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# Transforming Building Renovation: A Holistic, Strategic Approach with Construction Robot Management

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## ABSTRACT

The purpose of this research is to investigate the topic of the efficient renovation of existing buildings through construction robotics management. The main questions addressed are: How can we increase labor working conditions around construction sites? Why has the productivity of the construction industry decreased? What construction tasks require automation most? What is needed to smoothly integrate single-task construction robots (STCRs) into the established workflows? How can we optimize processes? What management system is required for STCRs? To answer these questions, thorough research has been conducted, including all identifiable resources for the area or problem. In addition, the research has been strengthened by an expert survey to define the focus areas. Further, the analysis of current established solutions and processes resulted in the presentation of a centralized platform for managing STCRs, which has been developed as part of this research. In conclusion, the strategic implications of deploying STCRs through Visual User Experience (VUX), the low-code cloud-based platform, are discussed and reinforced with a business plan to bring the product idea to life.

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# 1. Introduction

The construction industry plays a vital role in the development of a nation. One of the major industries in the world is constructed. It accounts for a significant proportion of the gross domestic product (GDP) and gross national product (GNP). The construction and building industry directly impacts economic growth and, thus, the economy [1]. However, the industry contributes significantly to the global economy's current unsustainable development path [2]. This paper aims to present a solution that helps reduce the cost and time with the help of a holistic management system for the automated coordination of single-task construction robots (STCRs), integrated into the already established workflow. First, it captures the current culture characterizing the construction industry. Secondly, it overviews the necessity for improved performance through automation before elaborating on construction robotics as a viable solution to address the current challenges. Then, it presents a software-as-a-service solution combining a low-code application with Internet of Things (IoT) to deliver software for the centralized management of STCRs. Finally, it elaborates on future developments and the business plan.

## 1.1. Renovation of Existing Buildings with Google Arnulfpost as a Case-Study

The construction industry, together with the materials industries which support it, is one of the most significant global exploiters of natural resources, both physical and biological [3]. While the need for public housing is continuously increasing due to the overgrowing population [4], material and labor costs are rising. The increased competition and shrinking profit margins are some further challenges facing the industry [5]. The global construction industry accounts for 39% of all carbon dioxide emissions. Cement production alone is responsible for around 7% of worldwide $CO_2$ emissions. There is indeed a potential for energy saving by monitoring the waste around a construction site [6]. These are understandable reasons why errors produced by the human factor are not tolerated and should be minimized as much as possible. Furthermore, numerous tasks are highly repetitive, such as the tying of rebars associated with force and awkward wrist postures [7], and require automation.

On the one hand, the renovation of existing buildings will play a crucial role in maintaining energy efficiency in the construction industry. To achieve this goal, in 2020, the European Commission published a clear strategy to push the renovation wave forward. According to the European Commission, the strategy has in view to double the double annual energy renovation rates in the next 10 years. These renovations will increase the quality of life and reduce energy needs and emissions in the next 10 years [8]. Needless to emphasize, the current sustainability wave requires massive improvements from the construction industry [9].

On the other hand, the automation of construction tasks with the help of STCRs will significantly impact the improvement of productivity and the overall conditions in the construction industry [10]. Robots would carry out tasks such as drilling or monitoring more efficiently than humans. As numerous construction tasks are highly repetitive and require a significant level of precision, robots are generally more suitable to complete those when appropriately integrated into the workflow. However, the high complexity of coordination that the integration of STCRs represent make it challenging for contractors to do so.

The Arnulfpost, designed by Robert Vorhölzer and Walther Schmidt and located at the Arnulfstraße 62, was initially erected in the early 20th century. It was established by the Deutsche Post as the German Post Administration, as an internal School of Architecture for designing 350 post buildings for the Deutsche Post [11]. Considering the renovation of the Google Arnulfpost in Munich, this research aims to develop a holistic and strategic approach for the efficient renovation of existing buildings through construction robot management. Concretely, a low-code application as a centralized management platform has been developed to enable this strategy.

## 1.2. Problem: Delays in the Renovation of Existing Buildings

In renovating existing buildings, especially those involving structural works, there is always a high potential for unwelcoming surprises. The exact condition of an existing building can only be fully assessed after entering the construction phase. Usually, the damage is significantly more significant than what has been provided in the surveys of the different stakeholders.

Consequently, the technical due diligence reflects only some of the situation, making it challenging for the design team to foresee the full scope of work. Some of the issues include:

- Asbestos infestation.
- Pipe damage.
- Structural damage.
- HVAC system.
- Permits and documentation.

Consequently, the schedule set up ahead by the client team usually needs to be revised. It can be therefore stretched out due to the inability of the design team and the contractor to deliver at the required pace.

## 2. The Current Situation Characterizing the Construction Industry

Following the way a project is set up, from a project management perspective, makes it highly challenging to integrate construction robotics within the workflow. This is mainly because the different construction phases are entirely detached from each other.

Usually, in the early phases of the design processes, where the architects are the main stakeholders, more consideration of the later phases should be considered, especially the procurement and construction stages. With no holistic approach, it is impossible to implement construction robots on construction sites. This is for different reasons, mainly because construction robots require a high level of logistical organization since construction sites are typically unpredictable environments that constantly and continuously change. The logistical complexity must be addressed during the early design phases since the contractors jump in later. This fact is crucial since the contractor needs help correctly advising on integrating a fully automated setup or at least a hybrid one where the construction site can benefit from the human workers' dexterity and the robot's precision. Therefore, the systematic inclusion of the stakeholders will play a crucial role [12].

Furthermore, due to the traditional and conservative processes within the construction industry, the whole design is never finalized before entering the construction stages. The overlapping design and construction make it almost impossible to implement construction robotics. This is mainly because when a client gets the proper funding for a construction project from different institutions, the client rushes to the construction site and pressure all stakeholders to start constructing even though the design still needs to be fully compliant and finalized. Thus, the construction industry is currently shaped by a culture of change orders that implies a high level of complex coordination. Even when all financial and planning systems are in order, a last-minute alteration can throw everything out of sync, leaving decision-makers feeling like they have no choice but to throw more money at the project to keep it on schedule. Change orders account for approximately 8-14% of all capital construction dollars. 24% of the time, change orders account for over 10% of the total project costs. By integrating construction robotics into the workflow, there is a high potential of diminishing the risks implied through change orders since this will be no option as the design must be completely closed out before entering the construction phase [13].

Despite the high potential of significantly increasing the productivity around construction jobs through automation and robotics, construction robots still need to be widely available and are in short supply. Furthermore, the costs of traditional methods of completing a job site are still significantly low in comparison to the integration of construction robotics. Thus, not only should the implementation of construction robotics be maximized, but their benefits should only be regarded in the long term.

As a result, it only makes sense to implement construction robotics when holistically regarded. Further to increasing the productivity and quality of work, a significantly better overview of the current status of the progress can be provided. The latest can be achieved through a centralized dashboard that keeps constantly fed in by the information from the different robots and through the continuous comparison of the as-built and as-designed.

### 2.1. Vision for Robotics

Although robotics has been long applied in other industries, such as the manufacturing and automotive industry, the construction industry faces severe challenges in integrating construction robotics due to the harsh unforeseeable environment that nurtures the industry. Compared to other industries, such as the automotive, where the boundary conditions allow complete control of the environment and thus allow robots to navigate at ease, robots in construction are required to navigate in harsh environments. To achieve the goal of having robots move around a building site to complete tasks correctly, a digital twin of the construction site has to be continuously updated.

