SUCCESSFUL AUTOMATION OF A LINE OF G.R.C. PANELS USING SIMULATION

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ABSTRACT

This article presents the modeling and simulation study to optimize the manufacturing process of prefabricated G.R.C. (Glass Reinforced Cement) panels for building facades. The process optimisation has changed the tasks organisation, and a proposal to automate the works with more value added has been made to increase panels productivity and quality.

The main characteristic of this products is the flexibility to obtain panels with complex three-dimensional forms. The "DRACE System of GRC Prefabricated Panels for Building Facades" published in (DRACE 2001) has a detailed explanation of characteristics, specifications and manufacturing operations of GRC panels.

INTRODUCTION

Construction industry automation is still well bellow the levels of other industries, although an increasing effort has been made in recent years. Applying automation in this important sector is difficult because of the non-repetitive processes and the low level of standardisation. Construction activities can be divided into two main groups: off-site and on-site. On site processes are more relevant and form what is considered typical construction work, i.e. building, civil works, etc. Off-site construction processes are more suitable to be automated, since the work takes place in a structured environment and process variables are under control.

A common off-site process is the manufacturing of prefabricated panels which are later assembled on-site. In recent years one important material used in this kind of industry is the GRC. Thanks to its flexibility, this technology has become very popular. GRC material is prepared mixing cement with small cut glass fiber strips, achieving enough flex-traction strength while maintaining light weight (60 kg/m^2 in comparison with conventional concrete panels 220 kg/m^2). This allows the manufacture of large panels (7x3m) of any 3D geometry, see Figure 1, with the dual advantage of easy transportation and easy assembly on site.

Figure 1: Panels of GRC with Different Shapes

The Spanish construction company DRACE has been using manually manufactured GRC panels mainly as facade units, see an example in Figure 2, for a long time. The excellent finishing quality of the external parts of GRC panels enables to apply them in a great variety of circumstances. Therefore a project to develop an automated manufacturing factory of prefabricated GRC panels is been launched by DRACE with the financial support of the Spanish Ministry of Industry.

Figure 2: Aspect of Typical GRC Facade

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This article presents the use of modelling and simulation (O`kane et al 2000), to find the best process lay-out, see (Potluri and Atkinson 2003) for automation and optimisation of GRC facade panels manufacturing tasks.

OBJECTIVES

The main objective of the analysis is to develop a flexible manufacturing system that will be monitored with a simulation model that helps decision making both in the short term and in the long run, (Benjamin et al. 1999).

In particular, the main thrusts are:

- Improving panel quality.
- Reducing materials consumption.
- Increasing productivity.

Those ideas might be achieved by:

- Reducing manual labour: due to the high repercussion on the final costs.
- Improving the manufacturing process: tasks reorganisation and elimination, automation….

THE PRODUCTS

Panels differ according to the type and number of layers to be sprayed. The first layer, which forms the external surface of the resulting panel, is common to all of them.

It consist of mortar without fibre up to a total thickness of 2 mm. Depending on the remaining layers, there are five distinct types of panels showed in Figure 3.

- Plain shell: two more layers of mortar and fiber up to a total thickness of 10 mm.
- Shell with ribs: same as plain shell but with stiffening ribs.
- Stud frame: same as plain shell but with a steel frame structure.
- Shell with insulation: same as plain shell but with insulation sheets.
- Sandwich: same as plain shell with insulation with and additional GRC top layer.

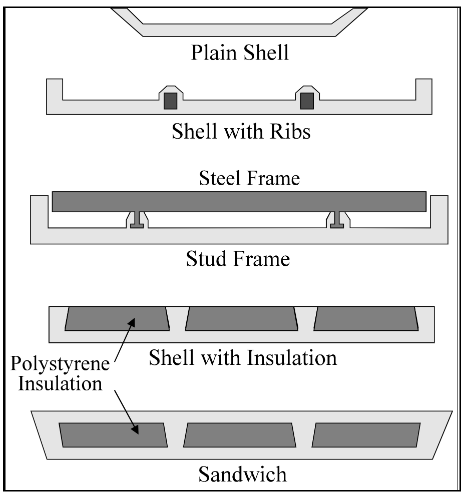

Figure 3: Types of GRC Panels

THE AUDIT OF THE ACTUAL PROCESS

The Actual Process

The complete process of GRC facade panels manufacturing is divided in three steps: panel geometry design, off-site manufacturing and on-site assembly.

