Use of 3D printing in repairing construction damages in social houses.

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Abstract. This investigation proposes repairing mechanical damages in recoverable social houses, with reinforcement concrete, especially in vertical and horizontal areas. The design of this study includes 3D detection of the damages with images that create a 3D photogrammetry to create a reliable piece close to reality to be printed in 3D concrete to replace the damaged piece finally. This investigation aims to prove the feasibility of this kind of replacement and, if possible, to generate an automatized system of repairing social houses.

Keywords: 3D printing, A qualitative Deficit of social houses, Mechanical damages, Point cloud, Mesh.

1 Introduction

This paper explores the possibility of repairing mechanical damages using 3D printing technology in the context of the housing deficit in Chile. According to Housing Foundation, the deficit is the number of necessary houses to satisfy the population's needs, divided into quantitative and qualitative groups (Fundación Vivienda, 2018). This study focuses on the last group, which includes houses with recoverable material and bad shape conservation, to find solutions using new technologies from the AEC industry.

In 2020 and 2021, NGO 'Un techo para Chile' mentioned that housing precariousness forces some people to live in illegal settlements. This situation shows a housing deficit and a lack of housing for the most vulnerable population (TECHO,2021). In this context, the Chilean Chamber of Construction states that there are approximately one million 450 thousand homes with high deterioration in Chile, which underlines the importance of improving these homes to prevent the situation from worsening (CChC, 2022).

Regarding the damage inside the recoverable houses, in 2019, the Chilean Chamber of Construction published a study called "Housing and Urban Environment Balance," which detailed the housing requirements due to deterioration. A materiality index was created to classify housing, which made it possible to identify possible cases of study and determine whether they are "recoverable" housing (CChC, 2019), meaning that in some cases, it shows mechanical damages such as fissures, cracks, or detachment of material due to external mechanical stresses (Broto, 2005). The manual of reinforcement and repairs of MINVU is also considered a valid reference to characterize pathologies and mechanical injuries, specifying the steps to replace concrete elements and make repairs (MINVU, 2018).

In this context, the study pretends to investigate and experiment with 3D printing technology to repair damaged concrete elements in houses.

3D printing is based on extruding two-dimensional layers previously generated virtually that form three-dimensional parts (Teizer, 2016). The material, driven by a pump, is ejected through a nozzle, directly establishing the concrete's printability, shape, and fluidity (Shakor, 2019).

Concrete manufacturing in 3D printing has advantages like computational control of sections and fast production of previously designed parts (Teizer, 2016). However, 3D printing has challenges, especially in the maximum time to print a part, since the material dries during the process. Also, there are size limitations because of the dimensions of the 3D printers used (Wu, 2016).

Furthermore, several studies have been made regarding 3D printing technology, including academic investigations that have produced and analyzed parts separately, such as walls, foundations, columns, floors, slabs, and roofs (García-Alvarado, 2021). Also, big projects have been carried out, such as the case of Winsun in China, which successfully built a 200m2 housing complex in Shanghai (Yuhong, 2014), showing the potential of this technology on a large scale.

Due to the mentioned advantages, this investigation considers the hypothesis that this technology could be useful in repairing concrete houses.

Despite the progress and testing in the creation of separate parts in projects of contributions of houses, at this moment, the use of 3D printing has not -to our knowledge- been considered as a technology for repairing concrete injuries or concrete elements to date. This situation presents an opportunity to investigate an experiment with this technology to repair concrete elements.

Thus, this work intends to conclude if it is possible to capture accurate information to create a part that replaces mechanical damage. Our main objective is to study and propose a workflow that links different technologies to repair architectural elements affected by mechanical damage.

For this purpose, it has been chosen to focus on a real case study, a building called "El Buque" in the commune of Pedro Aguirre Cerda in Santiago de Chile, where it will be evaluated and selected some of the existing mechanical injuries in the vertical and horizontal circulation cores, because of its easy accessibility.

2 Methodology

The design of this investigation has six steps, as follows:

Figure 1: investigation steps

2.1 Study casa election

The co-ownership "El Barco," in Pedro Aguirre Cerda communne, Santiago, Chile, was selected owing to diverse pathologies related to the mechanical damages defined for this investigation. The structure of the building is made of concrete, and there are concrete detachments and visible rebars in the horizontal and vertical circulation areas.

2.2 Interviews

Several interviews were made with experts to validate the development of the several steps of the investigation. The first meeting was with a specialist in social housing. After that, meetings were held with construction experts. Then, a specialist in photogrammetry and 3D laser scanner was also contacted. In addition, meetings were planned with professors specialized in 3D modeling and digital printing: for the use of Rhinoceros and Grasshopper, 3D printing, Rhinoceros. These interviews with experts made it possible to validate and obtain specific knowledge for each research stage.