### 2.2. Vision for a Construction Management System for STCRs

To date, there have been significantly few endeavors to provide conceptual and systematic approaches to successfully deploying STCRs on site. In academia, there are only a few researchers that deal with this topic. For instance, Uwakweh introduced a framework for managing construction robotics and automation [14]. Further, Linner demonstrated a technology management system for developing STCRs [15]. However, a holistic approach to strategically deploy STCRs and integrate them into the already established construction processes through a management system can be deployed as an application running on mobile devices.

The vision of this system is to facilitate the management of STCRs through a centralized platform that allows a smooth transition into digital construction processes.

## 3. Necessity for Improved Performance through Automation

### 3.1. Application

#### *3.1.1. Semi-Automated Drilling, Addressing the Economic and the Social Aspect*

The drilling process is considered one of the most repetitive tasks on a construction site and one of the most challenging jobs for a human. Further to the multiple-change requests originating from the job site, which are only sometimes fully documented, on-site manual installation of overhead applications can result in major mis-coordination issues involving different trades in reworking.

Robotic drilling offers important advantages for digital workflows and solutions. The following provides an overview of those advantages [16]:

- **Predictability**: Execution of works completed according to the plan
- **Prefabrication**: Allows for detailed fastening planning and coordination
- **Co-working**: Reduces potential conflict in execution between sub-trades.
- **Performance**: Speed gains by shorting planning sequence by sub-trades.
- **Consistency**: Cleaner holes drilled through a coordinated approach.
- **Hole quality**: Accuracy, perpendicular to the ceiling plane, dust free.
- **Process**: Easily bridge digital planning to digital execution.
- **Management**: Real-time progress tracking for just-in-time delivery.
- **Planning**: Securing resources are identified and pre-planned.

For example, Hilti developed a robot to automate the overhead ceiling drilling process by leveraging building information modeling (BIM) to address this challenge. Hilti Jaibot is a semi-autonomous overhead ceiling drilling robot for mechanical, electrical, and plumbing (MEP) that is steered by a remote control run by an operator to move from one location to the next. Once in the drilling area, the Jaibot drills all holes within reach fully automatically. A total robotic station, Hilti PLT 300 reference Hilti Jaibot. Hilti Jaibot allows real-time data upload and download for progress tracking from the Hilti cloud and an offline work modus for areas without a cellular network, such as basements. Data input requirements are drilling coordinates and hole-specific information, such as trade/size and marking pattern. Furthermore, Hilti Jaibot is an easy-to-use system that does not require experts' skills and can be deployed upon completion of a 2-hours workshop.

The digital data flow (Fig. **1**) allows real-time uploads and downloads to support the project management in tracking the progress. The data flow can be summarised in a 5-step process as shown below: (1) Data Input, (2) Upload, (3) Download, (4) Drilling, and (5) Reporting [16].

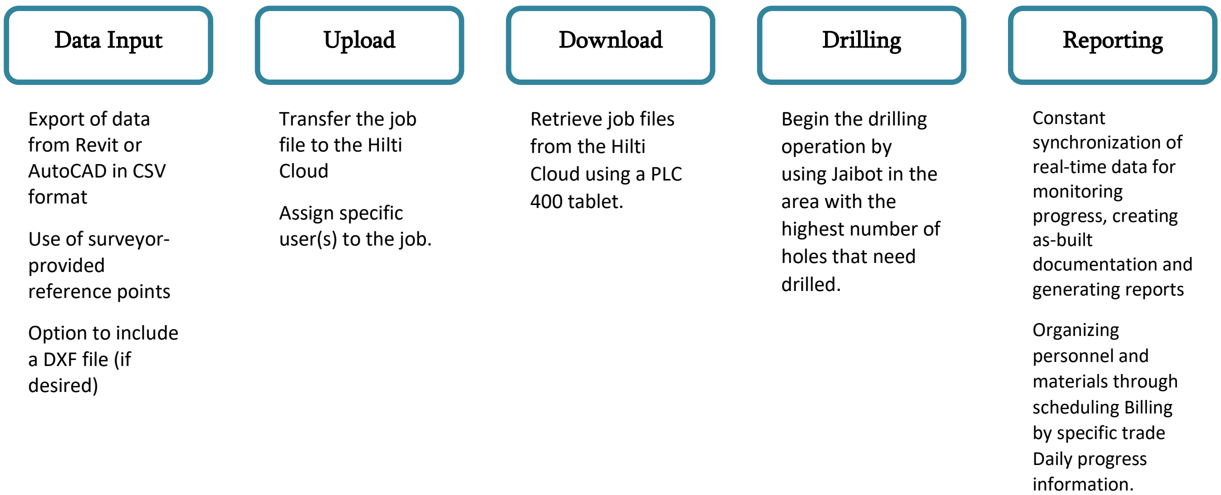


**Figure 1:** Digital data flow of the Hilti Jaibot [16].

The drilling performance of the Hilti Jaibot is compared against traditional and digital methods in Table **1** below, considering that the drilling process is heavily dependent on the following influencing factors:

- Drilling depth.
- Rebar hits.
- Hole layout.
- Obstacle on ceiling or floor.
- Accessibility on floor.
- Transport (crane, elevator).
- Availability of drilling data and reference mark positions.
- Availability of operator.

**Table 1: Performance of different drilling systems.**

| Traditional Method | Digital Method | Jaibot |
|---|---|---|
| Traditional layout and drilling | Digital layout and manual drilling | Digital layout incl. automatic drilling |
| 160 holes/day | 200 holes/day | >400 holes/day |
| 70 holes/day | 135 holes/day | >200 holes/day |

Hilti Jaibot is offered as a drilling service. The Jaibot costs approximately EUR 1200 -/day to rent out and can achieve around 900 holes daily, which translates to approximately EUR 1.33 -/hole. Considering the cost of drilling one hole manually being around EUR 5, - in Germany as a best-case scenario, major financial savings can be inducted in a major construction project. Concretely, EUR 367.000, - can be saved per 100.000 holes.

Further to the financial savings, the values that are driving the robotization of overhead drilling are as follows:

**Performance:**

- Time savings in measuring and drilling.
- Cost savings and improved quality.
- Less time for cleaning and vacuuming hazardous dust from drilling is eliminated.
- Allows higher quality installation.

**Innovation:**

- Extract drilling points directly from 3D plans/BIM for MEP installations.
- Data logging for all drill holes completed or uncompleted.
- Drives digitalization in construction.
- Optimization of logistic workflows.

**Health & Safety:**

- Reduce working at heights and fatigue.
- Great reduction of Work-Related Musculoskeletal Disorders, conditions, and vibrations.
- Reduction of worker exposure to respirable crystalline silica and dust in general.

## 3.2. Expert Interview

### *3.2.1. Introduction*

The development of STCRs has been pursued to address major challenges facing the construction industry, such as the lack of productivity, labor shortage, resources, and resulting delays. In the late 1970s, Japanese general contractors such as Shimizu Corporation saw great potential in construction robots. Consequently, with the onset of the robotics boom in the early 1980s, automation and robotics suddenly spread to all fields in Japan [17]. However, with its nature as a highly conservative industry, the construction industry has been facing difficulties in embracing modern construction methods, including construction robots. In order to gain insights from stakeholders on why STCRs still need to be adequately established in the construction industry, a survey has been conducted in this regard.

