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Cost efficiency: A comparison between labors and robotics in bricklaying masonry wall construction

ABSTRACT

The use of robotic bricklaying robots in the construction industry is still in its infancy, and the precise characteristics and capacities of these robots can change depending on various parameters. The study compared between the use of human force against robotic machines as we go in-depth to understand those points of comparison between labor utilization in developing and also developed countries and the use of robotic bricklaying machines as semi-automatic and fully automatic robots. We have carried out a survey and an on-sites investigations for the usage of semi and fully automated in developed countries and the usage of labors in developing countries and we have reached the output that the market is still not yet ready to swallow the overprice of the automated machinery in either developed or developing countries. However, by boosting productivity, decrease the production cost of the machinery, be able to sustain the machine for longer time to be used on several construction projects and have a near return of investment from buying those type of machinery, those outputs were gathered from a survey that was published covering nearly 120 key personal from different construction projects in the developing and developed countries combined, so that these robots have the potential to completely transform the construction industry.

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Keywords: Robotic, Bricklaying, Labor, Automation, Productivity, Cost Efficiency.

1 Introduction

We are all living now in the booming effect and the quickly escalating automation, machine learning and artificial intelligence era [1], in which we have tried to automate non-automated tasks all around us, yet construction activities have a difficulty to automate their activities, due various reasons which are but not limited to their uniqueness and complexity, that is what make the construction industry set back in the innovation trend [2], We quite understand that every project is unique in its own way nevertheless there are repetitive activities that every project would contain.

Numerous factors influence the integration of novel production machinery into various sectors. Globally, several machine learning robots have been developed, specifically tailored for construction applications, despite international exhibitions showcasing the latest advancements in semi-automated and automated machine robotics for construction sites, their limited adoption raises questions. One aspect contributing to this phenomenon is the apprehension among laborers about potential job displacement [3]. The perception is that automation may gradually replace human roles [2]. This labor-centric viewpoint contrasts with the perspective of business owners, who prioritize cost efficiency in their procurement decisions. The current market conditions prompt a critical evaluation of whether investing substantial sums—ranging from hundreds of thousands to millions—in robotic bricklaying machines aligns with the profitability objectives of business owners worldwide. The prevailing sentiment among business owners is reluctance to embrace robotics on construction sites unless a clear and advantageous return on investment is evident. Thus, a fundamental question emerges: Is the utilization of robotic bricklaying machines more economically advantageous than relying on human labor?

However, the word “robotic machine” is a random non-specific word because there are always different kinds when it comes to machines [3], Moreover, considerations pertaining to labor necessitate clarification regarding the geographic context, specifically whether the research is tailored for developed, developing, or both types of economies.

We are going deep to understand the main point of comparison between the use of labor force in developing and also developed countries and using robotic bricklaying machine as semi-automated and fully automated robots [4]. We are measuring specific comparison points in the terms of advantages and disadvantages, between the labors in developed and developing countries as well as between semi-automated and fully-automated robots.

2 Method Statement for Bricklaying Robots

As previously indicated, the term "Robotics" is a broad encompassing various application, analogous to specifying the make and purpose when expressing a desire to purchase a car, Robotics, too, comprises distinct categories. Notably, the focus of this discussion centers on two particularly noteworthy types: the semi-automated bricklaying robot and the fully automated

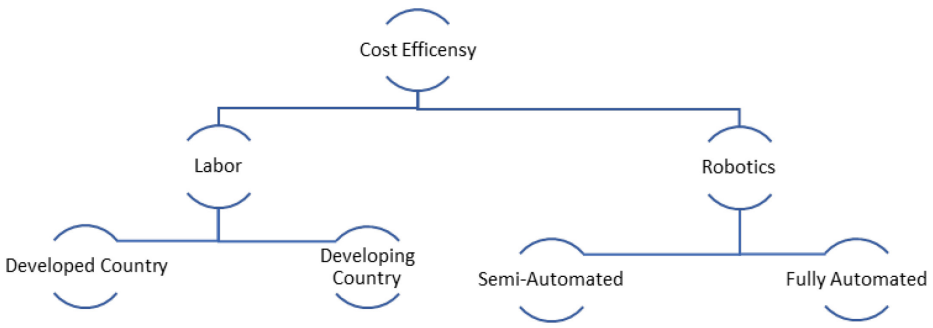

Fig. 1. The hierarchy in which the research is based on as a comparison between labors and robots, but each part has a more detailed two more segments

