$ max,Qu. P. [Mpa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
<td>65428.138</td>
<td>452</td>
<td>109.02328</td>
<td>147.85328</td>
<td>1.5</td>
<td>27.0</td>
<td>2.0</td>
<td>20.3</td>
</tr>
<tr>
<td>C3</td>
<td>11377.6</td>
<td>154</td>
<td>76.86328</td>
<td>110.50328</td>
<td>5.6</td>
<td>27.0</td>
<td>8.1</td>
<td>20.3</td>
</tr>
</tbody>
</table>

Tab 4.3.33: SLS verification for columns B3 and C3;
4.3.7 Bracing walls verification and reinforcement design

Technology:

Textile-reinforced concrete had been already applied for the design of lightweight concrete facades panels with high durability and high quality surfaces. In detail, solution of TRC sandwich panels had been already experimented and tested to analyze for bending behavior. On the other hand, the literature about buckling behavior is scarce. In consequence, the design of a possible lightweight and thin panel facade, able to cope with horizontal actions have been handled in reference to the few experimental test results that had been already performed in existing and available literature. In consequence the design and structural verification still lack of reliable knowledge to assure the correct behavior of the structure and has to be considered more as a possible vision of final design rather than an effective one. Nonetheless, this research was focused on understanding the structural behavior at bending of horizontal elements (see chapter 5 part 1) and any test on TRC sandwich panels had been performed.

In detail the article [2]" Experimental investigation of the buckling behaviour of Textile Reinforced Cement sandwich panels with varying face thickness using Digital Image Correlation" analyses the relationship with analytical predictions and effect of the face thickness subjected to buckling. The test results show the reliability of analytical predictions, with a difference of 4%, in case of sandwich panels with TRC faces 23 mm thick. In consequence as preliminary design had been chosen a panel of 25 exterior and 20 mm interior facades thick with a filling on polyurethane of 6 cm. The two faces are punctually connected by thin TRC connections; similar TRC joints have been already employed in commercial solution to connect exterior and interior faces of prefabricated concrete panels at the purpose to reduce thermal bridges effects. As in common prefabricated panels technology, and as for the other structural elements, the joints between panels and horizontal slabs are casted on site.

Horizontal actions:

The structure is subjected only to the horizontal action of the wind, since the seismic action had been excluded following the Brazilian norms.

The building has a rectangular shaper of 9x8 meters therefore, the geometric barycenter is located at.

\[ X_g = 4 \text{ m and } Y_g = 4.5 \text{ m} \]

On the other hand the stiffness barycenter is defined by the bracing wall location. Since the bracing walls are made of thin TRC panels the stiffness on the small side is neglected. Consequently the stiffness barycenter is located at:

\[ X_{kg} = 4.5 \text{ m and } Y_{kg} = 7.5 \text{ m} \]

The wind actions on the structure with two forces acting at 0° and 90° degrees, among those previously calculated were considered the most critical ones.
In detail the bracing walls 1 and 3 are subjected only to horizontal forces and among them the 3 one is the most critical one. On the other hand the bracing wall 2 is subjected both to wind load and vertical load of the slab. In consequence the latter had been verified both to bending moment and buckling.

The loads acting on the bracing wall had been evaluated taking in account both the loads on the influence area at each floor and the wind actions. In detail the combination of loads, both vertical and horizontal, had been calculated at the ULS considering once the prevalence of variable internal loads once the prevalence of wind loads.

<table>
<thead>
<tr>
<th>Tab 4.3.33: Wind actions at each floor on the bracing walls;</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="pic4.3.19" alt="Influence area of the bracing wall B2;" /></td>
</tr>
</tbody>
</table>

The loads acting on the bracing wall B2 had been evaluated taking in account both the loads on the influence area at each floor and the wind actions. In detail the combination of loads, both vertical and horizontal, had been calculated at the ULS considering once the prevalence of variable internal loads once the prevalence of wind loads.

<table>
<thead>
<tr>
<th>Prevalence of internal loads q1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>γ</td>
</tr>
<tr>
<td>Ψ</td>
</tr>
<tr>
<td>Third floor</td>
</tr>
<tr>
<td>Second Floor</td>
</tr>
<tr>
<td>First floor</td>
</tr>
<tr>
<td>Ground floor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prevalence of wind loads q2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>γ</td>
</tr>
<tr>
<td>Ψ</td>
</tr>
<tr>
<td>Third floor</td>
</tr>
<tr>
<td>Second Floor</td>
</tr>
<tr>
<td>First floor</td>
</tr>
<tr>
<td>Ground floor</td>
</tr>
</tbody>
</table>

Tab: 4.3.34,a: combination of loads in case of prevalence of internal variable loads; Tab 4.3.34,b combination of loads in case of prevalence of wind loads;
The behavior of the bracing wall had been considered equal to the one of cantilever wall and base reactions had been calculated for each combination.

<table>
<thead>
<tr>
<th>MEd [kNm]</th>
<th>VEd [kN]</th>
<th>HEd[kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>157.8530243</td>
<td>141.40854</td>
<td>19.14759864</td>
</tr>
<tr>
<td>394.6325607</td>
<td>109.39824</td>
<td>47.86899659</td>
</tr>
</tbody>
</table>

Tab: 4.3.35: base reactions on the wall.

In detail the walls had been fitted with windows, in consequence the verifications had been carried out considering both the base section and the reduced one due to window openings.

**Reinforcement design:**

The reinforcement design had been carried out assuming the structural behavior of the wall as a cantilever wall. Nonetheless the wall has openings at each floor to locate windows. In consequence, a strut and tie model had been drawn to verify the resistance of the wall and design the textile reinforcement. In detail the model had been defined by the adoption of stress trajectories and distributions from linear-elastic theory. The strut and tie model employed was taken from existing literature. The model employed was developed by Aurelio Muttoni [2]

“Selon cette procédure, un cheminement des efforts est librement choisi et l’état de déformation de la structure est étudié. Puisque pour activer le modèle choisi de grandes fissures s’ouvrent dans les zones très déformées, un modèle bielles-et-tirants additionnel vient s’ajouter afin de limiter ces déformations.” [3]

Pic 4.3.20: strut and tie model for a reinforced wall developed by Aurelio Muttoni [1]; final design of the strut and tie model in the cantilever wall with openings.
The efforts had been considered as equally distributed between the two faces of the panel and the verification had been carried out as following:

**Efforts on the strut-tie model:**

**Efforts on the pillars:**

The wind loads cause tension and compression efforts on the pillars, in consequence those had been verified taking in consideration the reinforcement layout previously designed:

<table>
<thead>
<tr>
<th></th>
<th>D1/D3</th>
<th>D1/D3</th>
<th>D2</th>
<th>301.5</th>
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<tbody>
<tr>
<td>Third</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>floor</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>ged,pl</td>
<td>40.1</td>
<td>40.1</td>
<td>39.4</td>
<td></td>
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<td>ged,pl</td>
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<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>ged,pl</td>
<td>4.3</td>
<td>40.1</td>
<td>39.4</td>
<td></td>
</tr>
<tr>
<td>VRd[kN]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tab 4.3.36: verification of pillar resistance.

