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Evaluation and Comparative Study of Robotics vs. Manual Spraying of GRC Panels.

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Abstract

The paper presents, in economic, quality and technical terms, several aspects of the robotics manufacturing of GRC panels, based on actual measurements of performance rates, and real estimates of all cost items. The comparison of robotics versus manual performance is also presented. The system has been finished, and is now producing in a Dragados y Construcciones factory near Madrid. This paper focuses on a detailed quality and technical evaluation of the robotized spraying of GRC panels, in comparison with the previous manual manufacturing.

1. INTRODUCTION

A robotized application of GRC (Glass Reinforced Cement) sprayed panels have been developed under CIM concepts in the last years by DISAM, jointly with construction company DRAGADOS. This process is still totally manual in most of the factories nowadays. However, the new trends in construction automation lead more and more to robotized solutions for the type described in this paper. The advances in the development have been regularly presented in ISARC symposia [1], [2].

The most commons applications of GRC panels are wall units, urban furniture, and ornamental motives. The main advantages over traditional forms of constructions are lightness, good mechanic resistance and excellent superficial finishing of GRC panels, which make them very useful nowadays. An example of the final product is shown in Figure 1.

Figure 1. Example of application of GRC panels as wall units

2. DESCRIPTION OF THE SYSTEM

The manual manufacturing process of GRC panels consists of two or four consecutive stages, depending on the panel type. Each phase consists basically of spraying a layer of mortar and glass-fibre with a concentric spraying gun. The mortar and the glass-fibre are mixed outside the gun while spraying. In successive projections, several elements, such as isolation and anchoring, are placed in the panels. Additionally, there are also series of operations prior to the projection as well as operations to be executed after the projection. See [1] for more detail about this subject.

The structure of the control system has three interrelated main modules which are executed sequentially or in parallel, depending on the task. The first one works under a common CAD environment with access to DBs of the manufacturing tools, parameters and design rules of the product, all assisted by a special interface. The off-line module is divided in three different submodules: kinematic control, path planning and task planning. It uses the information generated by the CAD environment. This process is described in detail in [2]. The last module is the on-line one, which controls the whole lay-out, including the robot and peripheral equipment. The on-line control performs both the scheduling and monitoring of the system.

