Fig. 19 a) CAD 3D facade drawing and b) panel mould obtained by facade partition

PLANNING OF THE ON-SITE ASSEMBLY

Once the facade panels of the building are obtained, it is necessary to plan their transport and assembly on-site, see Fig. 20. The architectural design of the building can also be used as starting point for the on-site assembly planning of the pre-fabricated elements. This planning consider the rhythm of the on-site works and the resources available for the assembly operations.

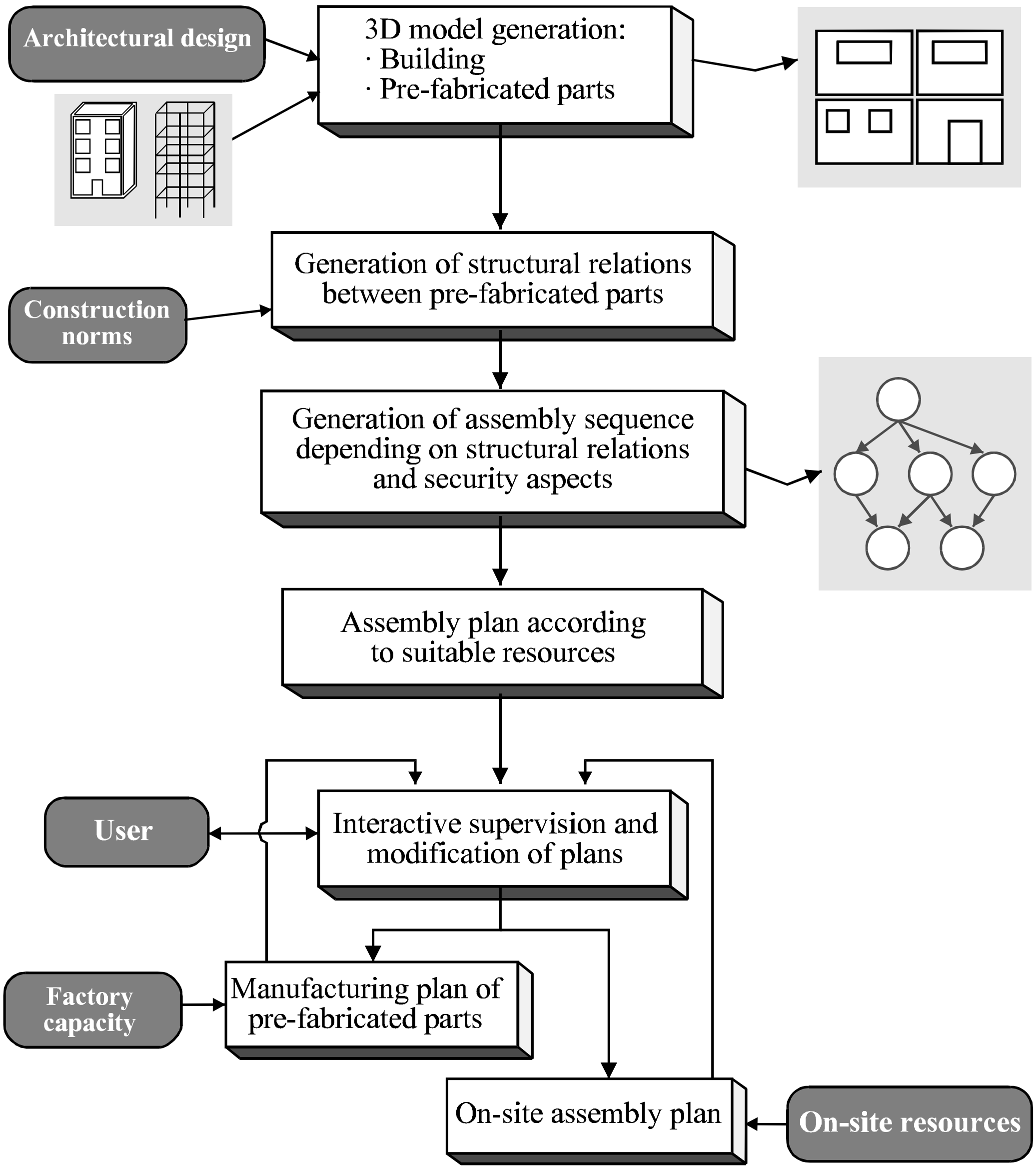

Fig. 20 Planning to assemble pre-fabricated parts

ON-LINE MANUFACTURING MODULE

The automation of the panels production is performed using the automatic generation of all the trajectories and tasks' sequences of manufacturing [11]. This generation uses the three-dimensional solid model of each mould obtained in the previous stage as input information [12]. This process goes through of several stages that could summarised in:

a) Generation of manufacturing tasks

For each panel, the operator must specify various general process and tool parameters, which normally remain fixed for several panels. Finally, the operator can launch the automatic process generation in the CAD environment.