### *3.2.2. Survey*

- This survey intends to determine the following:
- Potential areas for the implementation of STCRs and their integration in the workflow.
- Different stakeholders' interest in applying modern construction methods, specifically STCRs.
- The demand for STCRs with regards to the trades.

The survey involved general aspects of the construction industry about implementing STCRs. It has been conducted in two stages. Initially, a questionnaire was submitted as a Google Forms to a pool of experts from different layers within the construction industry. The experts include project managers, construction managers, architects, contractors, and site supervisors. After the first stage, the questions were structured and organized to reflect the results in different charts.

### *3.2.3. The Results*

a. The survey involved different experts from the construction industry. 11 feedback (90%) were received from the following area of expertise (Fig. **2**):

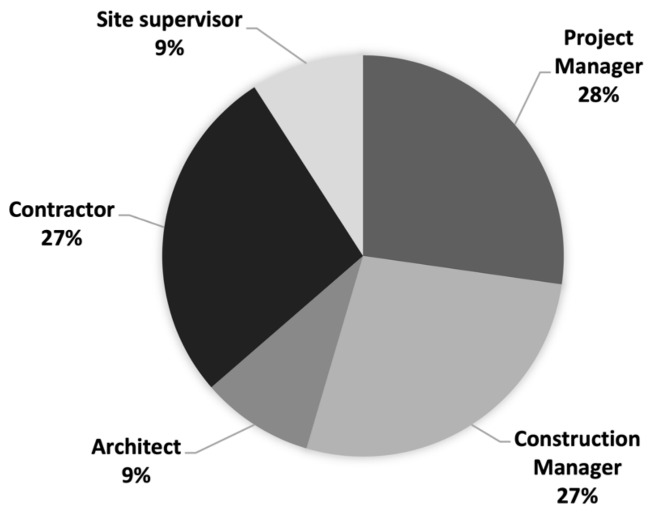


**Figure 2:** The survey involved different experts from the construction industry.

b. The survey involved different age groups (Fig. **3**):

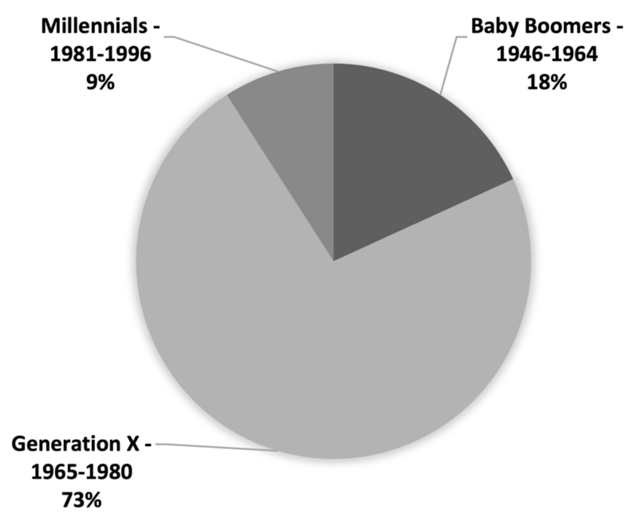


**Figure 3:** Age groups.

### *3.2.4. Potential*

a. Do you think construction robotics will play an important role in the construction industry's future (Fig. **4**)?

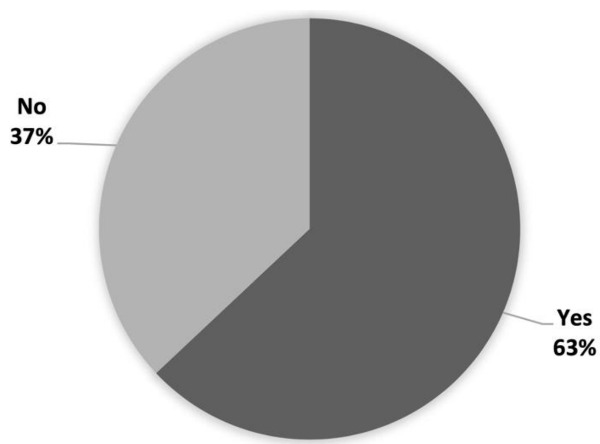


**Figure 4:** Do you think construction robotics will play an essential role in the future of the construction industry?

b. What potential do you foresee in implementing construction robotics (Fig. **5**)?

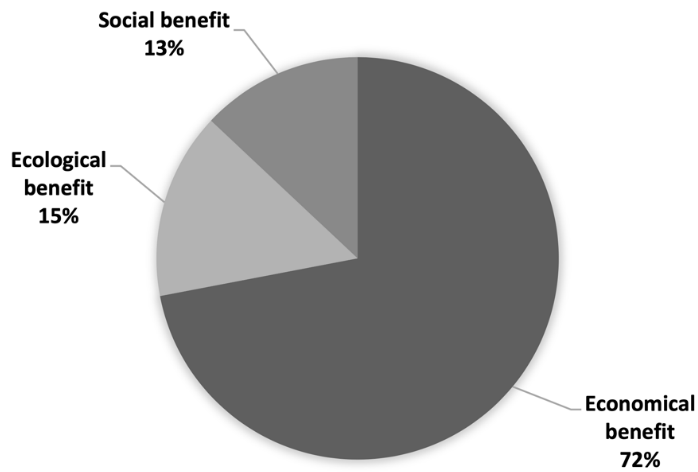


**Figure 5:** What potential do you foresee in the implementation of construction robotics?

c. In which type of construction do you see a potential need for construction robotics (Fig. **6**)?

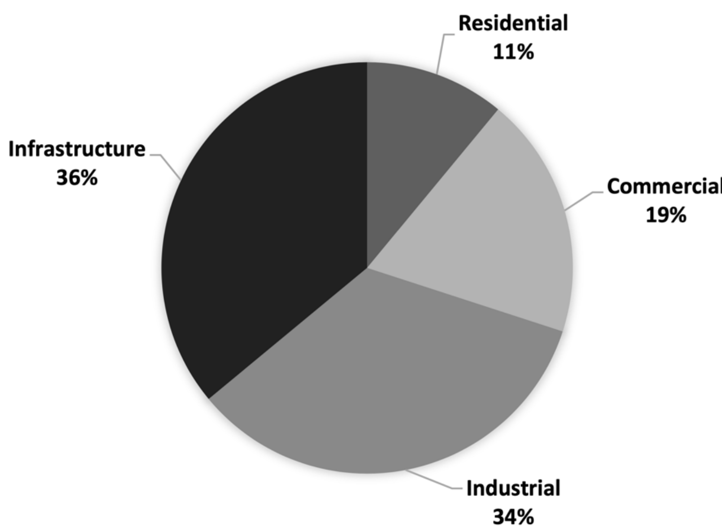


**Figure 6:** In which type of construction do you see a potential need for construction robotics?

d. Based on your experience, which scenario is more probable to happen (Fig. **7**)?