The panels design is obtained from building facades division, as shown in Figure 4. The facade partition must follows several rules: constructive restrictions, aesthetic criteria, transport and assembly capabilities, etc. see (Pastor et al. 2001). The panel design is used to construct a wood model of panel. This model is used to make one or several moulds of the panel in the same GRC material. The number of panel moulds is a decisive factor to define manufacturing planing and panels delivery to on-site assembly in building facade. However, usually only one mould is made because his cost is very high.

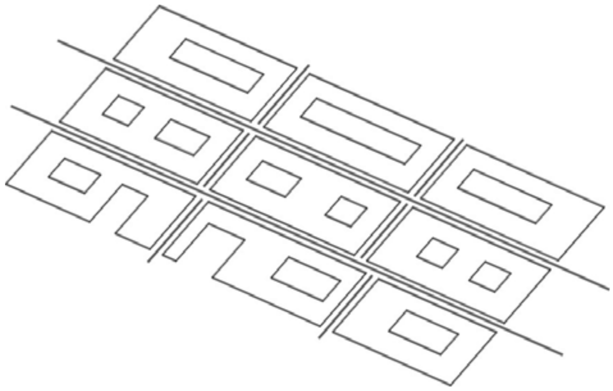

Figure 4. Facade Division in Panels.

To sum up, the manufacturing process is composed of the next tasks, see detailed information in (Peñin et al. 1998):

a) Mould cleaning and preparing for spraying
b) Successive sprayings and compactions of GRC layers depending on the type of panel.
c) Auxiliary elements positioning
d) Panel hardening during ten hours
e) Panel extraction and gathering with cranes

The process is made by hand, as shown in Figure 5, where we can see manual spraying and compacting.

Figure 5. Manual spraying and compacting operations

The last step is the panel transport by lorry, and panel assembly on facade building. The panel is usually welded or screwed down to the building structure.

The Process Audit

The first step of the study has been an audit, (Law 2000). The actual process is manual and must be understood before the automation study.

The production process is not linear but a one-station process. At each of the nine stations, the operations might be divided into, preparing operations, GRC spraying, layers compacting and finishing operations, see Figure 6.

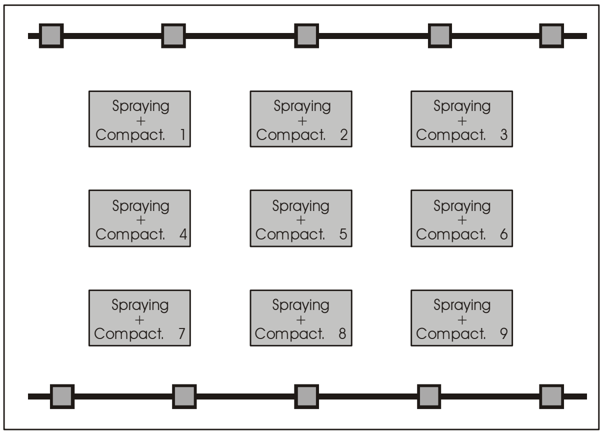

Figure 6: Current One-Station Process

To complete the audit, historical values are obtained to quantify the percentage per type of product and per size of the panel, as shown in Figure 7.

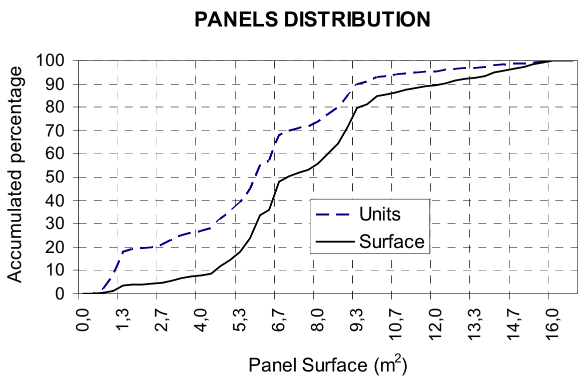

Figure 7: Statistic of Panels Surface Distribution

The first conclusion is that the manufacturing philosophy had to be changed from the fixed stations and the movement of operations between stations to an automated line in which a robot performs the spraying operations and the panels move between manual compacting stations with a set of conveyors. The main side effect is the specialisation of operators as well as the possibility of increasing the size of the panels thanks to robot spraying. The dimensions of the panel to be manufactured in the automated system are 7 m. long x 3,5 m. wide, total surface of 24,5 m^2.

The statistic study collects information of nine buildings with around 5.000 panels and a total surface of 48.000 m^2. The manufacturing percentages of different kind of panels grouped in Shells and Sandwich are: 35% of Shells and 65% of Sandwich.