In detail the most charged struts and ties are located on the third floor where the maximum wind equivalent force is located.

**Compression struts:**

The analysis of the compression struts had been carried out in reference to the Ec2 § 6.5 Design with strut and tie models, where:

$$\sigma_{Rd,\text{max}} = 0.6 \times \nu \times f_{cd}$$

Where:

- \( \nu = 1 - \left( \frac{f_{cd}}{250} \right) \)

<table>
<thead>
<tr>
<th>element</th>
<th>bw tot [mm]</th>
<th>Stress [kN]</th>
<th>z [mm]</th>
<th>angle</th>
<th>( \sigma ) [Mpa]</th>
<th>( \nu )</th>
<th>( \sigma \text{ max} ) [Mpa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>49.61</td>
<td>140</td>
<td>45</td>
<td>12.53</td>
<td>14.76</td>
<td>14.76</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>65.98</td>
<td>160</td>
<td>22</td>
<td>7.05</td>
<td>14.76</td>
<td>14.76</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>63.85</td>
<td>400</td>
<td>16</td>
<td>4.16</td>
<td>14.76</td>
<td>14.76</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>71.41</td>
<td>660</td>
<td>45</td>
<td>3.83</td>
<td>14.76</td>
<td>14.76</td>
</tr>
</tbody>
</table>

Tab 4.3.37: Compression struts verification;

Pic 4.3.21 Strut and tie model;
Reinforcement design, tension ties:

Once the tension had been calculated the minimum reinforcement area had been evaluated and in consequence the tensile net had been chosen. Since the chosen net has two different resistance depending on orientation, it was supposed to orientate horizontally the most resistant direction.

Buckling verification:

As previously said the knowledge about buckling behavior of TRC structure is still scarce. Nonetheless the preliminary design was based on the evidences showed by the article (xxx). In consequence the buckling verification had been carried out with the same analytical process.

The overall buckling load of the panel can be calculated as:

\[ 1/P = 1/PE + 1/PS \]

Where:

- **PE**: buckling load due to pure bending
  \[ PE = \frac{\pi Db}{(\beta l)^2} \]
  Where:
  - **b**: width of the panel
  - **l**: length of the panel
  - **\beta**: 1 (buckling mode factor that depending on boundary conditions)
  - **D**: flexural rigidity of the panel, simplified by the formula:
    \[ D = \frac{E_{cm} t d^3}{2} \]
    Where:
    - **t**: thickness of the faces
    - **d**: overall thickness of the panel
  - **PS**: buckling load due to pure shear
    \[ PS = G_c d^2 / t_c \]

<table>
<thead>
<tr>
<th>element</th>
<th>z [mm]</th>
<th>ftx,d [Mpa]</th>
<th>η</th>
<th>s [mm]</th>
<th>A min</th>
<th>Atx (1+1 layer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>48.5</td>
<td>1428.6</td>
<td>0.80</td>
<td>20</td>
<td>42.44</td>
<td>51</td>
</tr>
<tr>
<td>6</td>
<td>48.5</td>
<td>1214.3</td>
<td>0.80</td>
<td>20</td>
<td>49.93</td>
<td>51</td>
</tr>
<tr>
<td>7</td>
<td>6.3</td>
<td>1428.6</td>
<td>0.80</td>
<td>20</td>
<td>5.51</td>
<td>68</td>
</tr>
<tr>
<td>8</td>
<td>6.3</td>
<td>1214.3</td>
<td>0.80</td>
<td>20</td>
<td>6.49</td>
<td>34</td>
</tr>
<tr>
<td>9+10+11</td>
<td>101.44</td>
<td>1428.6</td>
<td>0.80</td>
<td>20</td>
<td>88.76</td>
<td>110.5</td>
</tr>
</tbody>
</table>

Tab 4.3.38: Tension tie reinforcement design; Pic 4.3.21 Strut and tie model;
Where:
• $G_c$: shear module of the core;
• $b$: width of the panel
• $l$: length of the panel

In detail the value of D had been calculated based not on the overall thickness of the panels but considering that the available section is partially reduced since a part is employed to address compression stress due to shear-force in the panel. In detail the minimum thickness needed to address compression stress have been evaluated and the buckling have been verified on the most critical point.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$b$ AA</td>
<td>6000 [mm]</td>
<td></td>
</tr>
<tr>
<td>$b$ BB</td>
<td>3000 [mm]</td>
<td></td>
</tr>
<tr>
<td>$t_{eff}$ AA</td>
<td>12.3 [mm]</td>
<td></td>
</tr>
<tr>
<td>$t_{eff}$ BB</td>
<td>15.8 [mm]</td>
<td></td>
</tr>
<tr>
<td>$d$</td>
<td>100 [mm]</td>
<td></td>
</tr>
<tr>
<td>$L$</td>
<td>9000 [mm]</td>
<td></td>
</tr>
<tr>
<td>$t_c$</td>
<td>60 [mm]</td>
<td></td>
</tr>
<tr>
<td>$E_f$</td>
<td>36 [Gpa]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>D [kNmm]</th>
<th>$P_E$[kN]</th>
<th>$G$[Mpa]</th>
<th>$P_S$[kN]</th>
<th>$P$[kN]</th>
<th>$0.9P$[kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>4421180</td>
<td>3232.2</td>
<td>3.2</td>
<td>3200.0</td>
<td>1608.0</td>
<td>1447.2</td>
</tr>
<tr>
<td>BB</td>
<td>5685137</td>
<td>2078.2</td>
<td>3.2</td>
<td>1600.0</td>
<td>904.0</td>
<td>813.6</td>
</tr>
</tbody>
</table>

Tab 4.3.39 Buckling verification of the panel at section AA and BB; Pic 4.3.22 sections AA and BB;

Bibliography:


4.3.8 Ground of Rocinha

The informations about the soil of Rocinha has been taken from the Mapa de solos do estado do Rio de Janeiro. This map is the only reference found about soil typologies. This data have been used to verify the stability of the retain wall built on the back of the building. In reference with the map it has been defined the typology of soil: PVa 09 - Podzolico Vermelho - Amareloálico. These soils are poorly drained and they are characterized by a dense subsurface clay layer.

Based on these elements, it has been supposed that this type of soil has similar properties of hard clays, whose main parameters are:

- $\gamma_s = 20 - 22 \text{ kN/m}^3$, which represents the volume weight;
- $\Phi = 10 - 25^\circ$, the friction angle.
- $C' = 100 - 20 \text{ kN/m}^2$, which represents the effective cohesion;
- $C_u \geq 150 \text{ kN/m}^2$, the undrained resistance.