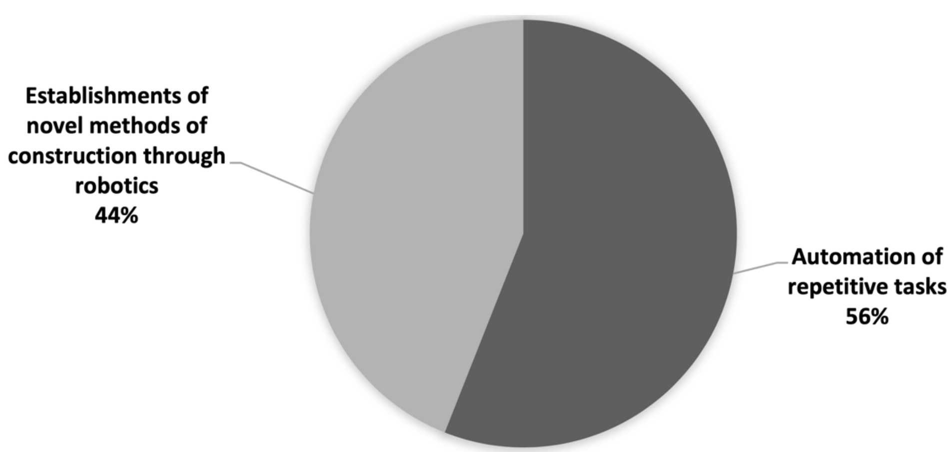


**Figure 7:** Based on your own experience, which scenario is more probable to happen?

e. Which setup would be beneficial for constructions (Fig. **8**)?

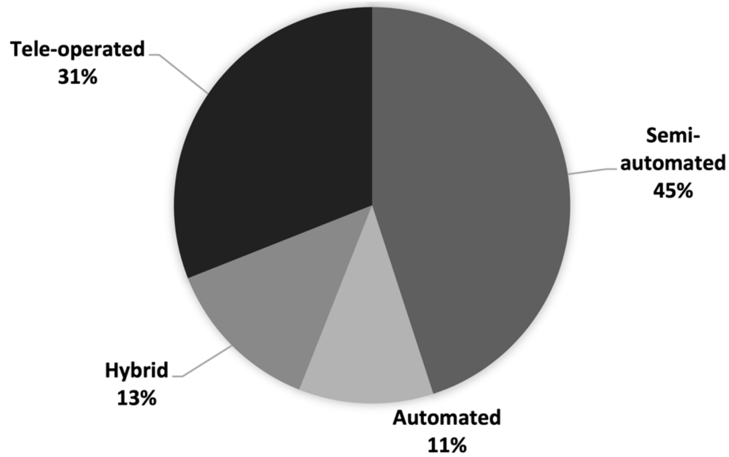


**Figure 8:** Which setup would be beneficial for construction?

f. Where do you foresee the most impact of integrating construction robotics (Fig. **9**)?

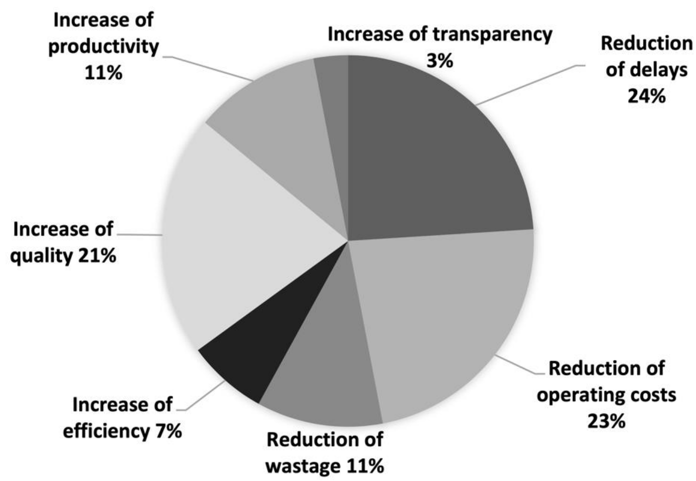


**Figure 9:** Where do you foresee the most impact of integrating construction robotics?

### *3.2.5. Interest*

a. Do you have any experience with construction robotics (Fig. **10**)?

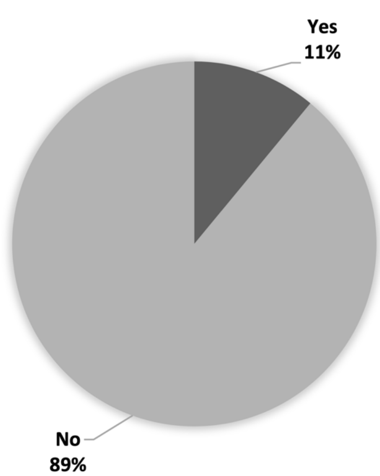


**Figure 10:** Do you have any experience with construction robotics?

b. Would you like to integrate construction robotics into your current workflow (Fig. **11**)?

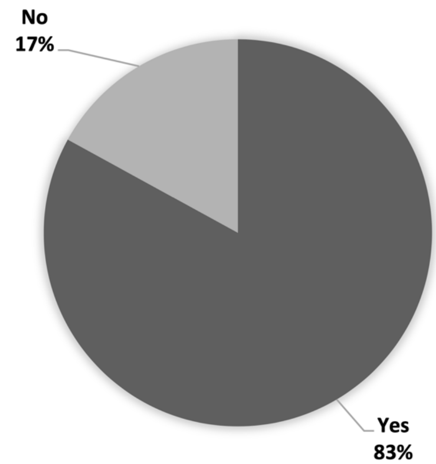


**Figure 11:** Would you like to integrate construction robotics into your current workflow?

c. Currently, there are major developments in construction robotics in the market. However, the construction industry has yet to embrace the change. In your opinion, what is responsible for that (Fig. **12**)?

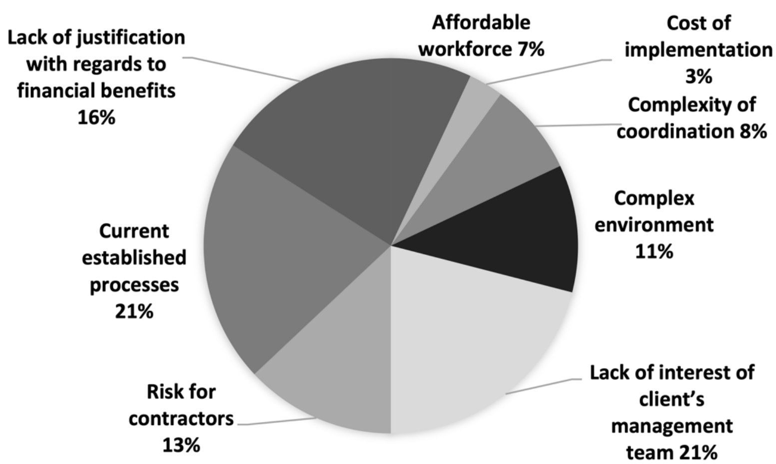


**Figure 12:** Currently, there are major developments in construction robotics in the market. However, the construction industry has yet to embrace the change. In your opinion, what is responsible for that?

d. Which institution or entities should arouse interest in construction robotics (Fig. **13**)?