robot. The consideration of mechanical bricklaying robots is omitted in this study due to findings that indicate their optimal utility in scenarios involving heavy bricklaying and extended, rectilinear walls devoid of curves. These mechanical variants exhibit limitations spanning adaptation to production rates, accommodation of unique work specifications, and mobility, often requiring rail systems for linear movement. Consequently, our investigation concentrates on the nuanced exploration of the two aforementioned robotic types.

2.1 Semi-Automated Bricklaying

Semi-automated bricklaying robots are made to carry out particular bricklaying jobs, such as placing bricks in a pre-determined pattern. The movement of these robots and the placement of the bricks are normally directed by a human operator, Semi-automated bricklaying robots have a number of significant characteristics, including:

- Robotic arm: The robot's primary arm, which lays bricks, it has several sensors, including cameras and force sensors, which enable precision movement and precise brick placement.
- Brick-laying pattern that has been predetermined: The robot can be programmed to place bricks in a certain pattern, such as a grid pattern or a straight line. This pattern must be established by the human operator [5].
- Greater flexibility and efficiency are possible on the construction site thanks to the robot's remote control and monitoring capabilities.
- Human supervision is required for the robot to place bricks in the predetermined pattern; at this point, a human operator steps in to direct the robot's movement and manage the brick placement.
- Semi-automated bricklaying robots are less sophisticated than fully automated robots and are typically employed in smaller construction projects, such the construction of homes or modest-sized businesses, as well as they also cost less and need less upkeep than fully autonomous robots.

In general, semi-automated bricklaying robots are a viable choice for building enterprises aiming to increase productivity and save labor expenses but aren't yet ready to invest in completely automated technology.

2.2 Fully Automated Bricklaying

Fully automated bricklaying robots are made to carry out a variety of bricklaying operations, such as mixing and supplying mortar, laying bricks, and even shaping and cutting bricks to match particular patterns. These robots are frequently computer-controlled, enabling precise movement and precise brick placement [6].

Automated bricklaying robots have a number of significant characteristics, including:

- High-precision robotic arm: The robot's main arm, which is in charge of laying bricks, is a robotic arm. It has a variety of sensors, including force sensors and cameras, which enable precise movement and block placement [5][7].
- Automated mortar mixing and delivery: The robot is capable of mixing and delivering mortar to the work area automatically if it is fitted with a mortar mixer and delivery system.
- Automated brick cutting and shaping: Some robots are furnished with cutting and molding equipment that enables them to modify bricks to fit particular patterns or designs [8].
- Greater flexibility and efficiency are possible on the construction site thanks to the robot's remote control and monitoring capabilities.
- High speed and efficiency: Fully automated bricklaying robots can lay bricks much more quickly and precisely than humans, which can save a lot of time and money on construction projects [4].

The usage of automated bricklaying robots is still a relatively new technology overall, and the precise characteristics and capacities of these robots can change depending on the manufacturer and model. However, by boosting productivity and cutting human costs, these robots have the potential to completely transform the construction sector.

3 Masonry Wall building, Labors and Robots

By continuing, are those types of robots cost efficient than the labor usage, following that so there are main comparison points between the two parties and those points go as follows:

Production Rate
Average Daily Wage
Performance Curve and Wasted Material
Adaptation to unique work circumstances
Availability and Mobility

We are covering the above-mentioned different points [4][9] from the point of cost and financial aspects, that are affecting the usage of labor force in masonry wall construction activity, knowing that the comparison is based on standard bricks, brick in the average size that can be held by one hand for labors and placed in position nevertheless the exact dimensions because we are only comparing cost efficiency for the whole bricklaying activity not just for specific type.

