REFLECTION

Robotic Restoration

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Graduation process

Position of graduation topic within the studio

My graduation thesis aims to explore and develop 3D printable gypsum mixtures in combination with an in-situ Additive Manufacturing process for the restoration of stucco ornaments. The thesis topic falls within the domains of Design Informatics & Digital Fabrication and Heritage & Technology. Hence mentors from each of these tracks are involved in this research to provide knowledge and guidance from their respective fields of expertise. Although, the Heritage department is not widely involved in the Building Technology Master track, I have found throughout my time working on this thesis that it is closely related and there is a lot to gain for both departments by working together on research projects.

The material exploration part is conducted with knowledge from material science, by studying technical aspects of conservation technology and with the hands-on approach taught to every Building Technology student in the Bucky Lab. Knowledge and experience gained from several courses taught by staff of Design Informatics department helped forge a solid base in computational design and robot programming. Throughout the thesis, these skills have been built on and improved. The thesis also presents paths for further investigation, relevant for both domains.

Research approach

The research approach combined literature research with practical testing in an iterative process to improve the designed 3D printing material and various 3D printing components. This approach is in line with the general approach of developing 3D printing technologies and is adopted within the department of Design Informatics.

To assist in making informed decisions for each iteration of the printing material design, a decision making model was set up, based on a cumulation of various literature research results. This method worked well initially, as observations made post-testing could be easily translated into measures of improvement through the decision making model. However, when multiple improvement measures would be taken, the efficacy of each individual measure would be difficult to assess in some cases. This could be due to a limited sample size or the lack of certain tools or equipment, which could have been to a certain degree avoided if the experimenting could have taken place in the laboratories of the university.

The latter part of the research was intended to be conducted in the Laboratory for Additive Manufacturing in Architecture (LAMA) at faculty of BK. However, due to measures taken to contain the spread of the worldwide Covid-19 outbreak, access to the lab and robot was no longer available. The thesis could have given better usable data for further studies on the topic of in-situ Additive Manufacturing with gypsum-based mixtures if the dependency of such facilities could have been avoided to a larger extent. This could have been done by designing experiments which could be performed with a simple desktop 3D printer, instead of a multi-axis robot. Experiments assessing the mixtures' buildability and adhesion on inclined planes in fresh state, gave results which are expected to be on the conservative side, due to manual inaccuracies occurring during the experiments. This is also something that could be avoided by conducting the experiments with a 3D printer or multi-axis robot.

Overall, the approach worked well, and the main research question could be answered, despite the limitations due to a lack of certain equipment and access to university facilities. I would recommend for a further research to build a prototype of the proposed Restoration Robot Platform and test the setup with a case study in which a copy of an actual ornamented ceiling is restored with the

proposed methodology. Building and testing a prototype of the proposed setup at a 1:1 scale will undoubtedly reveal aspects in need of improvement, which currently cannot be foreseen.

Relationship between research and design

The thesis is conducted through literature research, prototyping, designing and evaluating prototypes and printing components. This results in an iterative, research by design approach. The literature study helped to create a methodology for making, testing and evaluating the printing material. After initial manual experiments, insight was gained into requirements for the extruder and other tools which would be needed for the printing process of the created material. The extruder designed and built to work with the designed printing mixture, was tested and parts of it were redesigned and remanufactured multiple times, based on observations made during tests. This is a good illustration of the relationship between research and design. The proposal for a Restoration Robot Platform at the end of the thesis, is fully based on research conducted on the chosen context and restoration tasks. The conclusions of the research contribute to the current understanding of Additive Manufacturing on inclined planes and thus can serve as a source for further research in this domain.

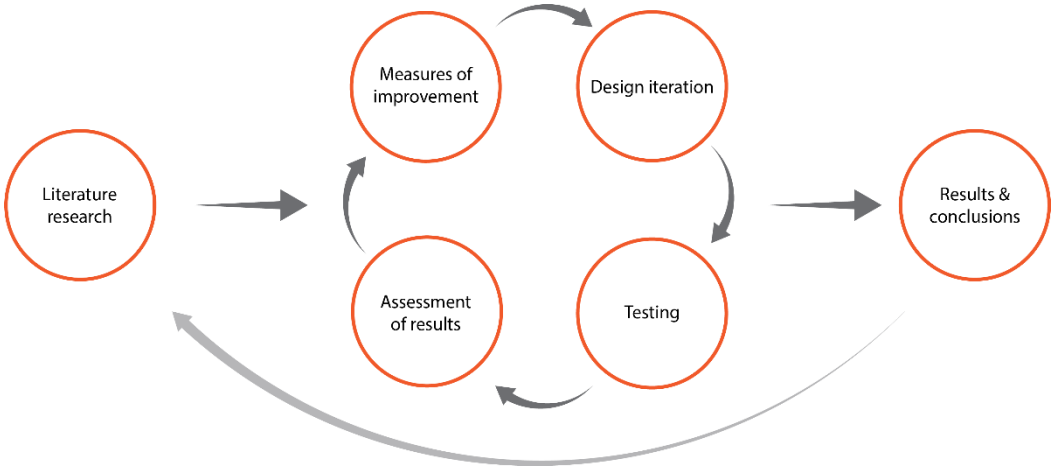

Figure 1 Scheme showing iterative design and research process. Source: Author

Societal impact

Application of results in practise

The graduation thesis concludes that restoration of stucco ornaments by means of in-situ Additive Manufacturing is a feasible alternative to current manual in-situ restoration methods. The threat of a disappearing craft of restoration plasterers can be resolved by embedding this knowledge and craft into new digital tools today, so it can be used to restore our collective cultural heritage for generations to come. The research is also translated into concrete products which could be further developed and tested to eventually be adopted in practise. The results are compiled in the form of a proposed plug-in for software used in digital fabrication in both research and practise today.

