For the last few years, a big increase in the Brazilian Real Estate Market, together with Government’s program resulted in a great demand for popular buildings. To fulfill the demand of building with lower costs, a very used system is the structural masonry. The highly competitive and demanding market required differentiation in the apartments, thus making development of projects with some flexibility, such as: openings for pass-through, kitchen balcony, hydraulic walls, and enlarge living rooms. These flexibilities brought the use of non-structure walls or even of taking out a whole wall. This has to be considered in the designing of structures and has direct consequences in its behaviour. The purpose of this paper is to present and compare the consequences of architecture flexibility in masonry structure designing for load distribution, wall resistance, use of materials and the interference in foundation. The procedure used in this work is a computational simulation of a structural masonry project in CAD/TQS Alvest system for a five floor building with four two-bedroom apartments in each floor. Three different situations were considered: architecture with no flexibility, with little flexibility considering an opening for a kitchen balcony, and a greater flexibility taking out a wall to enlarge a living room and to make a hydraulic wall. The results show that all flexibilities cause changes in project; however the ones that are considered small are diluted in the cost of the project, while the greater ones increase significantly and make great impact in the final cost of the structure.

Keywords: Design, masonry, architecture flexibility

Theme: Structural design

INTRODUCTION

For the last few years, there was a major growth in the Brazilian Real Estate Market, which along with the governmental programs resulted in a great demand for popular buildings.

In order to satisfy this increasing demand for low-cost constructions, there is a very popular system called structural masonry. This construction process successfully satisfied, and still does, the challenge of building houses and housing buildings within the deadline, with quality and low costs.

The early stages of a project are crucial for the evaluation of the technical and economical feasibility of a venture.

According to Hino & Melhado (2001), the importance of early stages of the process is evident and among such stages is project itself, as per Figure 1, adapted from the Construction Industry Institute – CII (1987).
The decisions made in the early stages of the project are the ones with greater influence potential on the final cost of the venture.

One of the initial stages is the definition of the architecture and construction. The architectural project is the reference base for the other projects that will arise from it.

However, for the constructive system in structural masonry, which consists of walls and which construction and dimensions need to be modular, the architecture and the structure are intrinsic and must be conceived jointly and collaboratively.

For the conception, one must consider the technical aspects of the constructive system, in addition to the economical aspects and those of user comfort and well being, always respecting the limitations of the state and municipal codes in effect.

A deficient project shall imply damaging effects on the totality of the construction. Such effects might occur as reductions in the venture’s markup, loss of the efficiency of certain technical construction criteria and even severe pathologies, which can become, in a large scale, condominiums that consist of several housing units.

The tough competition between the building companies and the market demand for differentials in the apartments in order to attract consumers, forced the development of projects with certain architectural flexibilities, such as: openings for a pass-through; kitchen balcony, hydraulic walls, 9-cm-thick walls for area maximization; and widening of rooms.

These flexibilities imply wall removal or use of walls with no supporting purpose, which must be considered in the structural project and bring direct consequences to its behavior.

The study aims at presenting and comparing the consequences of architectural flexibility in the structural project for load distributions; walls resistance capacity and material consumption.

Figure 1: Capacity of influencing the costs during the steps of the venture (adapted from CII 1987 apud HINO & MELHADO, 2001)
The methodology used is the computational simulation of a structural masonry project in the TQS Alvest software for a five-floor building with four two-bedroom apartments in each floor.

**STUDY CHARACTERIZATION**

The construction under study consists of five floors, as shown in Figure 3 of the building’s façade, with four two-bedroom apartments per floor with a private area of 47,0 m² per unit, as per the layout presented in Figure 2 and architectural floor plan Figure 4.
For the floor, 10-cm-thick floor slabs were considered, which are simply placed over the masonry.

The coverage is built with fiber-cement roofing tiles and with a ledge around the construction’s entire outer perimeter reaching a height of 1,2 meter.

The wind effect on the construction was not considered. The loading selected is presented in Table 1.

**Table 1: Loading used in the processing of the structure**

<table>
<thead>
<tr>
<th>Floor</th>
<th>Self-Weight (KN/m²)</th>
<th>Permanent overload (KN/m²)</th>
<th>Accidental overload (KN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>0,250</td>
<td>0,150</td>
<td>0,080</td>
</tr>
<tr>
<td>Coverage</td>
<td>0,250</td>
<td>0,150</td>
<td>0,050</td>
</tr>
<tr>
<td>Stairs</td>
<td>0,300</td>
<td>0,300</td>
<td>0,080</td>
</tr>
</tbody>
</table>

The structural walls are 14 cm thick and their self-weight is equivalent to 6,37 KN/m.

The headroom is 2,6 m. And the height from floor to floor is 2,7 m.

The projection area is 208,9 m².

The simulation considered the architecture with no flexibilization, with mid-size flexibilization comprising an opening for a countertop and with major flexibilization with the removal of a wall for widening the room and considering a sealing wall for hydraulic purposes, as schematized in Table 2. The structural walls removed or changed for sealing are presented in red for enhanced visualization.

**Table 2: Schemes of the models used with characterization of structural walls.**

<table>
<thead>
<tr>
<th>Name of the model</th>
<th>Schematic plan</th>
<th>Characterization of Flexibilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALVI</td>
<td><img src="image" alt="Diagram" /></td>
<td>All structural walls</td>
</tr>
</tbody>
</table>
RESULTS ACQUIRED
After the modeling of each situation presented in Table 2, the results were acquired for the masonry tensions, and for the results analysis the ground floor tensions are presented in the Table 3.