Due to the initial ignorance on how to optimize the new layout, a simulation model was developed in order to model the initial ideas and test new ones. The simulation tool used to make the model is the last version of SIMFACTORY of Caci company, see program interface in Figure 8.

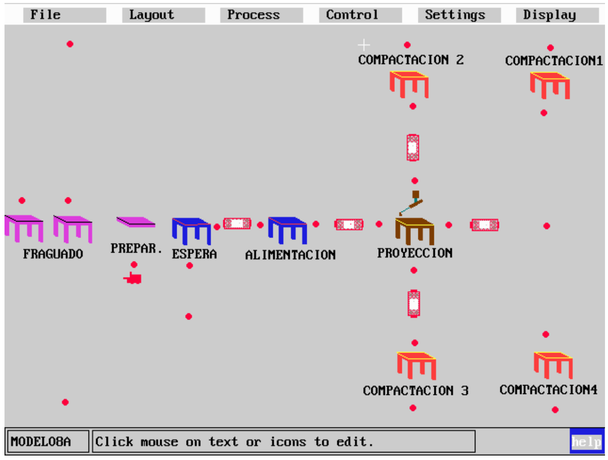

Figure 8: SIMFACTORY Interface

For that reason, a parameterized model was built in which the following variables could be modified:

- ♣ Number of spraying stations
- ♣ Number of compacting stations
- ♣ Number of compacting teams of operators
- ♣ Number of operators per compacting team
- ♣ Conveyor system and its control
- ♣ Feeding system
- ♣ Percentage of inefficiencies
- ♣ Assigning operators to zones or tasks
- ♣ Sequencing of panels

The main decision variables were determined to be:

- ♣ Throughput in an 8 hour shift per product
- ♣ Operators utilization
- ♣ Robot utilization

In order to do a more realistic and reliable simulation, processes times has been obtained directly from one of DRACE factories in Torrejón de Ardoz near Madrid.

The times of preparation operations before spraying and compacting are:

- Cleaning and oiling: 1,7 min/m^2
- Mould preparing: 3,2 min/m^2

The operation times after spraying and compacting are:

- Demoulding: 1,3 min/m^2.
- Panel extraction: 1,2 min/m^2.
- Panel gathering: 1,9 min/m^2.

In short, the robot spraying times and compacting times are summarised in Table 1 and Table 2, respectively. Panel are classified in three groups depending of his surface: Small (1-8 m^2), Medium (8-12 m^2) and Large (12-24 m^2). The units of robot spraying times are min/m^2, and the units of compacting times are min/(team·m^2) with three operator per team.

Table 1. Robot Spraying Times

Phase	Panel Type	Small Panel	Medium Panel	Large Panel
1	Shell	1,48	2,96	4,44
2	Shell	1,04	2,08	3,12
1	Sandwich	0,92	1,84	2,76
2	Sandwich	1,20	2,40	3,60
3	Sandwich	1,28	2,56	3,84
4	Sandwich	1,12	2,24	3,36

Robot spraying times are obtained from manual spraying taken into account that the velocity and flow can be greater than those in manual spraying. The supposition is that the robot velocity and flow are double that the ones in manual operation.

Table 2. Compacting Times

Phase	Panel Type	Small Panel	Medium Panel	Large Panel
1	Shell	3,52	7,04	10,56
2	Shell	4,10	8,25	12,43
1	Sandwich	3,52	7,04	10,56
2	Sandwich	2,48	4,96	7,44
3	Sandwich	2,48	4,96	7,44
4	Sandwich	4,10	8,25	12,43

The maximum throughput taking into account only the robot spraying capacity with 25% of inefficiencies is around 380 m^2/shift, with the same distribution of kinds and panel surfaces obtained from statistical studies.

THE SIMULATION STUDY

With the frameset correctly in place (input and output variables and the simulation model), it was the time to experiment with the model. The improvement routine in this case was based on an intelligent trial and error procedure in which all the people involved had something to say after each individual model was set, run and analyzed. It was an iterative process of learning and adding the acquired knowledge to the system.

What was crucial was that management, operators, automation specialists and software developers worked together in the definition of the input values and the restriction. As it turned out, the biggest restrictions were in terms of money and the control of the transportation systems, which requires a complicated software to develop and run.

The first considerations help reduce model variables. The number of spraying stations will be one, mainly due to robotized spraying cell costs. The reasonable number of compacting stations according to the tables of process times will be between two and four and the number of teams will be no more than one per table, i.e. between two and four. The number of operators per team will be between two, the minimum to do the compacting task, and four, the maximum to work in a table.