**Verification of excavation stability**

$H_c$ is define as the critical maximum height of the excavation. In case this value is smaller than the height of the excavation proper supports must be provided during the construction of the wall.

$$H_c = \frac{2C_u}{\gamma_s} = 14.29 < 4 \text{ m}$$

Where:

- $C_u$, the undrained resistance, is equal to 150 kN/m$^2$;
- $\gamma_s = 21 \text{ kN/m}^3$.

Therefore it is possible to state that there are no landslides.

![Mapa de solos do estado do Rio de Janeiro](image_url)
4.4 Energy and lighting analysis

The project building is located in an empty plot today employed as construction material warehouse. The plot has one side free on the Rua 2 and is surrounded, on the other sides buildings and by a green rocky wall. The project buildings have been designed to fit and exploit at its best the exterior condition enhancing passive strategies as natural ventilation and increasing of thermal inertia of the most irradiated surfaces. The majority of the windows have been placed on the east side to guarantee sufficient natural light inside the building. On the other hand, since this façade is exposed North-West the windows have been sufficiently shaded to avoid glare close to the windows and over irradiation limiting internal gains. Due to inclination values of solar radiation, that reach their picks in summer season at 89°, a green roof have been placed on the terrace to increase thermal mass displacement. PV panels have been sized to supply energy demands, especially in the summer season. In fact due to high temperature a cooling system has been designed to satisfy first and second floor demands. Furthermore the presence of the green rocky wall has been exploited to refresh air. The rocks have been stabilized by a concrete retain wall at the base. On the side facing the rock, despite poor lighting benefits, big opening were place to increase ventilation effect, guarantee by the presence of opening on each side.
Pic. 4.4.1: Schematic design during winter months, from June to September, average temperature is between 27.6 °C and 17.6 °C, Average solar radiation inclination $\alpha = 43.4^{\circ}$;
Pic: 4.4.2: Schematic design during winter months, from December to March, average temperature is between 32.9 °C and 22.2°C, Average solar radiation inclination $\alpha = 89.9^\circ$;
4.4.1 Lighting analysis

The lighting analysis have been performed for each floor thanks to the software Velux daylight visualizer. For each floor different analysis have been performed in order to obtain, in the limit of exterior condition, comfort values of illuminance and daylight factor. The Brazilian norms don’t impose minimum requirements about daylight, on the other hand it define a minimum of glazed surface equal or superior to the 40% of interior spaces. The parameter analysed are:

- **Daylight factor (FLD,%)**: The daylight factor is a parameter introduced to evaluate the natural lighting within a confined environment.
  
  FDL <1% = insufficient  
  1% <FDL <2% = discrete  
  2% <FDL <4% = good  
  FDL> 4% = excellent

- **Illuminance (LUX)** It measures the amount of luminous flux intercepted by a surface. The value is given by the ratio between the luminous flux emitted from a particular source and the receiving surface. The average value expected for each floor are:
  
  - 300 Lux for the workshop spaces at ground floor and first floor;  
  - 500 Lux for the studio on the second floor;

The illuminance analysis have been performed both the 21 of January and the 21 of July. It is important to remark that the façade that benefits the most form natural light is the north-West façade since it is the only one without close shading barrier as buildings. Therefore this analysis was also focused in defining the best ratio of window and shading to guarantee sufficient light in all the building and avoid over lighting of surfaces facing North-West.
Ground floor

The ground floor is open air and host the workshop activities. In detail the main source of daylight comes from the North-West façade that is open air, meanwhile the sides facing other buildings, North East and South West, are blind to contain noise and pollution form reaching residential buildings. A preliminary analysis have been performed to values without shading system on the west façade.

Pic: 4.4.1.1: FLD analysis, 1st configuration ground floor;
Pic: 4.4.1.2: Illuminance analysis 21 June, 1st configuration ground floor;

Pic: 4.4.1.3: Illuminance analysis 21 January, 1st configuration ground floor;
Both the FLD and the illuminance analysis show over lighting of the area close to the street. With LUX values on the 21th January that overcome 1000 LUX. On the other hand the values at the other side of the space are around the 300 LUX. In consequence a shading system has to be placed. Since the space is devoted to a worksite control of lighting must be to be guarantee the designed solution is a movable curtain. In fact a movable curtain allow to better manage the lighting on the space and to change the exposition depending on necessities. Therefore a second analysis have been performed with the shutter disposed at mid-height (3 meter). The analysis performed good values in the zone close to the street, with an average FLD of 4.7 % and 670 LUX the 21 January. On the other hand the values on the other side of the building are discrete. In fact the FLD average is 1.46% and 170 LUX. On the other hand, due to building proximity on North-East side and to stairs on the other side it is not possible to create opening to increase the value. Finally a flexible system as the shutter could be the most suitable solution to adapt and manage natural lighting in the space.

Pic: 4.4.1.4: FLD analysis, 2nd configuration ground floor;
Pic: 4.4.1.5: Illuminance analysis 21 June, 2nd configuration ground floor;

Pic: 4.4.1.6: Illuminance analysis 21 January, 1st configuration ground floor;
First floor
Due to the unfavorable position of the first floor in both sides facing North-West and South-East windows have been placed. In detail the first analysis showed discrete-good results in the working space with an FLD average of and an illuminance average of 281 the 21 of January and 170 the 21 of June.

Daylight factor Legend:
- 8%
- 7%
- 6%
- 5%
- 4%
- 3%
- 2%
- 1%

Illuminance Legend:
- 500
- 435
- 375
- 315
- 250
- 190
- 125
- 65

Pic: 4.4.1.7: FLD analysis, First floor;
Pic: 4.4.1.8: Illuminance analysis 21 June, 21 January, first floor;
Second floor

The second floor has been designed as an open space where different activities take place. Due to proximity with other buildings, the windows have been shaded with hollow bricks that allow light to enter and at the same time guarantee privacy to the neighborhood. On the other hand, with the exception of the North-East side, the quality of light coming from the exterior is very low. In consequence, the focus has been put on the design of the street façade. In detail, this façade has been designed with a continuous glass façade and afterward the shading system has been designed to fit space necessities.

The first analysis have been performed without any shading system on the North-East façade. The analysis shows, as expected, too high values close to the façade both for FLD, bigger than 10% close to the façade and higher than 3.5 on the other side, and LUX higher than 1000 in January and 700 in June.