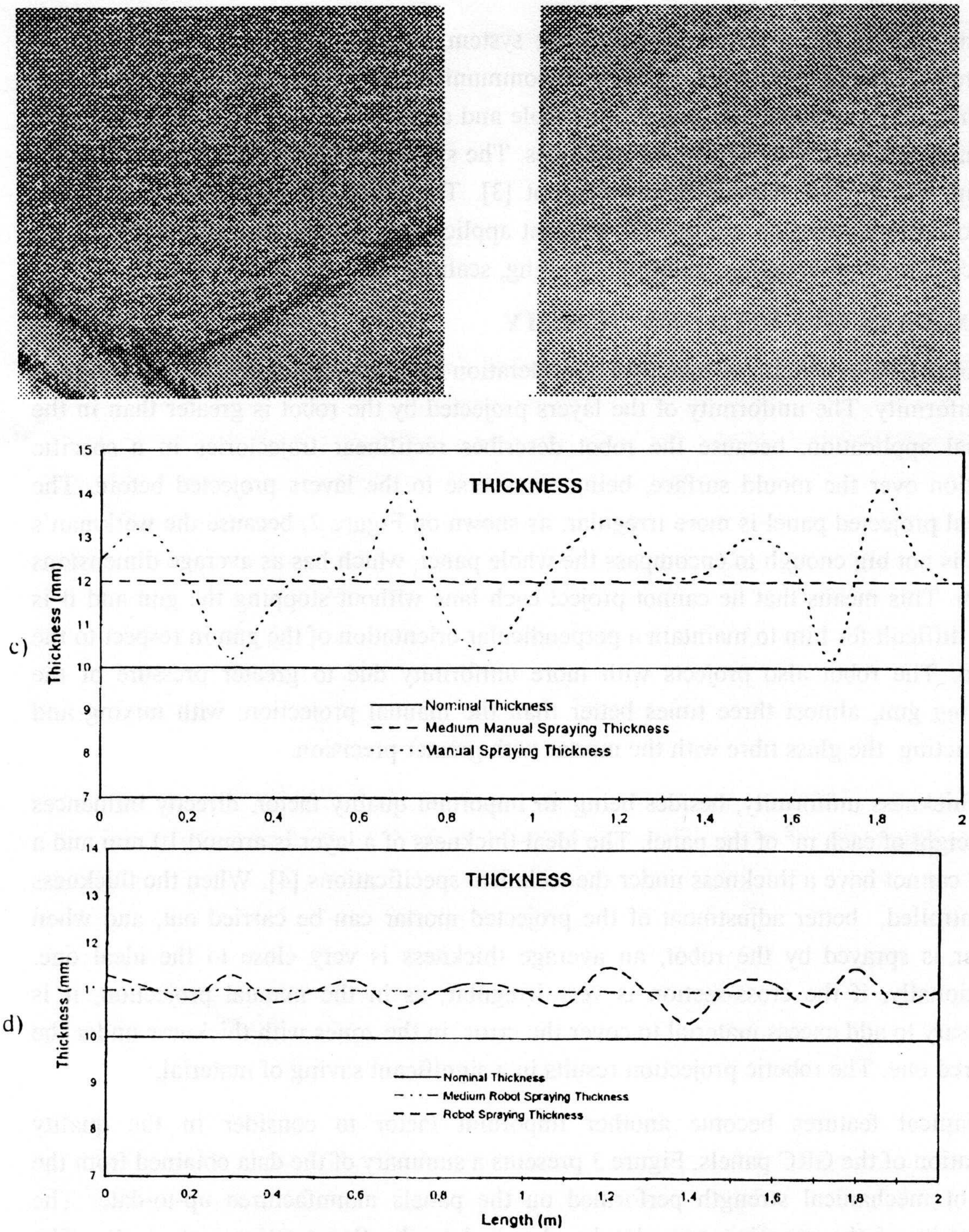
Key aspects of the robotic manufacturing system developed are: a) a high level of integration among the system modules, b) communications and management of data and information throughout the system as a whole and c) automatic processes, task and path planning of robots and specialized machines. The system has been designed to take into account the flexible manufacturing concept [3]. The robotized FMS system has been developed to be used on a group of different applications which are connected with 3D surface treatment: spraying, painting, cleaning, sealing, etc.

3. COMPARATIVE STUDY OF QUALITY

One of the main criteria to take into consideration for the product quality evaluation is its uniformity. The uniformity of the layers projected by the robot is greater than in the manual application, because the robot describes rectilinear trajectories in a specific direction over the mould surface, being transverse to the layers projected before. The manual projected panel is more irregular, as shown on Figure 2, because the workman's reach is not big enough to encompass the whole panel, which has as average dimensions 5x3 m. This means that he cannot project each lane without stopping the gun and it is more difficult for him to maintain a perpendicular orientation of the gun in respect to the mould. The robot also projects with more uniformity due to greater pressure of the spraying gun, almost three times better than the manual projection, with mixing and compacting the glass fibre with the mortar with greater precision.

The thickness uniformity, besides being an important quality factor, directly influences the weight of each m^2 of the panel. The ideal thickness of a layer is around 10 mm and a panel cannot have a thickness under the technical specifications [4]. When the thickness is controlled, better adjustment of the projected mortar can be carried out, and when mortar is sprayed by the robot, an average thickness is very close to the ideal one. Additionally, if the cross-section is very irregular, as in the manual projection, it is necessary to add excess material to cover the error in the zones with thickness under the required one. The robotic projection results in a significant saving of material.

Mechanical features become another important factor to consider in the quality evaluation of the GRC panels. Figure 3 presents a summary of the data obtained from the tests of mechanical strength performed on the panels manufactured up-to-date. The uniformity of the spraying can also be observed in the flex-traction test results. The strength of the tested piece measured in the longitudinal and transverse direction is very similar.



c)

d)

Figure 2. a) Panel manually projected. b) Panel robot projected. c) Cross section thickness of a manual projected panel. d) Cross-section of a robot projected panel.

