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Robotic application of foam concrete onto bare wall elements - Analysis, concept and robotic experiments

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ABSTRACT

In the course of frequently altering energy saving regulations, numerous buildings have to be comprehensively refurbished to meet the rising energy-efficiency standards in order to protect the global environment and to save resources. However, available materials as well as adaptable design concepts for additional energy-saving insulation layers are not yet convincing in terms of their long term recyclability or variation of shape. Therefore, we investigate the application of foam concrete onto bare walls of existing buildings to gain a façade finish which is highly insulating, easily recyclable and at the same time promises to be individually designable due to the properties of the raw material mixture. To ensure controllable as well as reproducible application and to react to changing working methods in architecture and construction, the research focuses on the automatized application of foam concrete using a robotic setup.

We analyzed manual application strategies of foam concrete, considering parameters of handcraft, used tools as well as the reaction on varying material characteristics during application. Based on the analysis results, we present a concept for the robotic application of foam concrete, including suggestions regarding end effectors, robot programming and surface design planning.

1. Introduction

Rising energy efficiency standards and saving regulations increase the number of building refurbishments [1,2]. The constructional implementation of these energy-oriented refurbishment processes mostly includes an optimization of the façade's external insulation often executed as External Thermal Insulation Composite Systems (ETICS) in order to reduce internal thermal loss [3]. At the same time, recycling standards for construction materials are constantly intensified attaching importance to separability of construction components into varietal raw material to increase reusability of construction material. However, recycling strategies for ETICS most frequently based on expanded polystyrene (EPS) are not fully developed [4]. And due to the high degree of material compound of ETICS, a material extraction with high purity of variety is expected to be only achievable to a minor degree.

To fulfill both mentioned regulations, we introduce the concept of a mono-material thermal insulation system based on an easily reusable as well as highly insulating mineral material. As basis material for this system we investigate the application of foam concrete using different foam concrete densities according to the layers functions. Fig. 1 depicts the structure of the system including the following layers: anchor with high density of $\leq 800\,kg/m^3$ (a), insulation with low density of $\leq 150\,kg/m^3$ (b), surface finish with low density between 150 and $250\,kg/m^3$ reinforced with specific cement suspension (c).

The depicted system is set up to be directly attached to given bare wall elements e.g. given brick walls.

2. Literature review

2.1. State of the art foam concrete

Foam concrete, also known as foamed concrete, is proposed as façade insulation layer because it is known for its excellent insulating characteristics due to its low density [5,6]. Furthermore, it is most suitable for façade application because of its higher sound absorbing rate in comparison to dense concrete [7] as well as its acceptable fire resistance [8]. Moreover, foam concrete is ecologically harmless and easily recyclable due to its mineral composition and minimal consumption of aggregate [6,9]. In comparison to similar highly insulating mineral materials such as aerated concrete, foam concrete is strain

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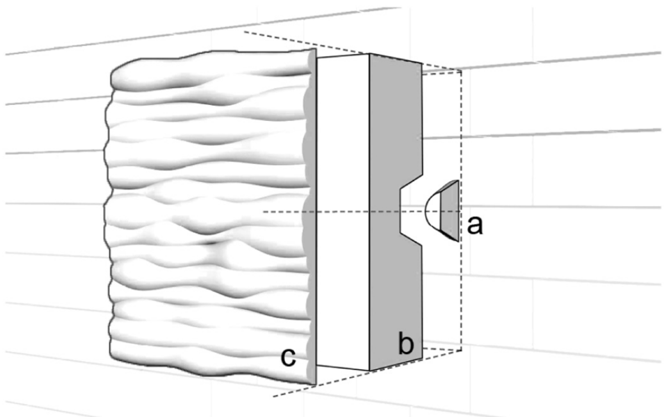

Fig. 1. Mono-material insulation system onto bare wall element: anchor (a), insulation (b), designed surface finish (c).

hardening and therefore also the production process is environmentally friendly due to its low energy consumption [9].

In addition, foam concrete is a competitive material in terms of costs. So far, no reliable study on cost comparison is published. A rough calculation of material costs according to information of local companies indicates a cost saving potential of approximately 15% using foam concrete with a density of 150–200 kg/m^3 instead of EPS based systems; even though the layer thickness using foam concrete has to be enlarged to reach the same heat transmission coefficient which EPS provides.