![Daylight factor Legend:](image)

- 8%
- 7%
- 6%
- 5%
- 4%
- 3%
- 2%
- 1%

Pic: 4.4.1.9: FLD analysis, 1st configuration, Second floor;
Pic: 4.4.1.10: Illuminance analysis 21 June, 1st configuration, Second floor;

Pic: 4.4.1.11: Illuminance analysis 21 January, 1st configuration, Second floor;
Different hypothesis have been analyzed. Hollow brick shading system on all the façade:

The analysis results show how the value obtained are lower than the expected target. In detail the analysis show bad results for the illuminance values both performed the 21 of January and June.

Pic: 4.4.1.12: FLD analysis, 2nd configuration, Second floor;
Pic: 4.4.1.13: Illuminance analysis 21 June, 2nd configuration, Second floor;

Pic: 4.4.1.14: Illuminance analysis 21 January, 2nd configuration, Second floor;
Hollow brick on the lowest and higher part:
This shading design is also the results of an architectural aim to employ hollow bricks as shading, to express a willingness to employ local construction materials, and the idea to design a permeable façade. Therefore the shading have been put on the lowest and highest area of the façade leaving the central one, from 1 to 2 meter, free. A first analysis was performed. The illuminance results for the analysis performed the 21 of June are good and on the average target of the space. In detail, the average in the area close to the glass façade is around 470 LUX meanwhile the rest of the room, both in the middle both on the bottom has value around 180 LUX. On the other hand, the value of FLD and illuminance at the 21 of January are again too high close to the glass façade, 8% and 800 LUX.

Daylight factor Legend:
- 8%
- 7%
- 6%
- 5%
- 4%
- 3%
- 2%
- 1%

Pic: 4.4.1.15: FLD analysis, 3rd configuration, Second floor;
Illuminance Legend:

- 500
- 435
- 375
- 315
- 250
- 190
- 125
- 65

Pic: 4.4.1.16: Illuminance analysis 21 June, 3rd configuration, Second floor;

Pic: 4.4.1.17: Illuminance analysis 21 January, 3rd configuration, Second floor;
In consequence a movable curtain wall has been implemented to manage over lighting during the summer months. A final analysis has been performed assuming the curtain totally deployed. The final results show a good results close to the glass façade for the illuminance during the 21 of January: 540 LUX and FLD results: 4.5%.

Daylight factor Legend:
- 8%
- 7%
- 6%
- 5%
- 4%
- 3%
- 2%
- 1%

Pic: 4.4.1.18: FLD analysis, 4th configuration, Second floor;
Pic: 4.4.1.19: Illuminance analysis 21 June, 4th configuration, Second floor;

Pic: 4.4.1.20: Illuminance analysis 21 January, 4th configuration, Second floor;
Pic: 4.4.1.21: Illuminance analysis 21 January, 4th configuration, Second floor, perspective view;
4.4.2 Energy management

Cooling system

To size the cooling system the internal thermal load, as well as the air exchange request had been evaluated. Due to lacks of information on Brazilian norms about solar radiation incidence and insufficient data to evaluate the exterior equivalent temperature different approximation had been carried out to evaluate the total of internal loads. Software as Climate consultant for climate data have been consulted. Moreover, to evaluate thermal summer loads had both Brazilian Norm (ABNT NBR 15575 2013 normas de desempenho) and Italian or European norms have been taken as reference too.

General conditions:

The values for external temperature and humid bulb equal to 35.1 and 26.5 °C and thermal excursion equal to 6.4 °C are defined by the table A2. The value of the relative humidity is taken from the climate analysis and is used highest among the summer months equal to 73.8%. The value of internal temperature is defined by the table E.1. In detail the internal temperature during February, the hottest summer month, must be included between 30.9 and 24.4 °C, in consequence an average temperature of 27 degrees had been used to size the cooling system with a relative humidity a value of 55%.

<table>
<thead>
<tr>
<th>Nivel de desempenho</th>
<th>Critério</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zonas 1 a 7</td>
</tr>
<tr>
<td></td>
<td>Ti,max ≤ Te,max</td>
</tr>
<tr>
<td>M</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Ti,max ≤ (Te,max − 2°C)</td>
</tr>
<tr>
<td>S</td>
<td>Ti,max ≤ (Te,max − 4°C)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Zona 8</td>
</tr>
<tr>
<td></td>
<td>Ti,max ≤ Te,max</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ti,max ≤ (Te,max − 10°C)</td>
</tr>
</tbody>
</table>

Ti,max é o valor máximo diário da temperatura do ar no interior da edificação, em graus Celsius;

Te,max é o valor máximo diário da temperatura do ar exterior à edificação, em graus Celsius;

Ti,min é o valor mínimo diário da temperatura do ar no interior da edificação, em graus Celsius;

Te,min é o valor mínimo diário da temperatura do ar exterior à edificação, em graus Celsius;

NOTA Zonas bioclimáticas de acordo com a ABNT NBR 15220-3.
4.4.2.1 Thermal loads

Solar Radiations

To calculate the internal gains due to the solar radiation effect the overall surface of widows, included frame had been taken in consideration. In detail, solar radiation depends on building orientation, nevertheless the Brazilian norm define an unique value for daily solar radiation equal to 5722 Wh/m². In consequence, this value should have been applied for all window, without taking in consideration the reduction factor due to external shading, since solar radiation diffuse and direct values were not specified in the norm. On the other hand, with the support of the software climate consultant the hourly direct and diffuse radiation values in the month of February were obtained. Moreover reduction factors, taking in account external shading system from Italian norms, had been applied. Due to external shading a factor of 0.12 for brick shaded surfaces had been considered and a factor of 0.2 for external curtains, the internal gains had been evaluated on the hottest month of February when, as shown in the daylight analysis, performed the 21 of January, the curtains would be employed to avoid over light.

<table>
<thead>
<tr>
<th>Floor</th>
<th>Radiation</th>
<th>Surface [m²]</th>
<th>Reduction factor</th>
<th>Global Solar radiation [Wh/m²]</th>
<th>Diffuse Solar radiation [Wh/m²]</th>
<th>Solar radiation [Wh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>N-O curtain</td>
<td>7.3</td>
<td>0.2</td>
<td>526</td>
<td></td>
<td>767.5</td>
</tr>
<tr>
<td>2</td>
<td>N-O Brick shading</td>
<td>14.6</td>
<td>0.1</td>
<td>526</td>
<td></td>
<td>921.0</td>
</tr>
<tr>
<td>1</td>
<td>N-O diffuse brick</td>
<td>5.5</td>
<td>0.1</td>
<td>-</td>
<td>197.0</td>
<td>129.4</td>
</tr>
<tr>
<td>1</td>
<td>N-O diffuse no shading</td>
<td>7.5</td>
<td>0.9</td>
<td>-</td>
<td>197.0</td>
<td>1327.6</td>
</tr>
<tr>
<td>02-Jan</td>
<td>N-E</td>
<td>6.0</td>
<td>0.1</td>
<td>-</td>
<td>197.0</td>
<td>141.8</td>
</tr>
<tr>
<td>1;2</td>
<td>S-E</td>
<td>6.0</td>
<td>0.1</td>
<td>526</td>
<td></td>
<td>378.7</td>
</tr>
<tr>
<td>2</td>
<td>S-O</td>
<td>8.1</td>
<td>0.12</td>
<td>-</td>
<td>197</td>
<td>191.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3857.6</td>
</tr>
</tbody>
</table>