Extent of achievement of innovation

The thesis shows that gypsum-based mixtures can be developed for in-situ Additive Manufacturing with off-the-shelve products. Experiments performed with various printing mixtures show potential for the intended application on all tested aspects. Due to the sudden unavailability of a multi-axis robot for further experiments, the exact values of various printing properties of the mixtures could not be determined with great accuracy. Therefore, the projected innovation is mostly achieved, but

not fully, due to missed opportunity of testing the complete printing setup. However, the results obtained from manual experiments show the proposed restoration method is certainly feasible. It is expected that results obtained with the use of such a multi-axis robot will be much better because this would give a higher level of control over all relevant parameters in the printing process. The thesis proposes several additional experiments which can be conducted to obtain more accurate results with the use of such a robot. Various suggestions are also made for the further exploration of this topic to bring the proposed restoration technique closer to application.

Sustainability and ethics

The act of prolonging the lifespan of a building or object is inherently a sustainable act. Therefore, proposing a new method for restoration, which can alleviate the pressure on the decreasing number of restoration plasterers, fits within the current understanding of sustainable development of the built environment.

Furthermore, we see more and more labour intensive and physically demanding jobs being taken over by machines and robots across all industries. On the one hand this may be a good development, because growing pension ages demand longer years of labour from workers, whose bodies may not be able to cope with physically demanding work at later age. On the other hand, automation tends to lead to lead to more complexity in the given task, and thus new jobs in this field require people to be able to deal with this higher level of complexity. It may not be realistic to expect restoration plasterers in the future to be able to program a robot for a task they do by hand today. Therefore, efforts must be put into creating user friendly interfaces for such new automation processes in order to maintain a job market that suits people from different backgrounds and walks of life. I believe that in the case of restoration, robots will work alongside human co-workers, but will not replace them entirely. The ability to judge the value of architectural elements and conduct complex investigations will remain a task needed to be performed by restoration experts. At least for a while. The human restoration experts can do investigation work on site and set up a restoration plan, which can then be executed by their robot co-workers.

Socio-cultural and ethical impact

Figure 2 Artist impression of the construction of The Great Pyramid of Giza. Adopted From: https://www.ancient-origins.net/history/demystifying-egyptian-pyramids-hard-facts-009730

The previous paragraph describes the social- and ethical impact of the restoration method developed in this thesis. However, development of autonomous restoration robots and construction robots, as discussed in the thesis, would have an even more significant socio-cultural and ethical impact. Throughout history, an observation can be made about the decreasing number of workers on the construction site. The Great Pyramid of Giza was built by thousands of workers, doing harsh, physically demanding work, thousands of years ago (see figure 2). Today, modern constructions sites have on average 25 construction workers (Change, 2017), who can use motorized heavy duty machines to do much of the heavy lifting work. Yet the construction profession remains physically demanding and is therefore unquestionably unsuitable to be in until the age of retirement. Today's construction machines are used to replace muscle and manpower to a certain extent but cannot perform complex or precise movements or autonomously work together with other machines or workers. Not *yet*. Introducing robots which, can perform highly complex tasks with great power, high accuracy and speed, do not need lunch or toilet brakes

and could potentially work nonstop in cooperation with each other, would revolutionize the construction site like never before. Physically demanding construction work could be taken over by robots, as human workers, with knowledge of construction, may fulfil less strenuous supervisory roles on site. This may sound like science fiction, however there are already research projects which explore the idea of deploying partially or fully autonomous robots to build or repair the built environment, as presented in the final chapter of the thesis and can be seen in figure 3.

Figure 3 Rendering of digitally fabricated earth & timber housing by IAAC. Adopted from: https://iaac.net/educational-programmes/applied-research-programmes/otf-3d-printing-architecture/

Impact on Architecture and the built environment

Not being able to conserve, preserve and restore our buildings would lead to a deteriorating state of the built environment. This could mean we would lose some of our most valuable cultural assets in the built environment due to our inability to meet the demand for preservation of these assets with traditional means. The thesis presents a feasible and affordable alternative to restoration of stucco ornaments, which has the potential to fill in gaps in the absence of skilled labour in this specialized field.

The introduction of robots in architecture, can change the architectural and construction landscape and challenge current design and construction methods. For example, bricks are made in their distinct size and shape because this makes it easy for a mason to lift and place them with one hand. Architects knows this, so they design their buildings with “brick sized bricks” and therefore the aesthetics and construction process of a brick building is directly related to this traditional construction method of a brick building. Robots offer different possibilities than a construction worker. A brick building built by a construction robots, may have much larger bricks, as the robot may be much stronger than a construction worker. Or perhaps the building will no longer consist of clay in the form of discrete brick elements, but instead of continuously 3D printed clay walls (see figure 3). This can change the aesthetics of future architecture, while the possibility of using sustainable materials for digital fabrication with construction robots could also contribute to the sustainable development of the built environment and human health.