2.3 Evaluation and study case.

Three visits to the case study building were completed to capture images and create photogrammetries. The first visit focused on identifying the main damages in the co-ownership. Three mechanical lesions were selected in this process, and preliminary photos of them were taken. The following two visits allowed us to capture more photos and improve the development of the photogrammetries. During this time, a meeting was held with a specialist in photogrammetry, thus obtaining a guide in photogrammetric detection and calibration with Agisoft software.

These injuries were selected due to the deterioration of the existing concrete, which caused the rebars to be exposed and unprotected. Since the country is in a seismic zone, studying ways to repair these injuries is very important in Chile, making this reinforcement crucial. As mentioned in Chilean 430 Official Normative, minimum coverings are required for the rebars for three main reasons. First, to ensure the transfer of stresses from the reinforcing bars to the concrete, which contributes to the strength and stability of the structure in case of loads. Secondly, to protect the reinforcement against corrosion since it is exposed and susceptible to environmental elements and corrosive agents. Finally, it is to protect the reinforcement against the effects of fire, creating a retardant effect that works as a thermal barrier and slows down the heating of the reinforcing bars.

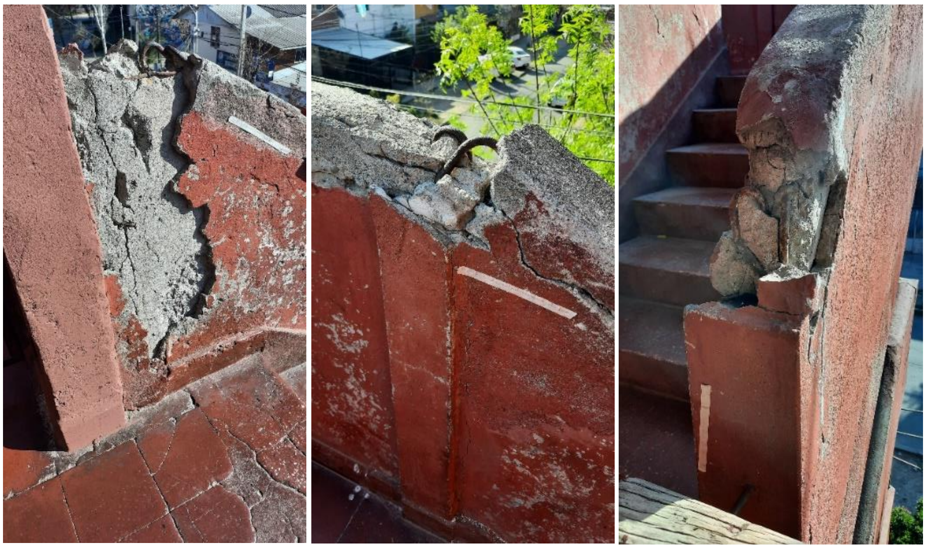

Figure 2: Photos of the three study cases

2.4 Photogrammetries

During the second visit to the building "El Buque" approximately 70 to 80 photographs were taken to process each lesion in Agisoft. After doing the first detection, due to the lack of accuracy of some photos, the process had to be repeated due to errors and inconsistencies within the first photogrammetries. During the third visit, a new round of photos was completed for each case of lesions, and thus a more reliable result after processing the images in the program.

Subsequently, several attempts were developed to create a solid from the mesh generated in Agisoft. The polygon mesh generated in Agisoft was only a surface, not a solid. This mesh was then exported to Rhinoceros to begin exploring ways to create a closed volume that could be used for 3D printing. This process was unsuccessful, so help was sought through interviews with professors who were experts in 3D modeling and 3D printing.

2.5 Creation of models

Three models were created with a 3D printer using thermoplastic filament to analyze in each case how the ties and fittings would go and the size of the parts concerning their section.

The first case represents a handrail lesion with an ascending shape. The second case represents a lesion that spans an initial ascending section and then extends horizontally. Finally, the third case shows a lesion that is vertical in shape.

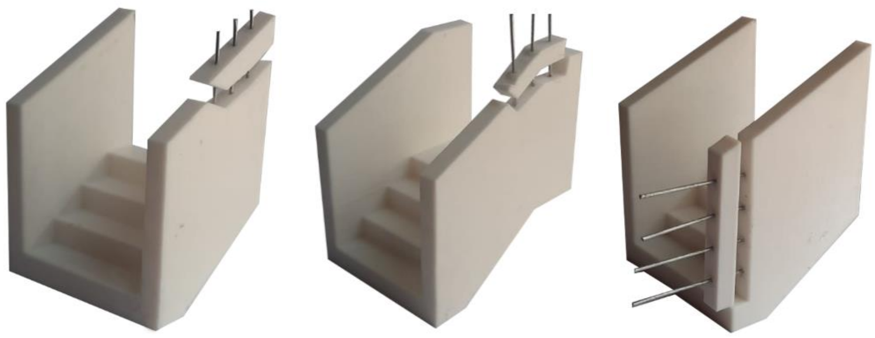

Figure 3. Models of study cases.