Tab 4.4.2.1: Value of solar radiation (For the North East and South West sides only diffuse radiation value had been considered due to external shading as well as for the Surfaces exposed North west on the first floor, since they are entirely shaded by the top floor);

Thermal transmission external walls and windows

To the thermal exchange between wall and roof and interior spaces is defined as the:

\[ Q = \sum U^* S^* \Delta t \]

In detail the value of equivalent temperature difference \((t_{eq} - t)\) is defined by recorded values depending on
thermal shift (6.4°C) latitude (22°), thermal mass, absorption coefficient and daily time. Looking at Rio de Janeiro values no record was found and consequently the Δt was considered as the difference of internal and external air temperature. In consequence the same formula, had been applied for transmission trough windows:

<table>
<thead>
<tr>
<th></th>
<th>U [W/m²K]</th>
<th>Surface [m²]</th>
<th>Δt[°C]</th>
<th>Total Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.C.01</td>
<td>0.43</td>
<td>72</td>
<td>8.1</td>
<td>250.8</td>
</tr>
<tr>
<td>H.C.02</td>
<td>0.42</td>
<td>36</td>
<td>8.1</td>
<td>122.5</td>
</tr>
<tr>
<td>H.C.03</td>
<td>0.31</td>
<td>36</td>
<td>8.1</td>
<td>90.4</td>
</tr>
<tr>
<td>V.C.01</td>
<td>0.26</td>
<td>84.3</td>
<td>8.1</td>
<td>177.5</td>
</tr>
<tr>
<td>V.C.03</td>
<td>0.42</td>
<td>10.8</td>
<td>8.1</td>
<td>36.7</td>
</tr>
<tr>
<td>Windows</td>
<td>1.4</td>
<td>54.948</td>
<td>8.1</td>
<td>623.1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>1301.0</strong></td>
</tr>
</tbody>
</table>

Tab 4.4.2.2: Thermal transmission of walls and windows;

**Internal loads**

Those had been calculated with the hypothesis of a production of 70 W/m² per person, the equivalent of office buildings, for the second floor and 150 W/m² per person for the office/workshop at the first floor. For the light consumption had been hypothesized an equivalent of 11 W/m² (led low consumption lamp) and the equivalent of 100 W for computer, printers and other electrical devices.

<table>
<thead>
<tr>
<th></th>
<th>Power [W]</th>
<th>Surface [m²]</th>
<th>Crowing coeff.</th>
<th>Total Power [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamps</td>
<td>11</td>
<td>83.1</td>
<td>-</td>
<td>914.0</td>
</tr>
<tr>
<td>Computer Floor 1</td>
<td>100</td>
<td>-</td>
<td>2</td>
<td>200.0</td>
</tr>
<tr>
<td>Computer Floor 2</td>
<td>100</td>
<td>-</td>
<td>10</td>
<td>1000.0</td>
</tr>
<tr>
<td>People Floor 1</td>
<td>70</td>
<td>18.0</td>
<td>0.4</td>
<td>502.8</td>
</tr>
<tr>
<td>People Floor 2</td>
<td>150</td>
<td>65.1</td>
<td>0.1</td>
<td>976.9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>3593.7</strong></td>
</tr>
</tbody>
</table>

Tab 4.4.2.3. Internal thermal loads.

**Latent heat**

It considers the effect of different humidity due to air exchange and presence of people and specific machines. Once again the value of latent heat due to people presence was take from Italian norms, of 70 W/m² per person, the equivalent of office buildings, for the second floor and 315 W/m² per person for the office/work-
shop at the first floor.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>People Floor 1</td>
<td>65.1</td>
<td>0.4</td>
<td>70</td>
<td>1823.6</td>
</tr>
<tr>
<td>People Floor 2</td>
<td>18.0</td>
<td>0.1</td>
<td>315</td>
<td>565.6</td>
</tr>
</tbody>
</table>

Tab 4.4.2.4: Latent heat;

The total air exchange per hour needed to supply internal loads is equal to:

<table>
<thead>
<tr>
<th></th>
<th>Total Power [kW]</th>
<th>Total Power [kcal/h]</th>
<th>G Total Vol [m³/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitive Int. Heat [W/h]</td>
<td>8752.3</td>
<td>7545.1</td>
<td>3212.1</td>
</tr>
<tr>
<td>Latent Int. Heat [W/h]</td>
<td>2389.3</td>
<td>2059.7</td>
<td>876.8</td>
</tr>
</tbody>
</table>

Tab 4.4.2.4: Latent heat;

4.4.2.2 Cooling system sizing

To size the ventilation system is necessary to obtain the value of air exchange (volume/hour) necessary to guarantee the comfort temperature of 27 °C and 55% of relative humidity. Firstly the volume exchange necessary to cope with internal thermal loads had been calculated:

\[
G = \frac{\text{Total summer thermal loads}}{(0.29 \times \Delta t)} = 3212.1 \text{ m}^3/\text{h}
\]

Ventilation

The Brazilian norms define a minimum value of air volume equal to 1 volume/hour for residential buildings. Seen the different affection of the designed buildings the Italian norms had been taken in consideration and the air exchange values taken in consideration is 2.5 and the volume per person is 10 l/s. In detail both the office at first floor and both the open space at the second floor had been considered as offices. Meanwhile, the air changes due to crowing values had been evaluated using the maximum crowing coefficients defined by the Italian DM 22.02.2006 and equal to 0.1 for workshop(1st floor office) and equal to 0.4 for working spaces open to public (2nd floor).
Tab 4.4.2.6: Total air volume exchange for each floor (the maximum value had been taken in consideration for further evaluations);

Once the volume of exchange had been calculated the Mixing design temperature has to be calculated taking in account that the exchange air would be partially taken from the exterior and partially for the interior, in proportion with the needed exchange volume per hour: $T_{mix} = 28.8 \, ^{\circ}C$

Moreover the thermal factor, depending on latent and sensitive heat had been calculated: $R=0.72$

Once fixed the point E (external values) and the point A (internal values) on the line connecting the two point the point M(corresponding to the $T_{mix}=28.8$) at which corresponds an enthalpy of 68 kJ/kg.