Spraying rules: task path planning process depends mainly on some spraying rules that were obtained from a careful study of manual spraying.

b) Robot path planning

There are several steps in the automatic robot path-planning algorithm. This algorithm receives data of the 3D mould drawing together with the spraying parameters, and it generates the real robot path and manufacturing commands (Fig. 21).

b.1) Robot path generation. The path planning algorithm works in first place with a spraying path only and then transforms it to a robot path [13]. From the mould data (Fig. 21a) a theoretical spraying gun path (Fig. 21b) and a real spraying path (Fig. 21c) are calculated.

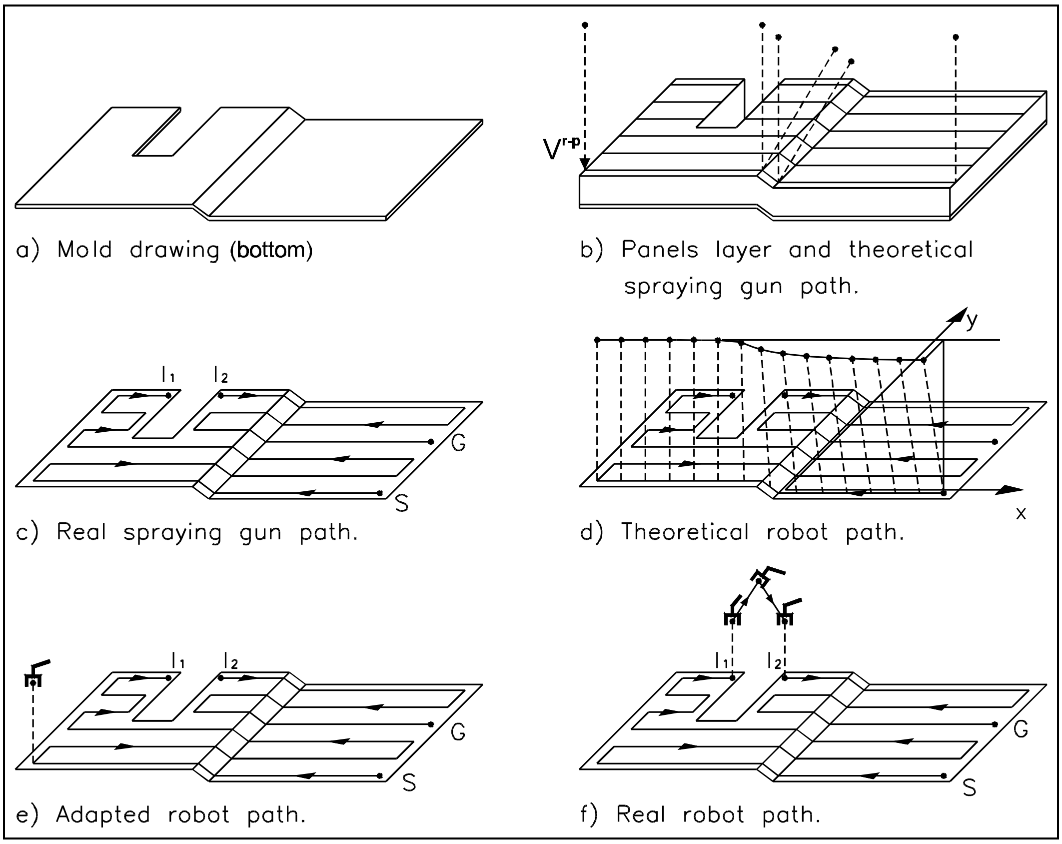

Fig. 21 Robot path planning steps

b.2) Kinematics robot path. The objective is to position the robot with the appropriate theoretical orientation over the panel (Fig. 21d). Following, the robot kinematics is analysed for the first time generating de adapted robot path (Fig. 21e).

b.3) Robot approach and retreat. The final step in the path planning is the generation of a real robot path (Fig. 21f) through the use of robot approach and retreat algorithms.

c) On-line control of the robot cell

The manufacturing of a GRC panel goes through several stages: 1) mould preparation (including the placement of clamps for later assembly on site), 2) spraying/compacting, 3) hardening, 4) panel extraction from the mould, and 5) curing.