2.6 Workflow

To complete the workflow, it was first proposed the creation of the model from negative to solid generated from the mesh exported of the photogrammetry process. On the other hand, there was an essential question about the composition of the mixture to be considered in this process.

In this context, three meetings were conducted with experts to solve doubts. The first meeting focused on analyzing the final solution for the attachment of the printed part to the main damaged structure after its regularization. Furthermore, it was defined that all selected lesions must be self-supporting to be repaired with the proposed method.

After that, in the second meeting, it was decided to incorporate filaments into the mixture and anchor the previously created part to the damaged structure with rebars.

Finally, in the third meeting, with the collaboration of a 3D printing expert, various options were explored to define an optimal design solution for the harmful mold. This phase would complete the entire process, as proposed in this investigation. As a result of these discussions, it was agreed that the last step regarding the design process would involve modeling the remaining section of the lesion on the mesh generated in the photogrammetry software.

3 Results

Below, figure 4 presents the results of this work, summarized in a workflow that shows the methodology developed to capture and solve mechanical damages in cement constructions and how to repair them using 3D printing. Next, it is explained each step and its development in the workflow.

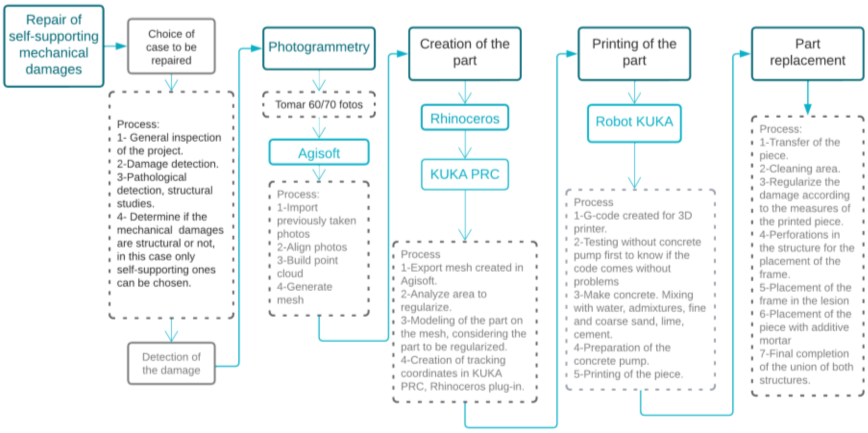

Figure 4. Workflow.

3.1 Selection case to repair

After choosing the case with its difficulties in concrete, begins the phase one of evaluation, which has four steps: general inspection of the project, damage evaluation, pathological detection, and structural studies, defining whether the damage is structural or not.

3.2 Development of photogrammetries

Afterward, to complete the evaluation of the case to repair, the photogrammetry detection of the damage selected must be completed. The ground must have measurements to accomplish such detections in fieldwork. In this study, we use paper tape with measurements every ten centimeters. This method is helpful to scale the photogrammetry.