Cooling cycle: the air is cooled till $15.5 \, ^{\circ}C$ at which corresponds an enthalpy of 44, in consequence the $\Delta h=28$

The Cooling power is calculated as:

$$Q=G\times \rho \times \Delta h/3600= 20.2 \, kW$$

Fan power is defined by:

$$Q_f=(G \times 1.5)/\eta/3600=1.5$$

Where: $\eta=0.9$

$$Q_t=Q+Q_f=21.7 \, kW$$

Finally the ventilation nozzle ventilation have been designed taking in account the total flow for each floor.

<table>
<thead>
<tr>
<th>Floor</th>
<th>Volume [m³]</th>
<th>Air exchange coeff.</th>
<th>Crowing coeff.</th>
<th>Exchange per person [l/s]</th>
<th>air exchange Vol [m³]</th>
<th>air exchange person Vol [m³/h]</th>
<th>Total per floor Vol [m³/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>172.8</td>
<td>2.5</td>
<td>0.4</td>
<td>10</td>
<td>432.0</td>
<td>864.0</td>
<td>937.9</td>
</tr>
<tr>
<td>2</td>
<td>7.4</td>
<td>2.5</td>
<td>0.4</td>
<td>10</td>
<td>18.5</td>
<td>36.9</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>7.4</td>
<td>2.5</td>
<td>0.4</td>
<td>10</td>
<td>18.5</td>
<td>36.9</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>44.3</td>
<td>2.5</td>
<td>0.1</td>
<td>10</td>
<td>110.8</td>
<td>55.4</td>
<td>129.3</td>
</tr>
<tr>
<td>1</td>
<td>7.4</td>
<td>2.5</td>
<td>0.1</td>
<td>10</td>
<td>18.5</td>
<td>9.2</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1067.2</td>
</tr>
</tbody>
</table>

Pic: 4.4.2.2: Psychrometric chart;
5 IMM Phase III, Retrofit

In the chapter 2.2 the IMM analysis had stress out the main weakness as well the main opportunities of the CAS on the local scale. The highlights were the structural lack of basic public services both as function and also as public transportation and the isolation stressed out by different analysis as accessibility interface, effectiveness and porosity of the residential neighborhood located on the North-East of the analysis area. In the chapter 3 actions to improve the urban quality as well to promotes the introduction of pilots project inside the favela. This chapter, trout the analysis of the project masterplan allow to forcast the future performaces of the CAS. Those have been evaluated both by re-perform an IMM analysis on future masterplan and by 135 indicators set to de-scribe the quality of the urban context.

Pic: 5.1 view on the Area 3 for the Garage of Il sorriso dei miei bimbi, ph. Perego Francesca, Oct. 2018;
5.1 IMM analysis, Retrofit

5.1.1 Horizontal analysis

Volumes and Voids:
About volumes the overall scenario is almost unchanged. One of the project goal was to obtain the maximum improvement of urban quality avoiding as far as possible the demolition of building inside the favela. In fact, as consequence of changes in Rua Nova, Rocinha’s inhabitants are very sensitive to the topic of demolition and relocation. In the project site only two buildings were demolished and the families relocated at few meters distance to guarantee the same living conditions. If on one side the volume outlook is not changed that much, the voids is visible how the entrance to the connection between Rua 2 and Rua 1 is now highlight. This new space, despite its reduced dimensions, would have a center role in the urban re-qualification of the area.

Functions
The new spaces obtained by the demolition of two building have been designed to host as much as possible new structural functions needed to enhance and create a new dynamic node for the neighborhood. In detail the new building have been designed to host at the ground floor shopping activities already present in the old building and other vital functions as an open space for a permanent market, that now use to take play in Sunday mornings, a garbage collecting point and the Waterhouse. The rest of the building, the first and second floor has been devoted to a structural function as an educational one. Non the less the connection between the Rua 2 and the Rua 1 has been emphasized by satellite functions an other Waterhouse and waste collecting point as well as a small dwelling for retail of farming terraces aside.

Transportation
The previous analysis had shown the lack of public transportation in the Rua 2 as well as the isolation of the residential neighborhood. In this case the efforts could be focused only on the main roads since the narrow path as well the high slope of the rest of the area made impossible to introduce any transportation alternatives. Many Dop’s concern the mobility issue, in consequence a pilot project have been studied to introduce and alternative mobility network of electric bike sharing stations, proposing a valid and safe alternative to the trafficked Estrada da Gavea. The Rua 2 have been included in this network, in consequence a bike sharing station have been placed on the new plaza in order to enhance the connection within existing network of bus, that connects the community with the rest of the city and the new ones. In consequence this new functional node have gained a role as infrastructural secondary node. Nonetheless, the new catchment area includes part of the residential neighborhood.
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Pic. 5.1.1 IMM analysis, Volume state of art/retrofit;

Pic. 5.1.2 IMM analysis, Voids state of art/retrofit;

Pic. 5.1.3 IMM analysis, Function state of art/retrofit;

Pic. 5.1.4: IMM analysis, Transportation state of art/retrofit;

Functions:
- Bank/Atm
- Post office
- Health services
- Education services
- Sport services
- Waste collection
- Shopping
- Market (food)
- Bar/restaurant

Transportation:
- Bus stop
- Bike sharing stop
- Bus
- Bike sharing
- Taxi bus stop
- Taxi bus
- Catchment
- Moto taxi bus
- Moto taxi
- Catchment

Pic. 5.1.3 IMM analysis, Function state of art/retrofit;
5.1.2 Vertical analysis

Diversity
Diversity is the superimposition of the Voids and the Functions layers. The state of art analysis has shown the prevalence of necessary occasional activities as bank/atm, post offices and shopping (NO) and optional activities as bar, restaurants and sport facilities (OP). On the other hand, it was observed a lack of necessary regular activities, among them event if was noted the presence of waste collectors and food market it was also identified a structural lack of educational and health services. At this purpose existing NR functions were improved and a new educational activity was added to enhance the role of this new urban node.

Accessibly:
Accessibility is the superimposition of the Transportation and the Functions layers. The previous analysis have spotted out the potentiality of functions placed on the Rua 2 since they are well connected with the network of public transportation on the Estrada da Gavea. Thank to this analysis both the improvement on the CASs for the function and transportation layers have been proved right. In fact not only the new functions on Rua 2 but, thanks to the bike sharing station, the satellite functions placed on the Rua 1 are all well connected with the public transportation network.