The data were collected over a comprehensive survey [10] that covered the above points, plus the construction industry point of views over the robotic usages over the near future.

3.1 The Production Rate

Production rate as for labors

The unit that which will be used to measure the production rate is (m²/day) were one day in defined by the PMI -which is the Project Management Institute- as one working day in which it contains 8 working hours [4][15].

Before elaborating with the production numbers, we shall know that we are excluding the quality standards from the equation not entirely but partially.

we are also eliminating the time consumed in different hand-ins to consultants/quality controls and assume that the net amount of meter squares the labor can build up whether it is the same wall or different located walls - to avoid settlement, as a result the production rate is equal to 27m²/day [5] for the developing countries.

On the other hand, the developed countries the production rate is nearly the same which is 25.6m²/day [11], which is nearly equivalent a wall 6 meters width by 4.5 meters height.

Production rate for bricklaying robots

Depending on and including: Automation level, fully automated bricklaying robots can lay bricks more quickly than semi-automated or human-operated robots because they can do a wider range of activities [4] with little to no human oversight.

Brick handling: As it influences the entire production rate, brick handling speed is an important factor. A robot with a quick brick handling mechanism, for instance, will be able to lay bricks more quickly than one with a slower mechanism.

Wall complexity: The complexity of the wall being constructed has an impact on the rate of construction [12][13]. A wall that is straightforward with straight lines and right angles can be built more quickly than one with numerous curves and angles.

Brick quality: If the bricks are not uniform in size or shape, a robot may have to operate more slowly, which will slow down production.

Operator skill: A skilled operator will be able to program and operate the robot more efficiently than an untrained operator, which can also have an impact on production rate.

Environmental factors: Weather, temperature, and dust can all have an impact on how quickly a product is produced because they may need a robot to work more slowly to maintain quality and safety.

A fully automated bricklaying robot can typically lay between 200 and 1000 bricks per hour which compensate to 20m²/hr. and 150m²/day when operating under ideal circumstances. The actual hourly output rate, however, will be influenced by things like the operator's expertise, the state of the bricks, and the type of wall being constructed [14]. This would equate to a daily output rate of between 1,600 and 8,000 bricks over an 8-hour work shift.

Although semi-automated bricklaying robots require more human supervision and may only produce 200-400 bricks per hour on average 8m²/hr. and 64m²/day [15], over the course of an 8-hour workday, this translates to a daily output rate of 1,600–3,200 bricks.

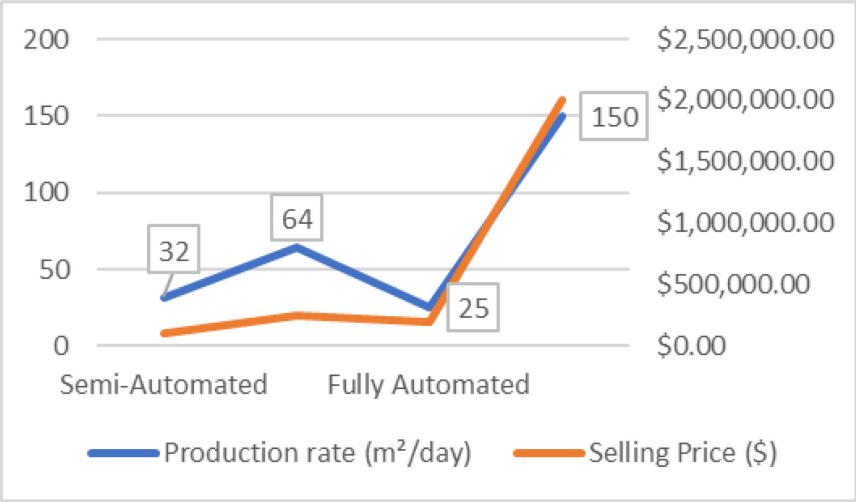

Fig. 2 the relation between the Production rate and the Selling price, for semi-automated and Fully automated Robotics.