The simulation models are developed from several proposed lay-outs. The lay-outs represent an organisation of the work stations and transportation system. The iterative lay-outs evolution is based on the successive simulation results. The first lay-out was proposed by DRACE company, Figure 9, with one spraying station and three compaction stations.

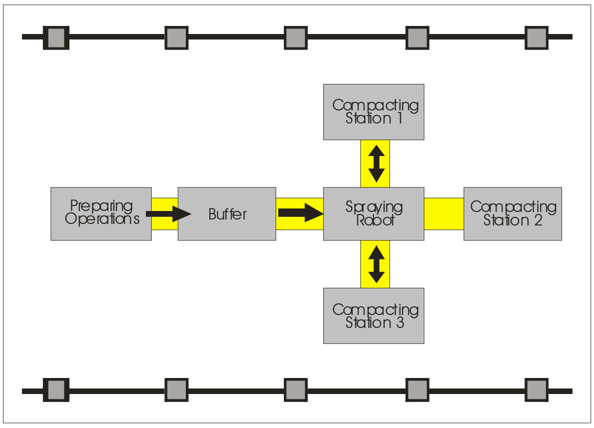

Figure 9: Lay-Out 1

The first simulation results, see Table 3, and the usual work organisation show that the best number of operators per compaction team is three. This is mainly due to the distribution of the different compaction subtasks.

Tabla 3. Simulation Results for Lay-out 1

Lay-out	Nº teams - Nº Oper	m^2/ 8H	m^2/ 8h Oper.	Robot %	Team %
1	2 - 2	185	46,2	35	85
1	3 - 2	211	35,1	39	67
1	4 - 2	229	28,6	42	48
1	2 - 3	268	44,7	51	82
1	3 - 3	288	32,0	55	61
1	4 - 3	315	26,5	60	45
1	2 - 4	316	39,5	60	73
1	3 - 4	320	26,7	61	51
1	4 - 4	337	21,1	63	36

The second proposed lay-out, Figure 10, adds one compaction station and the movement of the robot between two positions of panel moulds in spraying station, one awaiting while spraying in the other one.

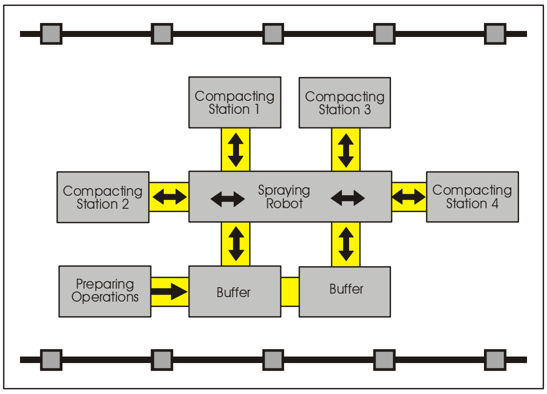

Figure 10: Lay-Out 2

The third proposed lay-out, Figure 11, follows the same philosophy, with slightly different station distribution and transportation system.

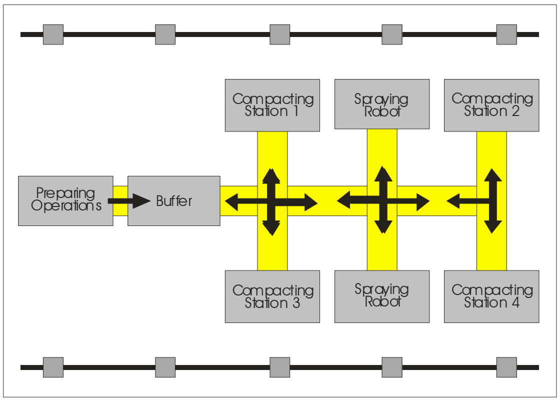

Figure 11: Lay-Out 3

The fourth lay-out, Figure 12, changes the transport organisation. It is a circulating system to do the successive GRC layers in each complete turn. The robot is now in a fixed position.

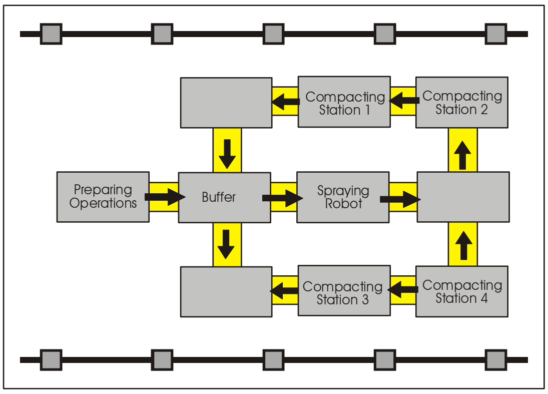

Figure 12: Lay-Out 4

The simulations results obtained to compare with the proposed lay-out are shown in Table 4.