Interface
Interface is obtained by the superposition of Transportation and voids. Interface is an indicator of the quality of movement provided by the street networks. On the global scale it was one of the most important indicator, on the other hand at the local scale it has few impact since is largely affected by changes on the whole network rather than local ones. To evaluate the interface quality was employed the software for the University College of London “UCL Depthmap” The color scale is proportional to the quality of the connection link: a warm color indicates a well-connected and safe street network; meanwhile, a cold color indicates a bad connected street. The previous analysis has stressed out ow the residential neighborhood is bad connected. New connections have been created between the Rua 2 and Rua 1. Non the less the impact of the changes on the interface indicator would be more relevant when performed on the global scale.
Pic 5.1.5 IMM analysis, Diversity state of art/retrofit;

Pic 5.1.6 IMM analysis, Accessibility state of art/retrofit;

Pic 5.1.7 IMM analysis, Interface state of art/retrofit;
Effectiveness:

Interface is obtained by the superposition of Transportation and Volume. As for the analysis on the global scale it was considered the potential gradient of the Effectiveness Key category to be zero since it is unrealistic to plan for any future urban development in such dense area. Despite global analysis the reference grid was reduced to 20 x 20 meters. The highest level of effectiveness are located on the Estrada da Gavea. Moreover, the level of effectiveness along the Rua 2 is still high thanks to the bus stop at the beginning of Rua 2 on Estrada da Gavea. Once again, in according to previous investigations the Rua 1 and the North/East area have no capability in terms of transportation.

Proximity

Proximity is the superimposition of the Volume and Function layers. Proximity is highly related with the pedestrian fruition of the space and is defined by the number of key functions within a walkable distance. The increase of new functions on the area 3 have brought improve the proximity values. On the other hand, this effect is limited due to the low level of connection and to the bad mobility network (interface). In fact the catchment area is still confined due to lack of roads and the steep path. On the other hand, once again the majority of the residential area is isolated. A new analysis, to evaluate the performance level of the fruition and the walkability of the case study area, have been performed with the retrofitted masterplan. The six values analyzed are:

- \( \frac{L_{sw}}{L_{st}} \): Ratio of window shop surface to the total lateral surface on the street level; Since the functions were increased and new structures were built this value have duplicated.
- \( \frac{S_{sw}}{S_{st}} \): Ratio of sidewalk surfaces to the total street surface; This value didn’t increase since the road didn’t change and it was already equipped with sidewalks.
- \( \frac{N_j}{N_t} \): Ratio of number of jobs to the total occupied population; due to functions increasing this value have slightly augmented. In detail, it shows how the majority of workers on the area 3 needs to use the transportation network to work.
- \( \frac{S_p}{S_{st}} \): Ratio of paved surface to the total street surface, since new pedestrian connections were added this value have slightly decreases.
- \( \frac{A_f}{A_t} \): Ratio of functional area to the total built-up area; due to functions increasing this value have slightly augmented.
- \( \frac{L_{nm}}{L_t} \): The ratio of non-motorized links length to the total street length.
Effectiveness

Proximity:

Intervention area

Tab 5.1.1a IMM analysis, Proximity values:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LSw/LSt</td>
<td>16.67%</td>
<td></td>
</tr>
<tr>
<td>Lnm/Lt</td>
<td>97.45%</td>
<td></td>
</tr>
<tr>
<td>Af/At</td>
<td>5.76%</td>
<td></td>
</tr>
<tr>
<td>Sp/St</td>
<td>7.27%</td>
<td></td>
</tr>
<tr>
<td>Nj/Nt</td>
<td>1.12%</td>
<td></td>
</tr>
<tr>
<td>Ssw/St</td>
<td>3.23%</td>
<td></td>
</tr>
</tbody>
</table>

Tab 5.1.1b IMM analysis, Proximity values:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LSw/LSt</td>
<td>32.10%</td>
<td></td>
</tr>
<tr>
<td>Lnm/Lt</td>
<td>97.70%</td>
<td></td>
</tr>
<tr>
<td>Af/At</td>
<td>7.84%</td>
<td></td>
</tr>
<tr>
<td>Sp/St</td>
<td>5.21%</td>
<td></td>
</tr>
<tr>
<td>Nj/Nt</td>
<td>5.50%</td>
<td></td>
</tr>
<tr>
<td>Ssw/St</td>
<td>2.98%</td>
<td></td>
</tr>
</tbody>
</table>
Porosity

Proximity is the superimposition of the Volume and Voids layers. Porosity value is strictly related to the morphology of the area. In this case due to area density and due to the project willingness the morphology has not be changed that much. In close the only relevant difference is the number of groups that has risen to 5, while previously were 3. On the other hand the final input is still very close 96% instead of 98%, as consequence of high density of the site and of an homogeneous morphology of the urban patten.

5.1.3 Conclusion

The retrofit analysis has shown results in coherence with changes carried on in the masterplan. In detail due to the high density and the slope percentage of the site it was difficult to implement remarkable changes. Moreover, it was a willingness of the project avoid massive relocations inside the neighborhood. The design choice were focused on improving the functions and mobility network. In fact the area 3 has become, as shown by the analysis a new functional pivot for the neighborhood as well a new transportation node where both the internal public transportation network, the bike-sharing system, an the existing one, the bus line, are connected.
Volume: 30.5%
Surfaces: 62.3%
COV (%): 69.5%
FAR (%): 38.9%
DISTRIBUTION: 98.0%
NB: 63.1%

Porosity:
- Intervention area
- 1 floor (3 m height)
- 2 floor (6 m height)
- 3 floor (9 m height)
- 4 floor (12 m height)
- 5 floor (15 m height)
- 6 floor (18 m height)
- 7 floor (21 m height)
- 8 floor (24 m height)

Pic 5.1.10 IMM analysis, Porosity state of art;

Tab 5.1.2 a IMM analysis, Porosity values;
Tab 5.1.2 b IMM analysis, Porosity values;
5.2 Indicators: state of art and retrofit comparison

Pic 5.2.1 Indicators;
Indicators

Integrated Modification Methodology (IMM) agrees on the basic principle of the System Theory that states that a system’s performance is rigorously ruled by the patterns of interconnection between its parts. Therefore it is necessary to outline a comprehensive framework for redefining and modelling the integration mechanism of the urban subsystems and formulating the relationship between the structural arrangements and the system’s performing manners. In consequence, the IMM, horizontal and vertical analysis, relays on a framework of more than 100 indicators. The latter had been outlined by the IMM DesignLab according with the 2030 Agenda for Sustainable Development, that was adopted by the General Assembly on 6 July 2017 (ONU). Among 17 set goals, the 11th is focused on cities and human settlements with the aim to making them “inclusive, safe, resilient and sustainable”. Therefore, the SDG 11 was integrated with the IMM list. Finally, a specific list of SDG indicators has been developed. This final list is able to describe the energy and environmental performances of a city seen as a Complex Adaptive System.

Collecting the data

The IMM indicators has to be translated in data inputs. To defines those parameters, the IMM DesignLab had chosen to adopt the same logic behind criteria used by the World Business Council for Sustainable Development for the Sustainable Mobility Project 2.0 (SMP2.0).

Hence, four of the five different methods reported in the SMP2.0 had been used to define inputs:

- Input data for parameter calculations, based on field’s measurements;
- Population surveys (e.g. asking transport users for their average commuting travel time);
- Data stored in existing databases and directly available;
- Data that need some geographical analysis (e.g. calculating the length of motorways in the city based on maps) by specific software (geo-graphical information systems - GIS - software packages).