c.1) System Architecture. Fig. 22 shows a scheme of the cell. The main elements are: spraying robot, spraying gun, on-line main computer, off-line computer, Programmable Logic Computers (PLCs) and roller conveyor

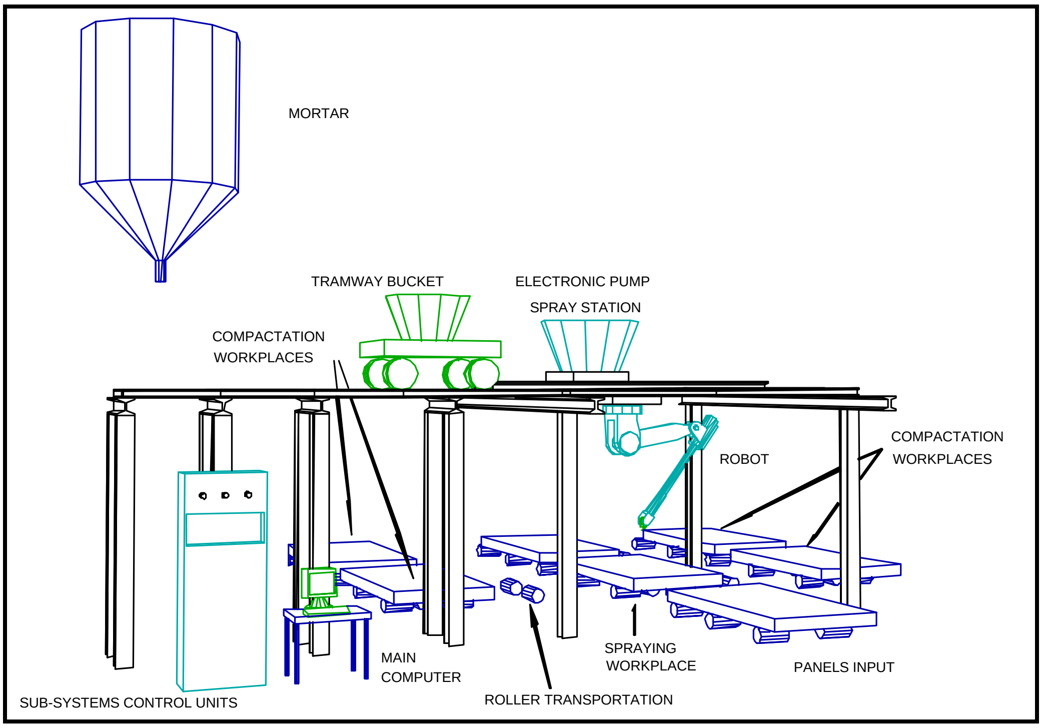

Fig. 22 Scheme of the cell

c.2) User interface. Fig. 23 shows the man-machine interface during on-line control of the cell. Different user friendly menus allow the interaction with the cell.

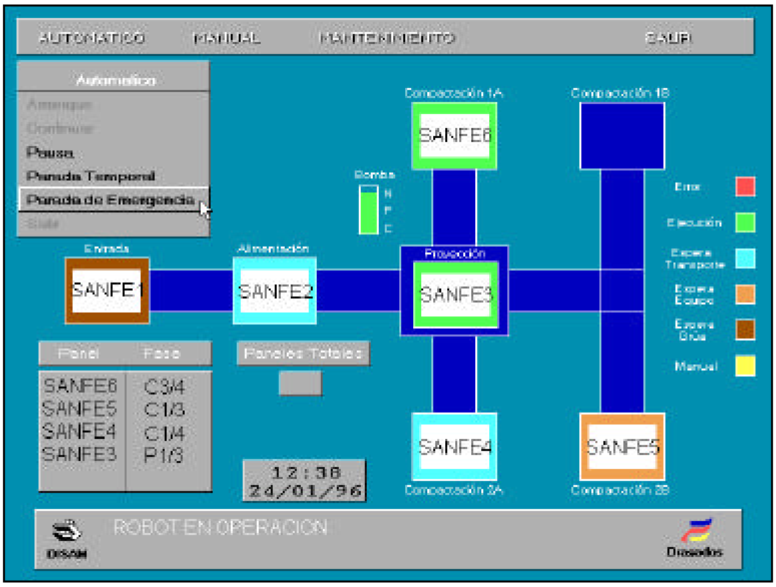

Fig. 23 Man-machine interface

EVALUATION STUDY

To evaluate the achieved improvements the developed automatic panel design system is compared to traditional design. The comparative study is based on two key factors: product life cycle time and overall productivity [14]. The panel manufacturing time cycle can be divided into two different phases: a) mould design and drawing followed by path planning, and b) manufacturing in factory. The first phase, which is performed completely off-line, can be done in the technical office.