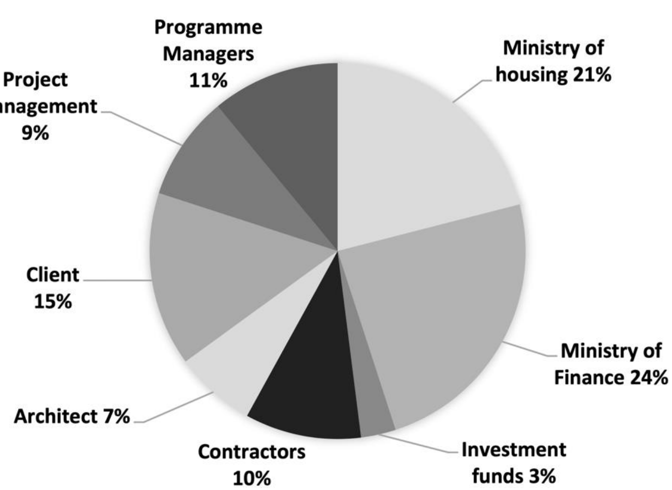


**Figure 13:** Which institution or entities should arouse interest in construction robotics?

### *3.2.6. Demands*

a. Which tasks are highly repetitive and should be considered for automation (Fig. **14**)?

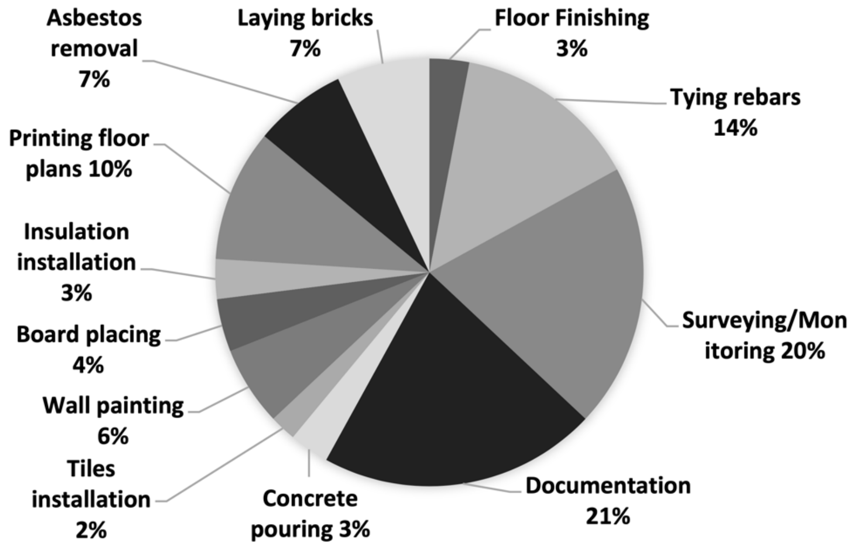


**Figure 14:** Which tasks are highly repetitive and should be considered for automation?

b. Which site job has the most deficiency in recruitment (Fig. **15**)?

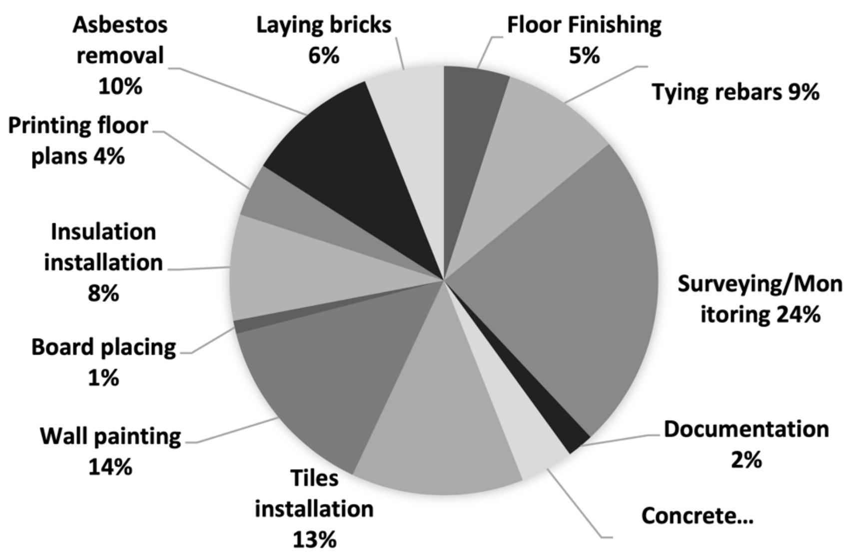


**Figure 15:** Which site job has the most deficiency in recruitment?

# 4. Construction Robotics as a Viable Solution

## 4.1. Current Solutions

Up to the present time, different solutions to manage constructions and track their progress have been developed. For instance, Autodesk Construction Cloud provides a tool to unify different processes on a centralized platform. Furthermore, HoloBuilder offers a 360° Reality Capturing SaaS solution for optimized construction project management. In addition to that, Procore provides a centralized dashboard to allow managers to handle project details, schedule tasks, and view progress. However, there is a lack of solutions that address the challenges of holistically managing STCRs on construction sites. Looking at the construction industry today, it is evident that there is a deficiency of systematic and automated evaluation and monitoring in construction projects [18].

### 4.2. Proposed Solution

A perpetual difficulty in construction will be the management of STCRs, deployed around different construction sites. However, the need for construction robots will constantly be growing since a higher demand for the construction of buildings is expected over the next decades to accommodate the growing population, while fewer resources, both from a human perspective and a natural perspective, will be available at the same time.

Construction robots are the major development that will revolutionize the construction industry over the following decades. Subsequently, VUX has been developed to help the positive disruption of the construction industry by enabling efficient integration of STCRs around different construction sites.

## 5. Product Introduction

### 5.1. Key Requirements of the Application

Four key requirements have been defined to address the challenges discussed above for a successful product implementation. First, the user interface has to be easy to learn and handle, engaging and kept as simple as possible. Furthermore, the platform should be possible to deploy on Android and iOS mobile phones and tablets and would require no additional hardware.

Lastly, the centralized dashboard should have the potential of high scalability, enabling the product to be continuously improved and its functionalities expanded to address the market's current needs.

### 5.2. Key Requirements of the Hosting Platform

In order to quickly assemble new processes and readapt the application to specific usage, it is mandatory to provide an application hosted on a low-code platform to enable any team member without specialized knowledge or expertise to conduct the required changes in the application. The low-code platform should be expected to provide the following benefits:

- Increased business agility.
- Less IT complexity.
- Automate more in less time.
- Rapid iterations.
- Greater productivity.

Further to that, some features that the low-code platform should provide are as follows:

- Direct integrations and low-code application programming interface (API) accessibility.
- Drag-and-drop workflow designers.
- Workflow testing/prototyping facilities.

Finally, the low-code platform should be hosted at a global player's cloud to ensure reliability and de-risk the project.

### 5.3. Visual User Experience (VUX)

The construction industry has seen major developments in STCRs in the last decades. Considered a viable solution to address the numerous challenges the building industry faces regarding safety, productivity, efficiency, and labor shortage, stakeholders face significant challenges in implementing them on-site. The fact that a construction project is divided into different stages where the stages are well disconnected from each other makes it even harder or even impossible to integrate the STCR into the well-established workflow, especially when construction projects are usually design-oriented and not robot oriented.

VUX has been developed as a holistic management system to address this issue by helping all stakeholders move forward in the right direction by providing them with a self-evident tool to automate the coordination and management of STCR. VUX is a cloud-based App that can be deployed on both iOS and Android. The application has been developed based on Appsheet, a no-code platform provided by Google that allows building apps and automated processes without writing a line of code. Appsheet apps use data sources such as Google Sheets, Excel, Cloud SQL, Salesforce, and other similar connectors.