Based on the wall tensions and the resistance of the blocks, the grouts were sized.

The sizing of grouts was carried out as set out by the Structural Masonry Calculation Standard for Concrete Blocks – NBR 10837 (ABNT, 1989).
A block resistance of 4.0 MPa was used with 80% efficiency between prism and block.

Only the numbers of grouts required for increasing the resistance of the wall was surveyed. The constructive grouts were not considered in this survey.

**Table 3: Comparative analysis of the results between models**

<table>
<thead>
<tr>
<th>Models</th>
<th>TENSIONS (KN/m²)</th>
<th>Linear length and area of the structural walls</th>
<th>Grouts of ground Floor</th>
</tr>
</thead>
</table>
| ALV1   |                  | L = 14,3m  
Area = 37,3m² | No of Grouts = 5  
Vol = 0,17 m³ |
| ALV2   |                  | L = 13,1m  
Area = 37,3m² | No of Grouts = 17  
Vol = 0,59 m³ |
| ALV3   |                  | L = 13,9m  
Area = 36,1m² | No of Grouts = 5  
Vol = 0,17 m³ |
| ALV4   |                  | L = 12,6m  
Area = 32,8m² | No of Grouts = 47  
Vol = 1,63 m³ |
By comparing the results of the tensions on the walls of the ground floors with the ALV1 situation, in which all walls are structural, it is possible to note that there was a variation in the tension values on the walls, which consequently require a greater number of grouts.

The tensions compared were on the walls that have endured greater changes as a function of new load distributions with the flexibilizations suggested and they are presented in the Table 4.

### Table 4: Comparative Table

<table>
<thead>
<tr>
<th>Model</th>
<th>Percentage of added tension</th>
<th>Nº Grouts</th>
<th>Wall length/Projection area</th>
<th>Flexibilization Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALV1</td>
<td>Reference</td>
<td>5</td>
<td>0.0685</td>
<td>With no flexibilization</td>
</tr>
<tr>
<td>ALV2</td>
<td>10% to 20%</td>
<td>17</td>
<td>0.0627</td>
<td>Major</td>
</tr>
<tr>
<td>ALV3</td>
<td>5%</td>
<td>5</td>
<td>0.0665</td>
<td>Small</td>
</tr>
<tr>
<td>ALV4</td>
<td>10% to 15%</td>
<td>47</td>
<td>0.0603</td>
<td>Major</td>
</tr>
<tr>
<td>ALV5</td>
<td>20% to 35%</td>
<td>89</td>
<td>0.0527</td>
<td>Major</td>
</tr>
</tbody>
</table>

The simulations studied show that all flexibilizations proposed are structurally feasible. It was possible to size all walls with the same resistance of 4.0 MPa blocks.

Some of them considered small, such as the kitchen’s pass-through (Model ALV3), do not result in major alterations; due to the results acquired, the increase of wall tensions were absorbed by the resistance of the block used.

Nevertheless, the flexibilizations for enlarging the living room (Model ALV2) and the kitchen’s hydraulic wall (Model ALV2) resulted in the increase of wall tensions with an expressive amount of extra grout spots.

With all flexibilizations performed jointly (Model ALV5), the walls tensions increased expressively and therefore require many more grouts. For this situation, the resistance of the concrete block should already be increased.

**CONCLUSION**

Although all flexibilization options are structurally feasible, as a result, they require more grouts and the addition of grout spots is always inconvenient for the construction process.
The ideal process for a decent grouting is the implementation of an inspection window at the base of the wall for cleaning the residues of materials that fall into the hole of the block during the construction of the wall, trussing (when required), pour the grout at the wall’s half height, proceed with the vibration of this grout and then repeat the process in the second half of the wall.

Therefore, there was an interruption in the wall construction productivity, in addition to introducing another element, the grout, for implementing the effective technological control.

All flexibilizations cause project alteration; however, the ones considered small can be diluted in the cost of the venture, while the major ones imply substantial increases in the structural levels and will consequently influence the final cost.

Structural masonry is a construction system that must be analyzed jointly with several subsystems, therefore, in addition to the consequences produced by the flexibilizations to the structural aspects, it is also relevant to analyze the other subsystems involved in the process, such as the installations that must be projected for several flexibilization situations, the attention during the project implementation, since there will be different plant options and the post-occupation maintenance.

These aspects are hard do size for they involve the loss of labor productivity in view of the differences and implementation options. There is also a greater risk of errors during the implementation.

The concern of post occupation lies on the management of future improvements to structural masonry buildings and the potential removal of any structural wall along with sealing walls.

There is a cost of superposing the activities that harms the development of the project. This superposition, which consequence is labor productivity loss, is not evaluated and calculated in the budgeting and planning steps and is often concerned as a labor attribute, when in fact, the deficient planning as a consequence of the flexibilizations ends up eliminating the potential of an employee to have a linear and repetitive activity.

The feasibility feedback of masonry constructions with and without flexibility has shown that the major flexibilities not only render the structural masonry system unfeasible, but are also responsible for a system reproach, which is then blamed for the excessive feasibility cost. According to the aforementioned, it is valid to substantially evaluate if the decision making process of the venture’s feasibility to offer the options of sales plants to the consumer market with architectural flexibilizations really adds a lot more value to the product than it increases the costs involved with the structure and the direct costs that are difficult to size with the control of the implementation.

Nevertheless, it is common sense that any type of flexibilization, either small or major, must always be set out in the project and defined in the early stages of the project.
BIBLIOGRAPHIC REFERENCES