The life cycle to construct building facade with prefabricated parts is formed by two different phases: off-site operations and on-site assembly. Firstly we have automated the off-site operations which are:

- Building design, that is the input for next automated processes
- Facade design
- Establishing facade specifications
- Facade division in parts

- Production and assembly planning
- Automatic generation of tasks to manufacture facade parts
- Graphic simulation of manufacturing operations

The process is very similar to manufacture special parts, in this case we design the part and then we obtain the mould to manufacture it. When we have the panel the process is the same as the one described previously for panels obtained from the automated process.

OFF-LINE PROCESSES¡Error! Marcador no definido.	Time (min.)			
	Manual	A	B	C
Facade design	180	22		
Facade division	30	10		
Manual modifications of facade division	40		15	
Panel and mould generation	90	9	9	
Tasks generation	150	18	18	
Manual modification of tasks	60			20
Production planning	20	3	3	3
Total time		62	40	23

Table 1 Off-line operations times

Despite of the several advantages of the proposed automatic design and manufacturing system, it is necessary to stress one of the most important contribution of this work, which is the implementation of the CIC concept making easy access and sharing information. Some of the operations were already done in a more or less efficient way, but the necessary integration of the information did not exist.

Regarding the off-line works the analysis of the productivity leads to analysing the execution times of each operation. Table 1 presents estimation times for each phase. The facade design is carried out having as input data the building design. The A option represents the required time in order to generate a new facade from a building design. The B option represents the required time in order to modify the division of a previously calculated facade. Finally the C option represents the required time in order to adjust the production parameters and generate new tasks.

CONCLUSIONS

The developed system (Fig. 24) presents a new step towards fully automatic prefabricated manufacturing. The development of this system has shown some of the great advantages that automation can bring into quality and productivity in an off-site manufacturing process of construction.

Toda la arquitectura software se ha montado para la empresa constructora española Dragados sobre AutoCAD Version 14, donde se han programado todos los algoritmos de división de fachadas que se han desarrollado mediante programación orientada a objetos utilizando Visual C++ Version 6.

Con la ayuda del entorno CAD se estan fabricando paneles de todo tipo, partiendo del diseño CAD 3D del edificio. Se han mejorado sustanciamente los tiempos de ciclo desde que se entregan los planos del edificio hasta que comienza la fabricación de los paneles de la fachada. La oficina técnica y las bases de datos residen en la sede central de la compañía, que estan conectadas con las fabricas que reciben las ordenes y programas de fabricación.

This research project has had a total duration of more than two and a half years. It proves that new robotic technologies can be introduced in construction industry with good results. The research done during this time has also contributed to a better understanding of the production process and to search for new ways of automation.

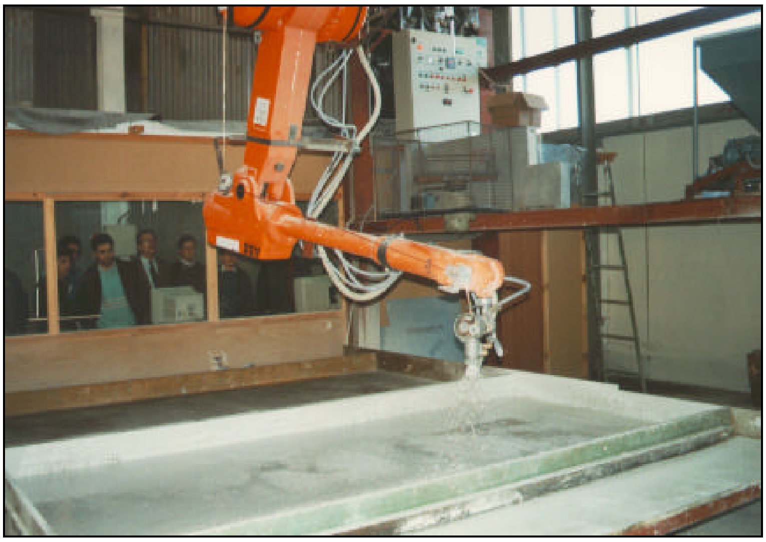

Fig. 24 developed system

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