Seen the informality of the context, it is difficult to rely on official data for all the voices reported on the list. Nevertheless, the majority of the information was provided by analysis performed with specific software.

Organizing the data

The analysis data are collected in a spreadsheet file of 135 indicators. Each indicator has different characteristic which identify the information and allow an easier comparison among them. In detail, each indicator has three main properties:

- DOP family, associated with the IMM Design Ordering Principles;
- Key Category, associated with the Vertical Investigation analysis;
- 2nd level of integration, associated with the determinant macrofamilies influencing the performances of the CAS: Compactness, Intricacy, Connectivity, Governance plus Management.

Due to the informality of the context, from a pool of 135 indicators, it was possible to obtain data on 47 of
them. Priority was given to indicators about the 6th DOPs family (Cyclability and Walkability) and about Interface property (Vertical Catalyst). The most reliable data were the impartial one referred to objective sources as geographical data. The results are shown below.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Actual CAS Performance (Output)</th>
<th>New CAS Performance (Output)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ground Use:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Urban Built density. Building Volume Density</td>
<td>136.051549</td>
<td>140.742982</td>
</tr>
<tr>
<td>c) Number of buildings per hectare</td>
<td>5866.63664</td>
<td>5829.10518</td>
</tr>
<tr>
<td>e) Street Cover Ratio (SCR) %</td>
<td>4.12%</td>
<td>3.20%</td>
</tr>
<tr>
<td>h) Solar energy potential of a given area</td>
<td>1700</td>
<td>1700</td>
</tr>
<tr>
<td>3. Multiplicity and Variety:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Ratio between numbers of residents and activities*</td>
<td>833.67</td>
<td>276.11</td>
</tr>
<tr>
<td>c) Job/housing ratio (%)</td>
<td>1.1%</td>
<td>5.5%</td>
</tr>
<tr>
<td>4. Urban biodiversity:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>i) Proportion of the resident living 300m of a park</td>
<td>0%</td>
<td>0.00%</td>
</tr>
<tr>
<td>n) Indication of vegetation cover in overall area</td>
<td>3%</td>
<td>3.000%</td>
</tr>
<tr>
<td>5. Green Spaces:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) a) Lawn Cover Ratio (LCR)</td>
<td>0.13818961</td>
<td>13.82%</td>
</tr>
<tr>
<td>b) Extent and number of parks (%)</td>
<td>0%</td>
<td>0.00%</td>
</tr>
<tr>
<td>f) Percentage of Residents within Walking Distance of a Recreation Area %</td>
<td>0.00%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

### 6a. Cyclability:
- c) Number of bike parking spots: 0% | 0.60%
- d) Bike Sharing: 0% | 0.60%
- e) Percentage of daily trips by bicycle: 1.82% | 4.00%

### 6b. Walkability:
- a) Number of key function in a walking distance from residential buildings: 8 | 12
- b) Car free or minimal car traffic streets: 0.039 | 0.039
- c) Percentage of daily trips on foot: 57% | 57%
- d) Pedestrian street paths (%): 97% | 98%
- i) Sidewalks that are lined with continuous ground-floor activity in a given area (%): 24% | 42%

### 7a. Urban flow (people)
- c) Inhabitants living within 300m from public transport,%: 56% | 87%
- d) Length of roads per capita. Road Ratio: 0.61 | 0.68
- h) Number of cars owned by urban residents: 12% | 12%
- i) Motorcycles per thousand inhabitants: 58 | 58
- l) Total number of journeys by public transport: 39% | 39%
- p) Average duration of a public motorised trip: 44 | 44
| a) Average duration of a private motorised trip | 22  | 22 |
| r) Length of reserved public transport routes per urban hectare - road modes | 0   | 0.33 |
| s) Length of reserved public transport routes per urban hectare - rail modes | 0   | 0 |
| t) Length of road per urban hectare | 0.36 | 0.40 |

**9. Energy management:**

| a) Consumption per capita | 756 | 756 |
| p) Primary Energy for public lighting | 0   | 1260 |
| r) Renewables: Renewables electricity production | 0% | 3.45% |
| u) PV-power plant | 0   | 64865 |

**10. Food management**

| a) Food needed daily | 657.763 | 653.555 |
| b) Amount of urban farm production per person | 0   | 0.195 |
| c) Extent of municipally organised plots for cultivation | 0   | 0.026 |
| d) Retail Food Environment Index | 0   | 2 |
| g) Access to stores that provide healthy foods and/or that accept government food assistance programs | 0% | 100.00% |
| l) Access to community gardens | 0% | 0.04% |

**11. Waste management:**

| a) Amount of solid waste produced | 17.507 | 17.395 |
| b) Rate of waste recycled* | 30.05% | 48.86% |
| c) Rate of materials coming from re-cycling | 0 | 17.25% |

**12. Water management:**

| c) Runoff coefficient | 0.7 | 0.55 |

Tab 5.2.1 Indicators state of art and retrofit;
Conclusion

The indicators analysis show results in coherence with the IMM investigation results. Due to the topography and high density of the site was not possible to implement remarkable changes all over the area. On the other hand, the project site, has high potentiality to be a new pivot node for the favela as already spotted on the previous global analysis carried out during the Polimi para Rocinha project. The area has a strategic location since is close to the Estrada da Gavea and consequently has access to various services as well to public and private transportation networks. Therefore it is in a strategic position to connect the residential neighbourhood above which is served only by the Rua 1 and consequently is isolated from the majority of functions and public services included the transportation network. The urban action are focused on the creation of a functional and transportation node that serves not only the neighborhood facing the Rua 2 but also, through the creation of a direct connection between Rua 2 and Estrada da Gavea to Rua 1 on the top part, the residential neighbourhood. Finally, the indicator analysis shows that the most relevant changes have been carried out improving in the key categories functions and transportation, meanwhile voids and mostly volumes didn’t change. In general functions in the area have considerably increase, in fact the ration between residents and functions has increase between 2 and 3 time. Moreover, the number of key functions has considerably increase from 8 to 12. Not only the number of key function has increased by also the accessibility to public service, in face on the state of art the key function are only food markets and waste collection points. On the retrofit masterplan vital functions as educational facilities has been added. Public transportation has become more accessible thanks to the introduction of a new connection which reduce the time from 20 minutes to less than 5 to reach the main transportation services and to the implementation of a connection with the new bike-sharing network. The number of inhabitants living in a walkable distance from public transportation has increased from 57% to 87% as well as the values about cyclability. Improvements are also reported on the energy management, thanks to the implementation of the PV panels smart grid and about the food supply. About the latter, small improvement are reported due to physical lack of space where implement urban farming practices.
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PART 1: RESEARCH

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