Analyses of Automated Bricklaying Workflow Regarding Time and Arrangement

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Abstract. Bricklaying has been one of the determinant technologies of the construction industry for several thousand years. Even in our modern times, it is one of the most commonly used fields of building construction technologies. There are several reasons, like the lack of human resources on the construction markets or the increasing demands on both reasonably short construction time and high construction quality, the combination of which leads to consideration of applying innovative, automated technologies in more and more fields. With the spread of these advanced techniques, changes and further development on the construction site can be predicted. One of these developing fields will be presumably the field of small, solid construction units, the innovation of which would result in changes regarding the elements and the technology too. In our research, automated bricklaying construction situations are modeled by applying a robotic arm equipped with a linear rail. Some new features are analyzed at the work of using automated systems. Namely, different brick wall construction methods are tested, measured, and analyzed to find optimal solutions for the cases of various sets of influencing factors, like element placement or palette arrangement.

1. Introduction

There have been many attempts regarding the automation of construction in the last sixty years, which means applying electromechanical robots in the first place. In the construction industry, and particularly in bricklaying, the two main directions of applying robotic technology are the use of 4 or 6 axis robotic arms and large-scale robotic structures, mainly external lifting frames above the manipulation area. According to some researchers, flying robotic systems can be regarded as the third category (Sousa et al., 2016). It is a developing field with great future potentials; however, its application is far more experimental than the other two.

The theoretical background of construction automation was evaluated in the 1980ies and 1990ies already. The initiation of the ROD (Robotic Oriented Design) (Bock, 1988) has been a new approach for planning and executing buildings. The ABC (Automated Building Construction) emerged as a new way of thinking about construction automation, which involves the organization, the machinery, and the logistics of the supply chain (Skibniewski-Wooldridge, 1992). This approach leads us to the evaluations of the last decade when large-scale robotics-based constructions are considered as integrated automated construction sites (Bock-Langerberg, 2014).

As far as there are many highly repetitive tasks in bricklaying, it is one of the filed that can be automated with success. There were also many projects focusing on the automation of bricklaying in the last decades. The first attempts for such automation were maybe the early patents for bricklaying machines in the 1960ies, like the so-called “Motor Mason”, filmed in Essex (British Pathé, 1967). It was followed by some further attempts in the 1970ies 1980ies too.

In the 1990ies, the theoretical basics of bricklaying robotics (Pritschow, 1993), was followed by the European ESPRIT II ROCCO (Robot Assembly System for Computer Integrated Construction) (Andres et al. 1994; Gambao et al., 1997) and BRONCO (Bricklaying Robot for Use on the Construction Site)
project (Pritschow et al., 1996). These researches made several basic statements about the details of bricklaying robots’ possible equipment and working methods.

In our time, there are some industrial bricklaying robots already, like the MULE, or the SAM (SemiAutomated Mason) developed by the American Construction Robotics company, or the Hadrian X developed by the Australian Fastbrick Robotics. While MULE is a semi-automated cooperative system helping the bricklayers to lift heavy construction blocks, SAM is an automated bricklaying technology developed for large-scale monotonous bricklaying activities, like long straight walls (Petters and Belden 2014). The most complex system of the ones mentioned above is Hadrian X, which erects the entire wall structure of a minor scale building autonomously.

About the unique forms and shaping of the walls with the help of robotic arms, the research in the ETH Zürich can be mentioned as an example (Bärtschi et al., 2010). Apart from the spectacular attempts of free-shaping of the bricklaying structures, they also developed a new brick bond for their twisted wall project. It was followed by many bricklaying projects with curved walls (Helm et al., 2012) or even with vaults (Parascho et al., 2020). An extension of these works is the research of bricklaying in a previously established, existing environment, where self-navigating mobile robots construct walls (Dörfler et al., 2016).

The research and technologies mentioned above basically use robotic arms for the executions, but there are some attempts to apply large frame structures too. Such an example is applying a cable-driven system for bricklaying (Bruckmann et al., 2016).

There have been some attempts with bricklaying drones as well. An example is published by Wilmann et al. (2012). However, the application of flying robots on the construction site is seemingly more complicating than other solutions. Apart from the technical challenges like the effect of the wind in outdoor environmental circumstances or the safety questions while working in the same area with human workers, flying is a strictly overregulated traffic issue in several countries, especially above a certain weight. Not forgetting its possible advantages, we can state that it is currently the less easily applicable one among the mentioned technologies.

In traditional construction, the allocation of construction objects on site is a partial task of the construction site layout planning (CSLP). In practice, the construction object allocation is carried out routinely (Sanad et al. 2008) based on human judgment using the first-come-first-served method (Zouein and Tommelein, 1999) or using the construction manager’s experience (Cheng and O’Connor, 1996). There are two basic methods to deal with CSLP problem (Moore, 1980). The first method is placing every kind of resource everywhere or composing a couple of arrangement combinations and selecting the best from these. The other is bringing objects of one type at a time only in a specific order and calculating the optimal arrangement after each step (Hegazy and Elbeltagi, 1999).

Due to the number of factors involved in the CSLP, computer-aided systems were applied lately to solve the related problems. These systems were either CAD-based (Sadeghpour et al., 2004), or applied AI techniques (Tommelein et al. 1992) or used genetic algorithms (Osman et al. 2003; Li and Love, 1998; Hegazy and Elbeltagi, 1999; Mawdesley et al. 2002; Tam and Tong, 2003, and others). Most developed models identify the number and size of the temporary facilities serving the construction site and search for optimal arrangement by minimizing the total transportation costs between the facilities or between the facility and the structure to be built (Sadeghpour et al., 2004).