In this use case, VUX's only source of truth is Google Spreadsheets. Since the app allows a bi-directional data flow and is fully based on standard sheets, users can easily be onboarded into the process and workflow. Very little to no knowledge of working with spreadsheets is required beforehand. Different spreadsheets are set up in a way that would allow the app to logically and automatically interpret the data. This action is required only one time, and once the spreadsheets are interconnected within each other and connected to the app, data can be extracted by any user provided with the right access to the platform.

By starting with the customer experience rather than with the technology while working backward to achieve the goal of providing a convenient user interface, the platform has been designed to cover the following aspects:

- Data gathering.
- Analysis.
- Logistics.
- Optimization.
- Scheduling.
- Performance capabilities of STCR.
- Monitoring.
- Reporting.
- Documentation.
- Process automatisation.

# 6. Product Working Principle

## 6.1. Centralised Platform as a Management System for STCRs

The core of this research is around the development of a no-code visual management platform that allows the automation of the coordination process of STCRs within each other to optimize the program and reduce the wastage around a building site. Until now, construction robots have been managed individually and thus require a high level of complex coordination. This coordination requires a human resource to manage each robot which again implies significant efforts to coordinate those within each other. This undermines the main advantages of integrating construction robots since the main reason for having construction robots around a building site is to automate processes and, thus, reduce human effort [19].

Furthermore, companies producing construction robots have limited to zero experience with their implementation on construction sites. By introducing a centralized platform that continuously gathers information on the current status of each construction robot and on the progress of the construction site itself by analyzing the as-built vs. as-design, data can be analyzed to support the optimal implementation of different robots to respective tasks in different construction sites and thus increase their benefits and the overall productivity.

VUX - Visual User Experience - aims to provide an easy-to-use platform to the construction project stakeholders to automate the assignments of single-task robots to different job tasks in different construction sites. Further to the program optimization and the increase in productivity, VUX's primary goal is to increase transparency to define optimization and improvement opportunities. Since the Deming cycle for continuous improvement [20] is also applicable to the development of STCRs, VUX will be able to provide data-based feedback to companies developing STCRs to optimize their products.

### *6.1.1 Benefits of a Centralized Platform*

VUX makes construction projects more efficient with better communication and collaboration. A data-driven management approach is possible with VUX, providing exact and concise visual information about a construction site's current status and progress. A client would be delighted to be informed about what has been achieved accurately instead of the processes to be undertaken. It also enhances the project with improved coordination and error detection in early phases, helping the execution team handle at the right time and place to avoid knock-on effects that often result in significant delays and budget explosions. According to KPMG, adherence to the project schedule is the most efficient way to perform on-site, while it is considered the core challenge in the execution of construction projects [21]. Furthermore, it provides increased clarity around scheduling and sequencing, improved productivity, and safer working conditions.

## 6.2. Product Workflow

The data collection process for VUX begins on-site with the assigned operators of each STCR providing data through the application or spreadsheets. The management team has access to the spreadsheets for data cleansing purposes. The data processing step involves transforming the raw data stored in the cloud into a structured dataset for documenting and reporting. This involves assigning the data to different projects, tasks to different statuses (in progress, completed, and incomplete), STCRs to open tasks, STCRs to different projects, tasks to different operators, and operators to different projects (Fig. **16**).

## 6.3. Product Methodology

VUX is a system designed to optimize STCRs deployment and logistics at different construction sites. In addition to logistical planning, it provides dynamic scheduling to account for any knock-on effects caused by typical or untypical delays. To optimize the logistical planning and maximize the potential implementation of STCRs, VUX combines the schedule provided in a single spreadsheet Gantt chart with the availability of each STCR. It is constantly supplied with real-time data for each STCR through an assigned spreadsheet. It has an operating platform that helps showcase and automate tasks' organization throughout the construction process. This allows team members to focus on more important and vital tasks rather than repetitive ones. VUX also can analyze the performance of each STCR deployed on-site for a specific task, including the time spent on the task, STCR type, energy consumption, area or volume covered, material consumption, and material wastage. This data is compiled from various construction sites and used with machine learning to continuously improve outcomes by considering a dynamic system environment.

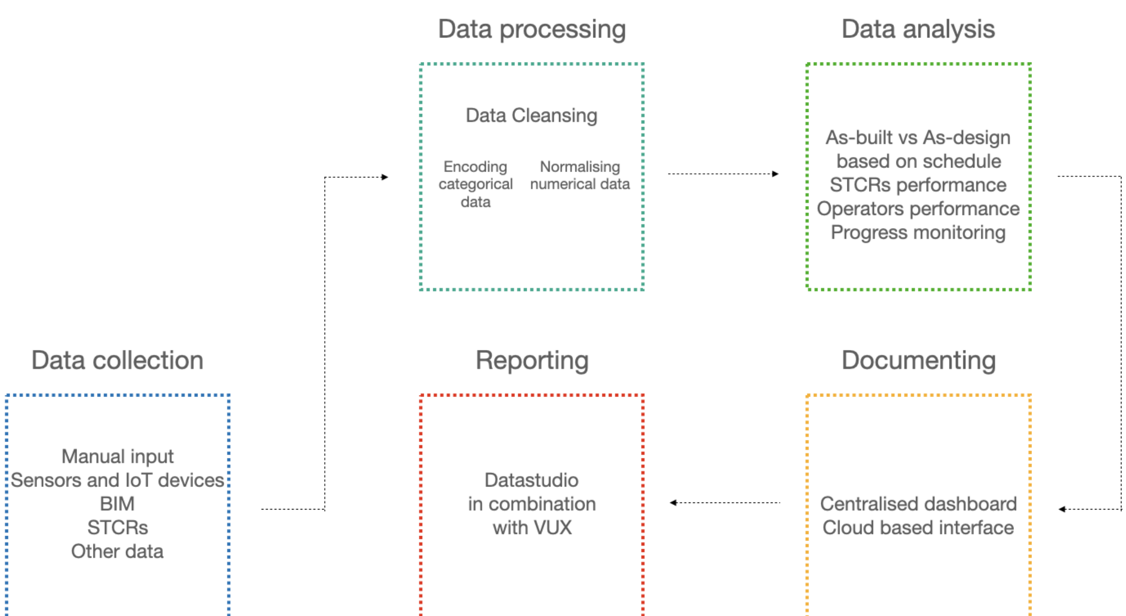


**Figure 16:** System architecture of the VUX platform.

VUX is a system that has several capabilities to optimize and automate the construction process. It monitors the advancement of construction sites by comparing the as-built and as-design using a BIM model and digital twin created through continuous 3D scanning. It also has bi-directional data flow and various sensing systems installed on the robots to monitor air quality, temperature, and humidity levels. VUX can automate repetitive tasks such as notifying stakeholders of task completion, STCR failure, knock-on effects, scheduling process, STCR assignment, and dynamic logistical planning. It uses a cloud-based tool to combine and analyze all data collected to provide a clear, concise overview to stakeholders through a friendly visual interface, increasing transparency and clarity in usually chaotic construction environments and organizations. VUX also helps to provide reliable documentation on the cloud-based platform, which can be used to collect evidence in case of legal issues and decrease insurance costs. It tracks the performance and outcomes of each STCR throughout its lifecycle. It has an operating platform that helps to showcase and automate the organization of tasks throughout the construction process. This allows team members to focus on more important and vital tasks rather than repetitive ones (Fig. **17-20**).