3.2 Average Daily Wage

As for labors in different countries

Then, It is the average daily wage for the bricklaying labors, we shall also add that to reach the above numbers of the production rate, we need a number of 1 expert masonry labor and 1 masonry labor assistant, so we shall talk first about the developing countries in which the wage is 6.7$ for the expert masonry labor per day and 4$ for the labor assistant also per day [16], with a simple math you would pay nearly 10.7$ per day for 27m² masonry wall, then for the developed countries the average daily wage is nearly 200$ [17] and for the assistant it would cost as well 165$ per day, taking into account that the previously mentioned wages cover the social and medical insurances as well as this numbers is based on the exchange rate of January 2023.

Robotics on the other hand

The daily average wage for robotics whether they are semi-automated or fully automated are a little tricky to calculate because the actual selling price and you still have taxation which is completely different from one country to another and also the importing price which is also the same problem as the taxes, it is completely different from one country but always tend to be higher to another, and this is not the last variable, you still have the running cost, maintains and storage cost, plus for the semi-automated robotics you need a high qualified labor to work on the robot, those are all affecting the average cost per hour, so to overcome this variables, we will provide the average selling price from the providers, knowing that the selling price increase linearly with the increase in the production rate, so you end up for semi-automated robots with 100k$ for 32m²/day and 250k$ for 64m²/day, and for the fully automated robotics go way beyond those numbers, for 200k$ for 25m²/day and nearly 2Milo$ for 150m²/day, as seen in the below figure, (see Fig. 2

3.3 Performance Curve

About human involvement, involuntarily there must exist some human error also that this human error might decrease by hiring experts but that does not oversee the existence of the human error [18].

For human error existence [19], it has two sides of impact, either it is a waste material and/or excess use of material, for wasted material, the amount of wasted material when it comes to masonry wall construction it could reach up to 10% with an average of 5% [13],those materials are as sand, cement, water, the bricks itself, knowing that by past projects, we worked on, the cost for 1m² of masonry cost, would cost 0.7$ for developing countries and 14$ for developed countries [20].

As a conclusion, we end up with 10% waster material, 5% excess used material, and the average cost for the 1m² is nearly 0.7$

and 14$ for developing and developed countries.

Robotic bricklayers that are fully automated have sophisticated cameras and sensors that enable them to lay bricks precisely. Typically, these robots can lay bricks with an error rate of less than 1%.

While for Robots that are semi-automated bricklaying, which need more human supervision, they might make more mistakes. There is a 2-3% [4] mistake rate for these robots.

It's important to remember that the quality of the bricks utilized affects a bricklaying robot's error rate as well. If the bricks are not same in size or shape, a robot may make more mistakes. Environmental factors like weather and temperature can also have an impact on the mistake rate.

3.4 Adaptation to unique work circumstances

We have covered in the “Average Daily wage” section, the wage for a professional worker as our baseline for comparison and that is based on the hierocracy that we created that a professional labore will also be capable of overcome certain challenges when it comes to performing the required work, those challenges are:

Concrete beams may have a camper,

Concrete columns may have a slight deviation, and

The last bricklaying line just below the beams

All the mentioned points [16] go in the favor of the labore force as they can handle these problems on the spot, knowing that practical training is provided for labors in developed countries and from developing countries the workers usually start working in a very small age so that they gain a lot of experience as they reach their 20s, the experienced labore force will even have more advantage when it comes to building up a unique bricklaying wall, as round walls, curved walls, as well as walls with architecture decorative designs.