Besides the allocation of the objects, there are other aspects to take into consideration. The well-known time and motion studies of Frank and Lillian Gilbreth in the early 1900s illuminated the problem of unnecessary motions, and they invented new ideas to arrange bricks and pallets to improve productivity.

Bricklaying with robotics and the physical constraints of the bricklaying technology establish a similar set of tasks with CSLP and motion studies.

Despite the numerous researches mentioned above, there are many open questions in this field too. In this paper, some bricklaying methods and related pallet arrangements are investigated.
2. The applied methods

2.1 Tools and layout

This research aims to analyze the connection between the possible ways of bricklaying in combination with the pallet layouts. We were looking for the answers to real construction site problems, at the analyses of which we applied a modeled construction situation. For this purpose, a robotic arm and drystacked 30x15x9mm ceramic bricks were used. Our sample constructions were six full brick long and four brick high stretch bond walls.

We used Dobot Magician 4 axis robotic arm equipped with a sliding rail and a pneumatic gripper end-effector (Fig 1). It was initially programmed by the built-in application of the Dobot Studio; however, for the more complicated final tasks, we applied Python codes.

In this examination, we used a model environment with the following differences to the reality which have to be considered at the evaluation:

- no weather effects were considered – in a real environment, the weather may have some impact on the construction works,
- the proportion of the gripper to the brick is not realistic; the gripper was oversized, which enabled less smooth work and less freedom of the placement than in a real environment,
- the bricks were dry-stacked – no mortar was applied
- the pallet heights and the arrangements were limited by the model robotic environment.

![Figure 1. The arrangement of the robotic environment](image)

2.2 The bricklaying and the palleting

We applied different bricklaying and palleting methods to test out what is optimal in our model.
We considered two types of bricklaying methods. The first one is the traditional way of bricklaying, in which case the wall is constructed course by course (Fig 2a). The second one is a stair-wise method (Fig 2b) that would not come up too often in traditional bricklaying performed by human resources because it neither allows easy aligning at laying of the bricks nor enables the rapid work with the application of string lines. However, under certain circumstances, this second method might allow faster bricklaying in the case of automated technologies.

![Figure 2. Bricklaying modes: a) traditional bricklaying b) stair-wise bricklaying.](image)

According to the pallet arrangement, we applied two different conceptions. In the first case, the pallets were at one end of the wall symmetrically arranged (the wall was in the axis of the pallet configuration). We called it “head” palleting arrangement (Fig 3a). The other type, when we placed the pallets parallel to one side of the wall. This one we called parallel palleting arrangement (Fig 3b).

As a start, we made a typical linear layout constructed course by course with traditional bricklayer method. We started with half a brick in every second course to establish a proper stretch-bond wall. As a second step, we applied the same bond type with the stair-wise bricklaying method. Both bricklaying was tested by “head” and by “parallel” palleting too. The results of the measurements are summarized in Table 1.

![Figure 3. Pallet arrangements: a) “head” palleting b) parallel palleting](image)
3. Results and discussion

The optimal way of using pallets could be when the total delivery path of all built-in elements would be the shortest possible (Pérm & Malyusz, 2008). However, it would require the analyses of many combinations, most of which are irrelevant or are not applicable because of some physical barrier, like the physical extension of the gripper head.

For this reason, as a first step, we considered some possible cases by the calculation of the shortest route from the available (top) elements of the pallets at each brick placement. This method resulted in an unbalanced pallet consumption and seemingly long placing routes after some pallets were emptied. Therefore, we decided to apply additional rules. Our modified python code forced the differences between the pallets to be less than half of an element from the average value of the pallets in height, which resulted in a more balanced consumption of the pallets. However, it caused a longer execution time in our case. (Table 1, 5-6)

Finally, we applied a somewhat unconventional arrangement as well (Fig 4). In traditional construction circumstances, pallets have to be placed outside of the marked area of the walls, which is quite logical in any common cases. In the case of working with robotic equipment, however, it can be reconsidered.

![Figure 4. Placing the pallets in the marked out area of the wall](image)

The stair-wise bricklaying method enables the placement of the pallets in the marked-out area of the wall, right where the wall will be constructed later, resulting in the absolute shortest routes and time to the final positions of the wall bricks. (Table 1, 7)

| Pallet arrangement                              | Bricklaying mode       | Time(h/m/s)  |
|------------------------------------------------|------------------------|--------------|
| 1 “Head” pallet arrangement                    | course by course       | 00:10:46     |
|                                                | stair-wise             | 00:10:46     |
| 2                                              | course by course       | 00:10:06     |
|                                                | stair-wise             | 00:10:03     |
| 3 Parallel pallet arrangement                  | course by course       | 00:10:24     |
|                                                | stair-wise             | 00:10:21     |
| 5 Parallel pallet arrangement with limitations | course by course       | 00:10:24     |
|                                                | stair-wise             | 00:10:21     |
In this research, we made some examinations to get better times at automatized bricklaying in the case of straight solid walls by two means: establishing better arrangements of pallets and applying an unconventional bricklaying work method. Finally, the combination of the two, namely applying stairwise bricklaying and placing the pallets in the marked-out area of the wall to be constructed, resulted in the shortest of the times of our attempts.

5. Possible extension of the research
All the examined cases were bricklaying of solid, straight walls, without geometrical turns or any openings. It means that our observations are validated to the simplest layouts only. More complex cases, such as bricklaying tasks at brick walls with geometrical turns and openings, more complex pallet arrangements, and the application of a more convenient gripper, are planned to be investigated.

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