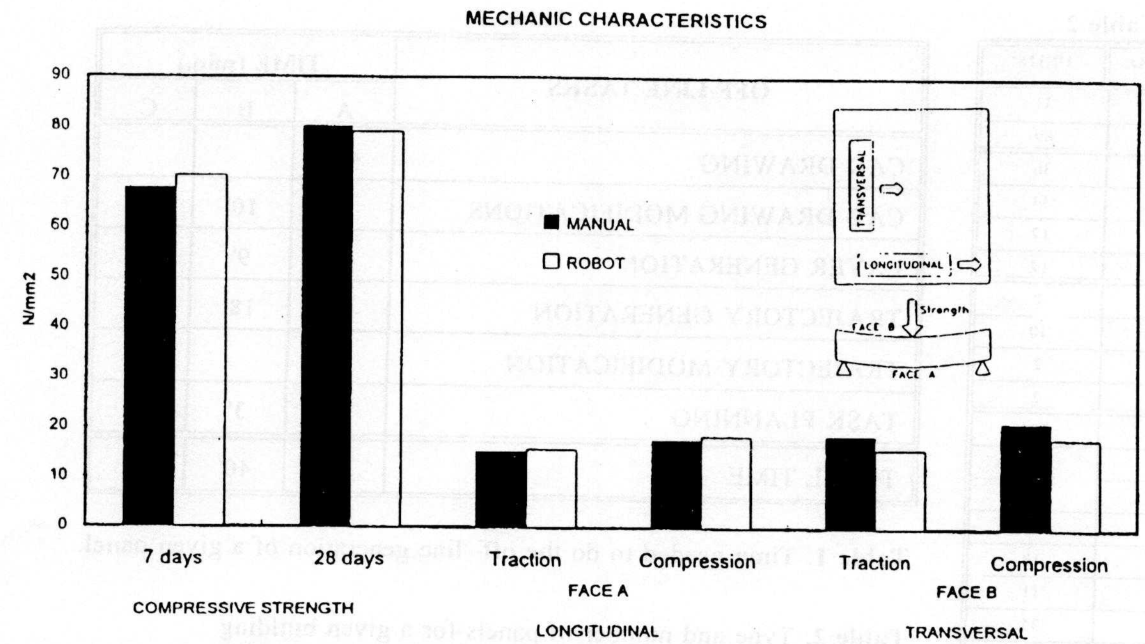


Figure 3. Mechanical strength test results for all types of panels manufactured up-to- date

Comparing flex-traction strength shows that the values are slightly higher in the manual cases, but the difference is by no means significant. It is important to note that with the robot all the intermediate compactions have been eliminated, with the number of compactions being a fundamental factor in the manual projection.

4. PRODUCTIVITY EVALUATION

The panel production cycle can be divided into two clearly different phases: a) the design and drawing of the mould and generating of the tasks and trajectories in the case of the robotic manufacturing. b) The manufacturing process in the factory. Phase a), which is completely off-line, can be carried out in the technical office following the high level planning.

The first step in order to generate the necessary data to manufacture a new panel is to draw the mould using CAD. The layers to be projected, the trajectories and the high level tasks for a given day are all generated from these drawings. Table 1 option A assesses time needed to do all generating. Table 2 describes the number of units of different types of panels for a given building. Some of them can be grouped together as panels with similar geometry and can be generated quicker with only slight modifications of the first one, as shown in Table 1 option B. It can be seen that with more than 5 panels of the same type the total time for the off-line tasks is 40 minutes. Option C of Table 1 indicates the time required to modify the projection parameters to spray the panel in a different way.