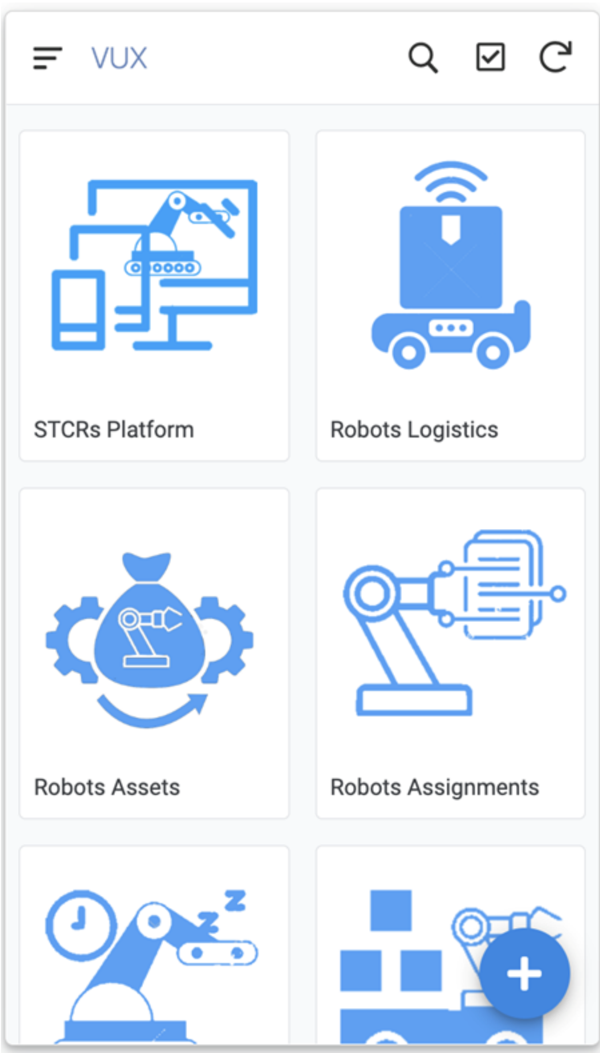


**Figure 17:** Landing page of the app.

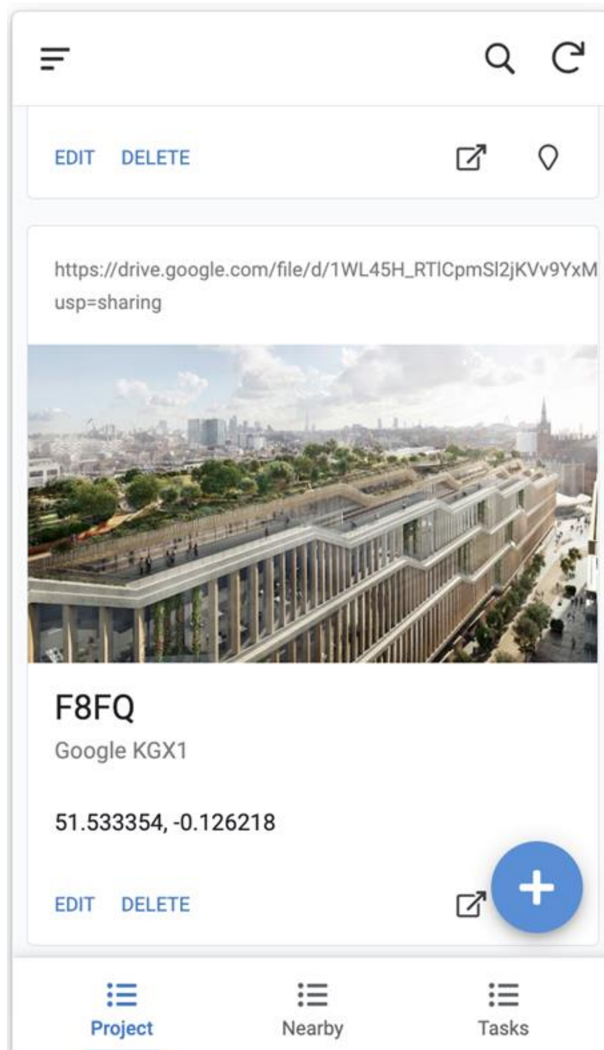


**Figure 18:** Project overview.

### 6.4. Technical Analysis of Product Prototype

VUX is a system that allows for manual input through an easy-to-use app and is established on Appsheet, a low-code platform provided by Google. Data is stored directly within connected spreadsheets on the Google Cloud and there is a bidirectional data flow between the app and the spreadsheets. The system's backend is established through the low-code platform provided by Appsheet, which requires no coding knowledge and has an interactive user interface (UI) for creating and customizing applications. The user interface, which project members can access with the proper access on a tablet or mobile phone, is kept simple for ease of use. A workshop of fewer than 1.5 hours is required for onboarding.