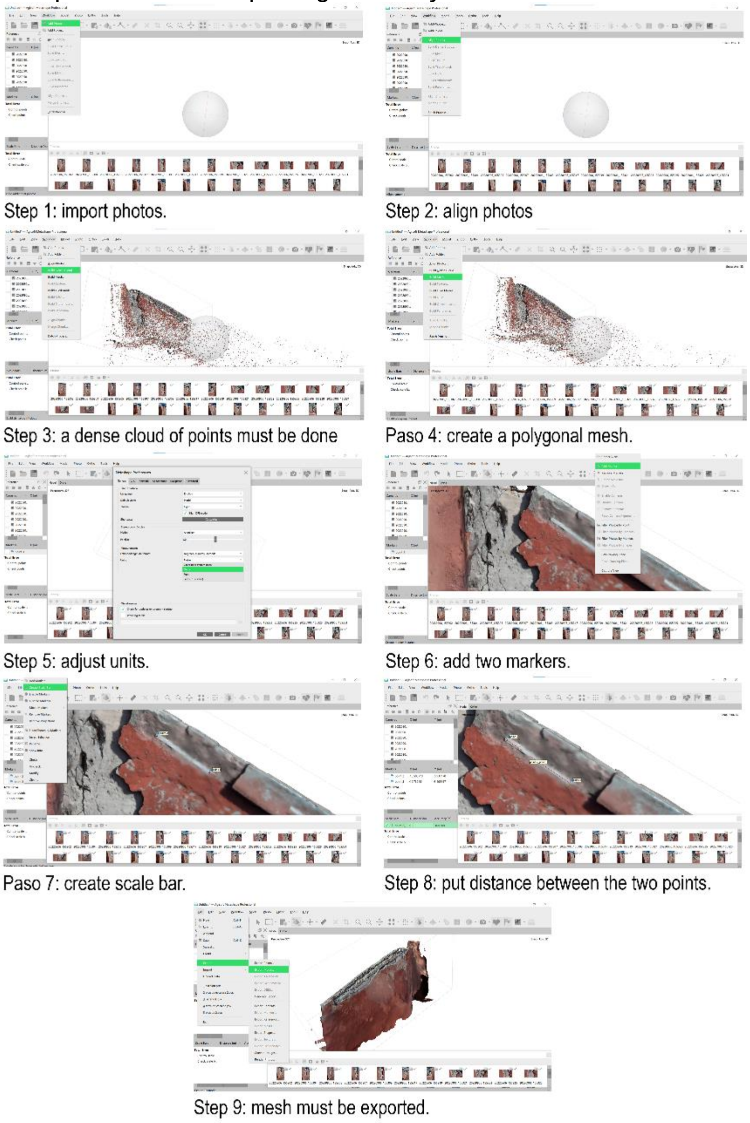

Figure 5. Workflow.

As can be seen in the image, the photogrammetry construction process has nine steps. First, field photos must be imported. Second, the photos must be lined up. Third, a dense cloud of points must be done. The fourth step is to create a polygonal mesh. Although after executing this process, the polygonal mesh is already closed, it does not have any scale or measure; that is why in step five, the units of measurement are adjusted in meters, and in step six, add two markers to create a scale bar in step seven. Step eight adds the distance between the lines within the markers. Finally, in step nine, the mesh must be exported to create the part in Rhinoceros.

3.3 Creation of the part

After creating a polygonal mesh in Agisoft, it must be exported to Rhinoceros. The polygonal model must be analyzed in the area to be regularized. Afterward, the part must be modeled on the mesh, according to the part to be regularized. To connect the part to the structure, it must include perforations both in the printed part and in the final area to repair, with rebars to secure the final ensemble. Finally, with the plugin KUKAprc, who translates the routine to KRL.

3.4 Printing of the part

3d model generates a printing code, which follows the part's printing. Several tests must be done without the cement pump connected to confirm no code failures in the process or incomplete movements of the robot. An operator does this with the commands. In parallel to this process, the morter must be prepared, which contains water, additives, fine sand, coarse sand, cement, and lime. Then, all these elements must be put in the cement pump, which a nozzle at great pressure will expulse. Finally, the pump is connected to the robotic arm and attached to the printing mouthpiece added to the arm's end to begin the printing process.

3.5 Part replacement

To complete the repair, the area to be repaired must be clean, and the damage must be regularized based on the previously created part, drilling the areas to include the rebars, moving the printed part to the place of repair, attaching the part to the base with cement and additives, and finally the ensembling both parts so that they work together.

4 Discussion

This investigation has allowed us to acquire knowledge, and propose a workflow, to capture and repair structural damages in buildings. Also, the successfully exported polygonal mesh was reached from Agisoft toward

Rhinoceros. Such achievements consisted of modeling over the polygonal mesh using this one as a reference.

Nevertheless, it has been identified that improving areas for the workflow model proposes. This area includes optimization of speed in the creation of parts, creation of samples based on regularization of the mesh generated previously in the 3d model, improvement in the technological capabilities of the cement 3d printer to print multiple parts, and experimentation with different sizes of nozzles. Also, printing several parts simultaneously can be studied after solving the pump problem in reabsorbing material.

In addition, we suggest creating a catalog of damages, which will allow a faster repair process in similar cases.

Another crucial aspect could be the investigation and experimentation with different types of nozzles in printing parts, which defines the layered dimensions.

All these improvements and considerations could help optimize the proposed workflow in future development, assuming each step according to its own challenges.

Finally, it is considered necessary to mention the challenges that appeared for the lack of advanced knowledge in modeling techniques, specifically with Rhinoceros or other modeling tools. This limitation complicated the generation of a harmful mesh mold which would have allowed us to obtain a precise representation of the part from the mesh. If this barrier is overcome, greater fidelity in part creation and improved accuracy in the proposed workflow model will be achieved. In addition, continued advances in material and nozzle experimentation for 3d printers could contribute to producing highly true-to-life parts.

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