While for robots can overcome many of the challenges of building walls, including round and curved walls, using specialized bricklaying tools and techniques. These robots can be programmed to lay bricks in specific patterns, follow curves and contours, and make precise cuts to fit irregular shapes. Using 3D modeling software, bricklaying robots can be programmed to build complex walls and structures that would be difficult or time-consuming for human bricklayers to build.

However, the ability of bricklaying robots to build unique walls is still limited by their current technology and capabilities [21][22]. They may struggle with tasks that require fine motor skills or dexterity, such as cutting bricks to fit complex shapes or laying bricks in tight spaces.

Country	Unit	2015	2016	2017	2018	2019	2020	2021
BANGLADESH	mil	62	63.2	67.2	68.6	69.9	72.54	74.66
BRAZIL	mil	99	100	102	103	105	106.3	107.8
CHINA	mil	792	794	795	794	796	796.6	797.4
ETHIOPIA	mil	47.7	49.4	51.2	52.9	54.6	56.35	58.08
GERMANY	mil	42.7	43.6	43.8	43.9	44.4	44.79	45.16
INDIA	mil	470	473	476	479	489	490.6	495
INDONESIA	mil	126	127	130	133	136	138.2	140.8
JAPAN	mil	66.2	66.7	67.3	68.4	69.1	69.79	70.54
MEXICO	mil	52	52.8	53.5	54.5	55.8	56.51	57.44
NIGERIA	mil	56.5	58	59.6	61.2	62.9	64.44	66.04
PAKISTAN	mil	67.6	68.1	68.7	69.6	71	71.49	72.32
PHILIPPINES	mil	42.6	43.8	43	43.8	45.1	45.16	45.66
RUSSIA	mil	75	75	74.8	74.8	74	74.06	73.84
USA	mil	160	162	163	164	166	167.2	168.6
VIETNAM	mil	54.5	54.7	55	55.2	55.8	55.97	56.28

Table 1. Represent the gradual increase in the labor force for different countries across the globe.

3.5 Availability and Mobility

In most of the developing countries as well as few of the developed countries they have a good labore force participation as followed from multiple resources, but still the point of availability is affecting few counties [23] due to some specific reason but as follows in table 1.

The majority of developed and developing countries, have a wide availability of labore forces, as well as the construction field is a wide major that exist in every place in the world [23], but this is not always the case, as some countries are now located at the edge of having no labore force or even a few, as the United Kingdom which literally is now on the edge of have completely no labore force, and after following up from the UK and as based on our survey [11], it is assured that this problem is already in action, due to Brexit [24] a lot of EU labors and even non-EU labors were exported, so they are trying to solve the problem by relaying on robotic machinery for small and medium projects, as they start to use the bricklaying robots, but there are different specs that can be adjusted in order to fit for the required project, but still, since the bricklaying robots are still in their development phase, their availability may vary by region, manufacturer, and demand. They are frequently pricey, which may prevent some businesses from using them. Most bricklaying robots are made to be mobile and employed on a single building site. They can be moved to various locations on the site, but they are normally not made to be moved around easily between other building sites. Some bricklaying robots can be moved around a construction site on tracks or wheels, while others are installed on a stationary platform.

Ithough certain bricklaying robot models are intended to be more mobile and able to move between different construction sites, these models are not yet commonly accessible and depend on the manufacturer.

But in big projects in UK for example, they are following up with the American system of adding cardboard and wood frames as interior separation and depend on cladding as an