2.2. State of the art foam concrete application

Foam concrete is mainly applied in situ as void fill, bridge abutments and roof insulation or as prefabricated blocks or panels [9,10]. Partly, the blocks are used as insulation material in a constructional setup comparable to external thermal insulation composite systems [11]. While foam concrete with densities up to 300 kg/m^3 is well investigated [6,12] and fabricated as listed above, the manufacturing of building elements made of foam concrete with a low density about 150 kg/m^3 is not fully examined nor in common use. However, the lower the density the better foam concrete functions as insulation material due to a decreasing heat transition coefficient [12].

To base the concept of the robotic process on the current foam concrete manufacturing techniques, we analyzed the production process. Mostly, this process consists of the following four sub-steps:

1. PREPARATION: Mixing of foam agent and cement slurry separately or mixing of all ingredients at a time
2. TRANSPORTATION: Pumping of the foam concrete slurry to its destination of application
3. APPLICATION: Pouring of slurry into casting mold or locally predefined in-situ shape
4. PROCESSING: Curing

The identified sub-steps have to be generally considered for the robotic concept. However, the commonly used application process via pouring material into molds is not compatible for the generation of the finish layer. The great issues thereby are on the one hand the dependency of form generation on the geometric and constructional producibility of the mold and on the other hand the economic competitiveness of small batch sizes using individual molds which are only reusable to a very limited degree.

3. Research aim

The overall aim of this research project is the development of a system for the robotic application of foam concrete onto vertical building elements such as bare walls in the context of the explained insulation system. A particularly robotic instead of manual application is targeted to not only reduce time and costs and gain accuracy but also to meet the demands of changing architectural methods. Ongoing efforts are focused on closing the digital gap in architectural process from digital designing to on-site fabrication through robotic manufacturing [14]. Such procedures additionally allow to establish adaptable building element generation according to varying structural, physical or aesthetic demands of different parts of one building [15]. This is leading to a mass-customized and automated design to production process triggering the rapid, affordable and predictable generation of manifold building elements even of small batch sizes [16].

The work described in this paper depicts the first part of the research project, which is focused only on the application of the outer layer being the designable surface finish. Consequently, the general investigations are extended to develop a robotic system which allows for locally adjustable design of the material application. The demand for this kind of designability is due to the complexity of building envelopes. Many factors for the detailed design of this outmost layer greatly vary along the surface area reacting on the different demands of the underlying construction or external circumstances. Some of these factors are exemplary listed below:

- Varying material thickness according to differing thermal insulation demands (especially in the context of refurbishment processes).
- Distinct composition of surface shape for sound insulation of surrounding city noise.
- Assurance of rain water discharge.
- Aesthetic aspects of architectural design ideas.

4. Research methodology

Harmonizing these aesthetic as well as building physics factors is a highly complex and to a certain extend artistic task of common architectural working methods. Therefore, the research methodology of analysis, identification, generation and testing was extended by manual application experiments (Fig. 2). These experiments were carried out using sculpturing techniques of the creative industry to gain new process insights through intuitive material handling. The experiment evaluation supported the robotic process development in two respects: Since the given application process is not compatible to robotic production, firstly, the experiments were used to find suitable application techniques as well as a tool capable of handling the specific material behaviour while allowing designability during the process. This tool then serves as basis for the development of the robotic end effector. Secondly, the manual application experiments were used to analyse

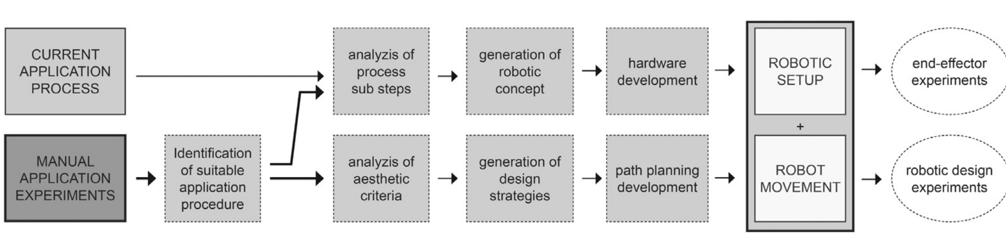

Fig. 2. Research methodology including manual application experiments as basis for development of robotic process.