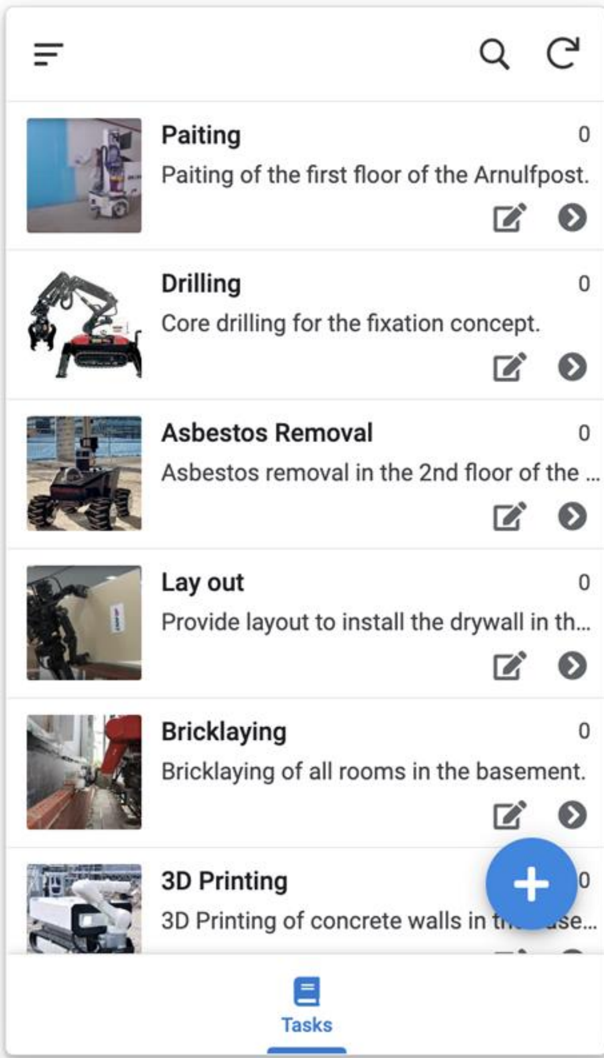


**Figure 19:** Overview of the STCR tasks.

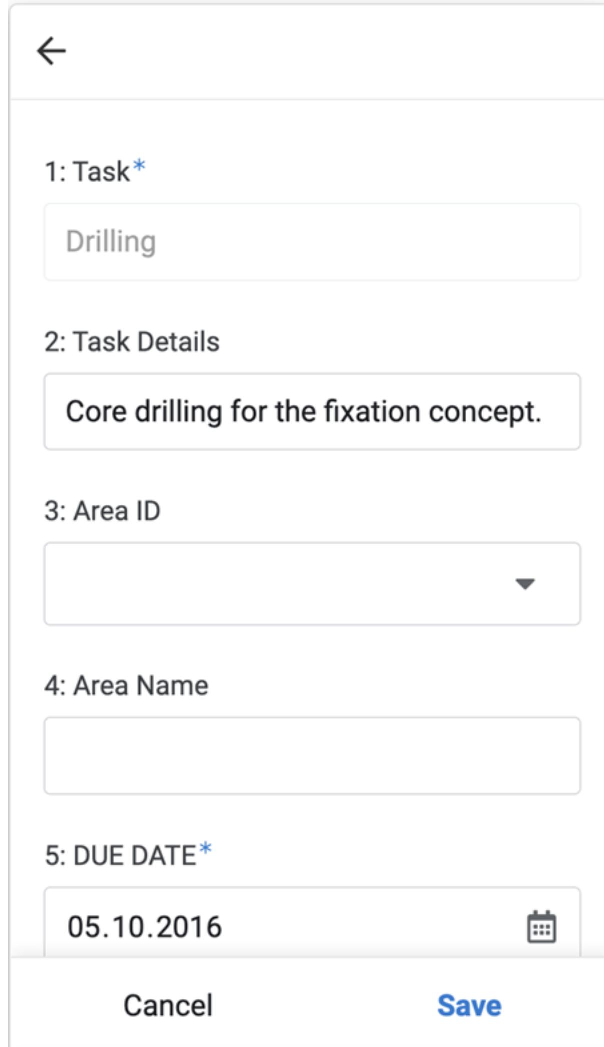


**Figure 20:** Interface to assign STCR tasks.

### 6.5. Expected Costs

The expected costs are highly dependent on the salary of the software development team. Further to that, it will cost 18$/user to deploy the application and run it on the Google Cloud Platform.

## 7. Advantages of VUX

The main advantages of VUX are its low cost and ease of use. It is a simple management system that centralizes the process management and coordination of STCRs in a construction site by acting as a centralized platform to monitor the progress, analyze the performance of STCR, gather data around the site, report to the stakeholders to facilitate the coordination process, document evidence, optimize processes and automatize repetitive tasks.

By providing a holistic solution for integrating STCRs, the stakeholders and the customers can deploy the cloud-based platform to leverage their BIM model to achieve their target in time and within budget. VUX's strength lies in its bi-directional information flow. Besides allowing the managers to feed in information from the numerous STCR software to VUX through conventional cloud-based spreadsheets, it also allows an optimized and automatized assignment of the different STCRs to specific tasks based on the integrated timeline.

Some of the benefits of VUX are as follows:

- **Better quality:** Following the integration of a hybrid workflow, relying on the dexterity of the human and the precision of constrained robots, a higher quality of work can be delivered with less effort and in less time, especially when it comes to repetitive tasks, considering the human focus constantly decreases when repeating the same task. VUX allows a smooth integration of STCR and facilitates the monitoring and inspection process in this regard.
- **The immediate return on investment:** Even though construction robots are considerably more expensive to acquire in the short term comparing it to conventional labor, VUX leverages the integration of STCR in construction sites to help the stakeholders achieve their targets without delay, considering that delays are the leading cause behind the budget explosion in construction projects. VUX aims to use the available technologies.
- **Increase of transparency:** With the help of VUX, structured documentation is provided automatically.
- **Decrease of wastage:** Since improved communication can be secured through a centralized dashboard, coordination errors will be diminished, ensuring rework will be diminished.

# 8. Challenges with VUX

There are some challenges for VUX since the conservative culture characterizing the construction industry makes it significantly harder to embrace changes. Further, implementing VUX will require extended planning periods, which most clients would only accept slowly. In addition, the complexity of implementation at the beginning of a project with an inexperienced workforce with regard to STCRs and VUX will require a level of acceptance currently lacking within the industry. For the proper integration of VUX within the workflow, very good preparation ahead of entering the construction phase is required for a successful implementation. However, the high number of stakeholders involved in a construction site makes it more complicated.

To conclude, the current culture requires fresh thought and a transformation from a process-driven into a data-driven approach to enable the acceptance of VUX.

# 9. Conclusion and Future Development

Based on an already established concept, Six Sigma validated in different industries, including the construction industry, VUX will be continuously improved to maintain and achieve higher efficiency. In construction projects where VUX will be involved, the knowledge gained throughout will be used to our advantage by applying the Six Sigma principles to increase the quality of communication between project teams and reduce delays. Consequently, construction efficiency and productivity will be considerably increased by diminishing errors, often resulting in a budget explosion [22]. The core of the Six Sigma principles lay in continuous improvement, reflected in a methodology known as DMAIC: Define, Measure, Analyze, Improve, and Control [23].

As a result, the proposed centralized management system and its methodology might be a unique and valuable solution to enable the deployment of STCRs by contractors and subcontractors. Detailed experiments have to be conducted to find the reliability of the proposal, alternate solutions, the possibility of improving the product, and challenges. A collaborative work through VUX, as the first centralized management system for construction robots. The challenges defined previously could be faced in different ways, but most importantly, a backup from different institutions beyond the construction industry is required to help innovate the construction industry. The practice of such a method might bring tremendous changes to the construction industry and lead to high technical and economic efficiency.

With proper planning and execution through partnership, as explained in the business model, VUX could be made a successful solution to construction robot management systems. Hence, a revolutionary change can be brought up through a user-friendly UI, which might mark the golden era in the construction industry.

Since the construction industry is facing a severe challenge of labor shortage at different levels [24], thus, construction robotics can reduce the impact of labor shortage at the level of construction workers by automating highly repetitive tasks. However, the issue of manually coordinating and managing a fleet of numerous STCRs around different job sites will introduce an additional level of complexity and a significant amount of human effort.

Consequently, it is required to anticipate a system and define a solution to avoid creating more coordination dilemmas. Therefore, a holistic approach that combines the following aspects is necessary:

- Prediction of required tasks.
- Evaluation of the progress of a project.
- Early detection of possible errors.
- Automation of dangerous tasks for the operators.
- Surveillance and inspection tasks.

Further to the development and establishment of VUX as a STCRs management platform, a logical next step will be to deliver a partner API to construction robotics companies to help centralize the whole approach of managing the workflow of construction robots and optimally coordinate them around different construction sites.

The API will allow continuous bi-directional data synchronization while reducing human effort and decreasing human error. By automating the data exchange between the individual software of each STCR, a digital twin of the logistics can be continually kept up-to-date to reflect the current situation of different construction sites in the centralized platform. In addition, the API will promote a strategic alliance between the VUX platform and the individual software provided by the construction robots companies to achieve full integration and fruitful collaboration as suggested by Roozbeh and Yasuyoshi in the paper dealing with developing and managing innovative construction technologies in Japan [25]. Through total integration and partnership, the platform will result in better outcomes than what could be reached separately.

To conclude, VUX aims to transform the construction industry from a process-oriented industry into a data-driven industry. Not only will VUX activate the smooth implementation of intelligent tools, such as STCRs, but will also increase the quality of communication around construction projects and thus increase transparency.

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