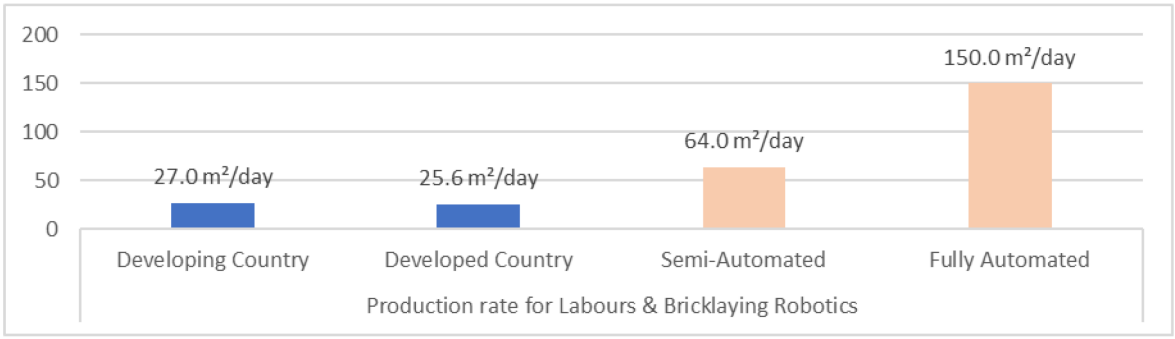

Fig. 3. Production Rate for different labors and robots' segments

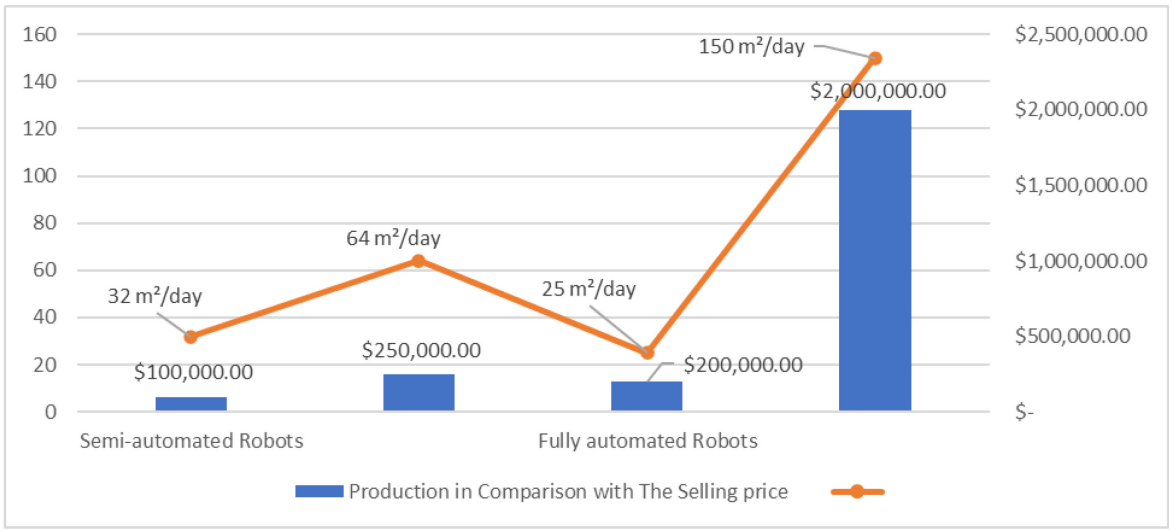

Fig. 4. Relation between productivity and prices

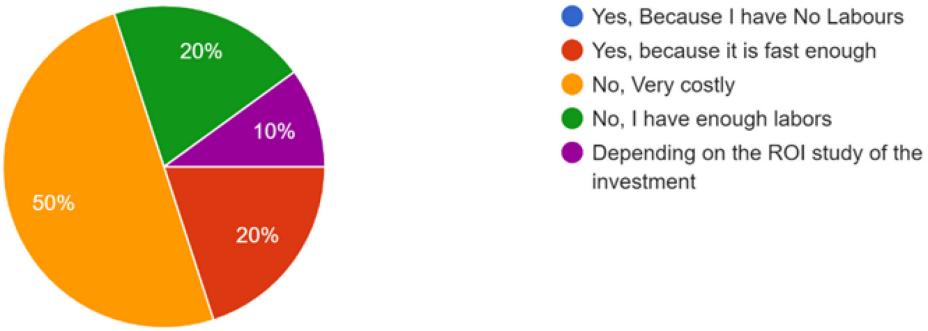

Fig. 5. The result from surveying whether construction projects would buy an expensive robot although it is more productive, or depend on labors.

exterior façade element, those two solutions might be effective for the time being but will it be effective on the long term, so we need to start depend on automation more even or/and adjusts the balance between countries with excess labor force and countries with few or nearly none labors [25].