Table 2

PANEL I.D.	UNITS
R-1	33
R-3	69
PC-1	36
PC-2	34
PC-7	17
PC-8	17
PE-147	1
PE-148	10
PE-156	2
PE-159	2
P-1	204
P-3	15
P-4	12
P-9	18
P-10	18
P-16	11
P-17	35
P-19	1
P-29	15

Table 1

OFF-LINE TASKS	TIME (min.)		
	A	B	C
CAD DRAWING	40'		
CAD DRAWING MODIFICATIONS		10'	
LAYER GENERATION	9'	9'	
TRAJECTORY GENERATION	18'	18'	
TRAJECTORY MODIFICATION			20'
TASK PLANNING	3'	3'	3'
TOTAL TIME	70'	40'	23'

Table 1. Time needed to do the off- line generation of a given panel.

Table 2. Type and number of panels for a given building

The robotized system substitutes the workmen in one of the hardest tasks involved in the production of GRC panels, which is the projection of the mortar, operation done in polluted environment due to the use of cement and glass-fibre. The working group consists of 4 men, 3 assigned to the compaction process and auxiliary tasks and 1 to the projection itself. One of the main advantages of the robotized spraying is the quantity of material to be projected by the gun in a given time: 28 kg/min in the robot spraying versus 12 kg/min for the manual one. Taking this into consideration, together with the non-productive times inherent to the molds transportation, it can be affirmed that the robot substitutes two projection workmen, and therefore projects enough panels in a given time to keep working 2 groups of 3 workmen working on compaction.

The use ratio of the robot depends of the lay-out selected, the quantity of the workmen working on the compaction and the speed of the transport system. In automated production the use ratio of the robot could reach 95% (1 minute to extract one panel and introduce the next one and 20 minutes of average time to project a panel). It can be assumed that all the workmen needed to compact the panels already sprayed by the robot are available at all times. The use of the robotization has also increased in automating other tasks, such as the conveyor system and the storing and retrieval of materials and products.

The average time of the manual and robot projection for a series of different panels is shown in Figure 4. The projection times are slightly inferior to the manual ones. The tasks productivity has increased insignificantly, but another type of factors has to be taken into consideration. The spraying of the mortar with a much higher pressure would allow the elimination of the intermediate compactions, having to do only one at the end of the spraying process. The removal of those compactions eliminates the transportation times and therefore the robot non-productive times. This increases the whole productivity significantly as can be seen in Figure 5, which considers the whole process of the manufacturing of the panel.

5. HUMAN FACTOR

The introduction of new and advanced technologies in a manufacturing, in human environment not accustomed to them, is not easy. And this project has not been an exception. The company receiving the technological transfer must try to acquire as much knowledge as possible during the development so it knows later how to use it. One of the reasons for the success of this project lies in this thorough approach. Another point learned from the experience of this development is that, the mutual communication between developers and the workers from the company involved, is also vital and should be maintained in good terms. It is also very important, as it has been in this case, that the workers that will have to work with the new system are ready to accept it and cooperate during the development [5] and are trained at the required technical level.