Table 4. Simulations Results for Proposed Lay-outs

Lay-out	Nº teams - Nº Oper.	M^2/ 8H	m^2/ 8h Oper.	Robot %	Team %
1	2 - 3	268	44,7	51	82
1	3 - 3	288	32,0	55	61
1	4 - 3	315	26,5	60	45
2	2 - 3	296	49,3	59	90
2	3 - 3	380	42,2	75	81
2	4 - 3	438	36,5	87	62
3	2 - 3	292	48,7	58	89
3	3 - 3	371	41,2	73	80
3	4 - 3	429	35,7	86	61
4	2 - 3	302	50,3	60	92
4	3 - 3	386	42,9	77	81
4	4 - 3	440	36,7	88	62

These results show that the first proposed lay-out can be discarded because of his low throughput compared to the other ones. The results of lay-outs 3 and 4 are good, but similar to lay-out 2, which is a less expensive system.

Table 4 shows too that the use of four teams has a pour efficiency with small throughput increment. The best option is manufacturing usually with two compacting teams and with three teams in peak productions.

The last proposed lay-out, Figure 13, try to join the advantages of the lay-out 1, simplicity and lower cost, and the lay-out 2, good results with high efficiency.

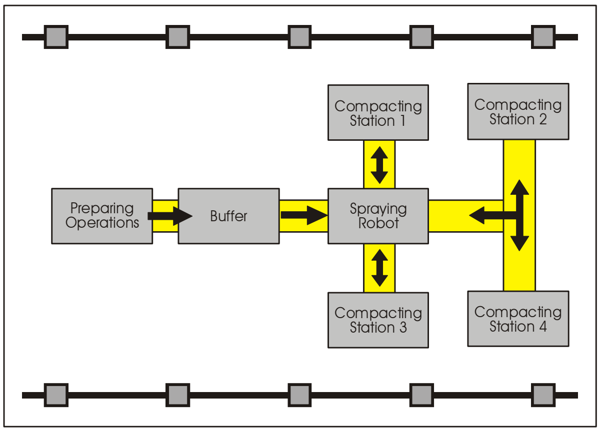

Figure 13: Lay-Out 5 Proposed after Simulation Study

The simulation results, collected in Table 5, permit the comparison of the lay-out 2 with the last proposed lay-out. Lay-out 5 has slightly lower results than lay-out 2, however its lower cost and simplicity justify the election of this final proposal.

Other simulation models were developed with the same lay-out to analyse other characteristics. One type of modelling assigns each panel and two work stations to a compaction team. These restrictions bear a small reduction of efficiency, however they suppose a better work organisation to assign responsibilities to teams.

Table 5. Simulation Results

Lay-out	Nº teams - Nº Oper.	M^2/ 8H	m^2/ 8h Oper.	Robot %	Team %
2	2 de 3	268	44,7	51	82
2	3 de 3	288	32,0	55	61
4	2 de 3	255	42,5	50	80
4	3 de 3	271	30,0	53	59

Other family of models analyses the influence of panel sequencing with several criteria: random, by panel type, by panel surface. The best results were obtained sequencing panel by type, from more simple to more complex. Each type must be sequenced by surface, from lower surface to higher surface.

CONCLUSION

The conclusion is what came out of the simulation analysis was the layout represented in Figure 5.
The chosen lay-out is the one represented in Figure 5.

It gives a robust design both under normal operation and under the presence of inefficiencies. Even losses of 25% only result in a 5-8% decrease in throughput with an 80% utilisation of the robot. The theoretical increase of throughput over the manual manufacturing process is of 15%, which is enough for management to proceed with the installation.

It is very important that the sequence of panels is planned by type and surface to optimise the system production. It is advisable to assign to each compaction team two work stations for arriving panels.

VALIDATION: THE BIRTH OF A NEW PROJECT

After year and a half of operation with the robot, it was time to assess if the results of the simulation model were correct. The utilization of the operators shows an increase of 10%, that, with the 80% utilization of the robot results in a total increase of a 12%. The difference was assigned to some of the new handling operations that take more than initially foreseen.

However the amortization of the robot was well on its way. So well, that the simulation project for the automation of the compacting operations is already under way.

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