4 As Results

As a result of the previously mentioned points and our published survey, the best production rate for labors against, the highest production rate that can be achieved by the semi-automated and the fully automated robots, figure (3),

you can see the quite difference between the two based comparison parties as the involvement of automation takes over the human's productivity by more than the double, but on the other hand the average cost for semi-automated robot is higher than the average, and for the fully automated robot even higher, as seen in figure (4).

By following our published survey [10], we reach the results that, 70% of the involved people in the construction decision making figure (5), they are againest buying such an expensive equipment even if they achieve such a high productivity.

Nevertheless, the labors in the developing country have an average of 10.7$ in a day and in developed country they have an average of 200$ a day, and assuming the you will buy the semi-automated machine for 250k$ to get double the productivity of the labor force with 64m²/day, plus assuming you will only pay the selling price without taxations, importing, shipping and running cost fees, you will end with 700$ per day, you can get 2 labors with less money and same productivity rate at the end.

The advantages of the labors does not stop here as well, both labors from developed and developing countries will be adequate and expert in this field with adabtability with diffierent and difficult job requirement, while forcing the robotics to adapt to different job requirements is difficult, even if you relay on the expensive fully automated models, they are still not capable of dealing with different bricks dimension in the same setup, but, the machinary have the edge on the waste material with 1% to 3% , in comparison with labors which could reach up to 10%, and as a summary in table (2) for the above mentioned number.

Leaving us with the avilability of both parties, as mentioned by many resarches and investigation the construction market in on the edge of not being able find enough workers in the upcoming future and we have already seen this impact on the UK [24] construction market, that is why we should start solving and clearing the air around the difficulties that the robotic bricklaying is facing right now to help with the expansion of the robotic in the upcoming near future

On top of the that and based on our survey, 60% of the construction site managers do believe that their sites are already capable of containing robotic bricklaying in anytime now, as well as 50% already think that the favor is with the robots when it comes to construction, maybe it is not ideal situation right now, but as

Comparison Points	Labor Force (Developing Countries)	Labor Force (Developed Countries)	Semi-Automated Robots	Fully Autonomous Robots
Production Rate	27m²/day	25.6m²/day	32m²/day - 64m²/day	25m²/day - 150m²/day
Average Cost	10,7$/day	200$/day	100k$ - 250k$	200k$ - 2Milo$
Performance Error (%)	5% - 10% Waste material	5% - 10% Waste material	2-3% Error rate	1% Error rate
Unique Work Requirements	Easy adapted	Training provided	Hard adaption	Hard adaptation
Mobility and Availability	Excess labors	Moderate availability with tendency to decrease And no longer available	Low availability with tendency to increase Lack of mobility	Significantly low availability with tendency to increase High Mobility

Table 2. The comparison points between labours (developed and developing countries) and Robotics as semi or fully automated.

we stated we think we shall start to clear the air for more automation and bricklaying to develop and adapted to the construction life.

5 Conclusion

As the use of bricklaying robots in the construction industry is still in its infancy, their use is limited and often expensive. Although the production capacity of robots is high, there are various limitations and accessibility issues due to the technology being in its infancy. Even if labor is economically advantageous in developing countries, labor quality is lower than in developing countries. While the labor force in developed countries is of high quality, it has problems such as cost and decreasing demand for labor.

In conclusion, in a comparison considering various parameters, in the financial choice between bricklaying robots and labors, labors are in the lead. When the technology for construction robots reaches a sufficient level of sophistication, this situation is expected to reverse, i.e., robots will be ahead in terms of financial efficiency.

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