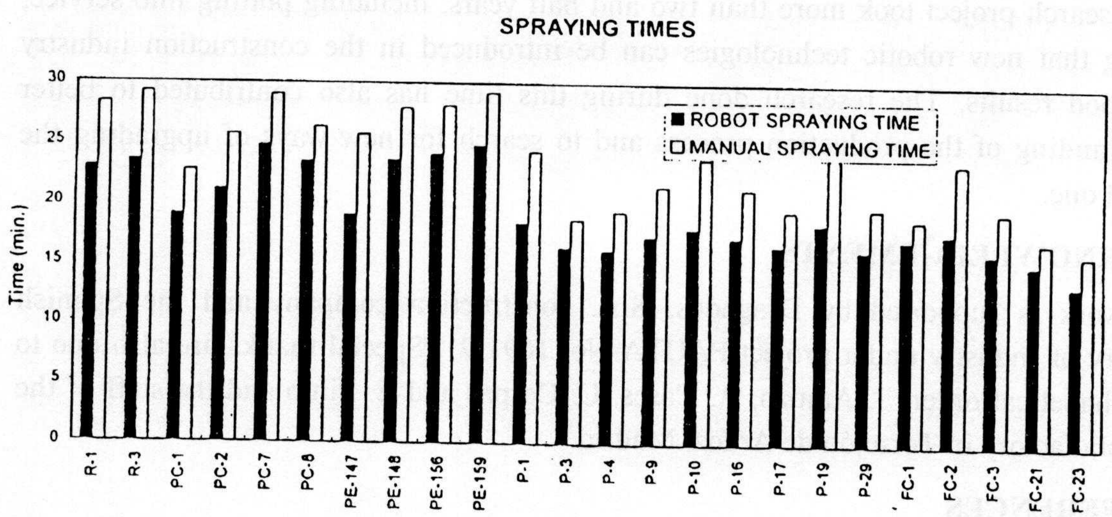


Figure 4. Average times of robot and manual projection for different types of panels.

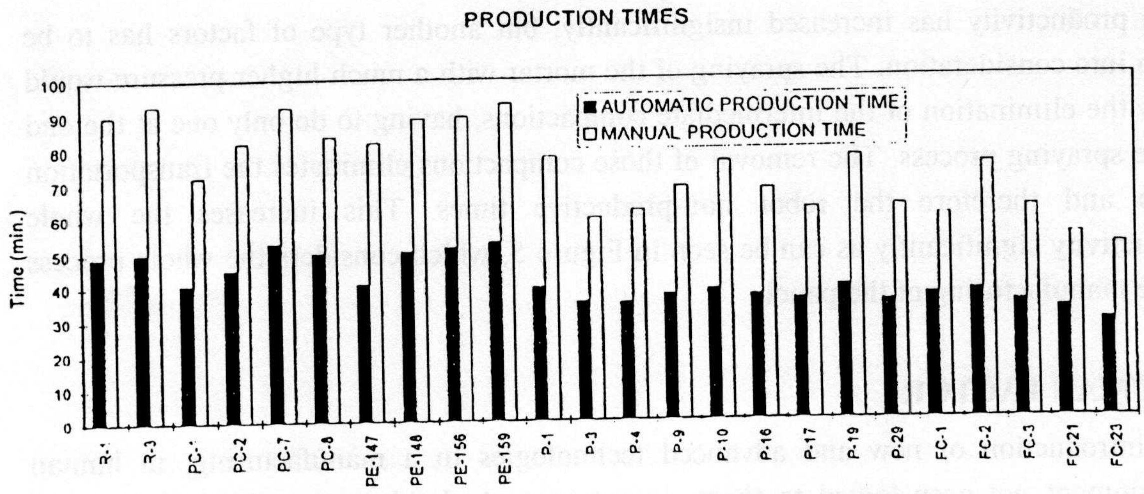


Figure 5. Productivity for robot and manual projection.

6. CONCLUSIONS

The developed system presents a new step towards fully automatic prefabricated manufacturing. The development of this system has demonstrated the great advantage that automation can bring into quality and factory productivity in an off-site manufacturing process in the construction industry.

This research project took more than two and half years, including putting into service, proving that new robotic technologies can be introduced in the construction industry with good results. The research done during this time has also contributed to better understanding of the production process and to search for new ways of upgrading the manual one.

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8. REFERENCES

[1] C. Balaguer, F.J. Rodriguez et al., *Robotized System of GRC Panels for the Construction Industry*, 10th ISARC, Houston (USA), 1993.

[2] C. Balaguer, J.M.Pastor et al., *Automatic Robot Path Planning for GRC Spraying Cell*, 11th ISARC, Brighton (UK), 1994.

[3] J.M. Pastor, L.F.Pe_ín et al., *New Approach to Low-Cost FMS for Wide Range of Manufacturing Applications*, Proceedings of the Intelligent Manufacturing System Symposium, IMS'94, Vienna (Austria), 1994.

[4] E.S. Knowles (editor), *Recommended Practice for Glass Fiber Reinforced Concrete Panels,* Prestressed Concrete Institute, 1987.

[5] M.Richardson and D. Trowell, *The Men and the Machine*, 11th ISARC,Brighton (UK), 1994.