Development and preliminary Evaluation of a concept for a Modular End-Effector for automated/robotic Facade Panel Installation in Building Renovation

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Abstract

This paper focuses on the Actuators and End effectors used in a robotized and automated process for the installation of customized façade components. It has to be said that those Actuators and End Effectors must be designed co-coordinately with the rest of the issues that determine the upgrading of the building. Depending on the strategy for fixing the component, the end-effectors will be arranged in a way or in another. The component installation process consists of two main steps. First, a separate connector is fixed on the façade using a specific End Effectors. This connector enables a fast clip or fastening of the component. Once the accurate coordinates of the connectors are measured, the component is manufactured with precision offside. After that, using another specific End Effector, the component is uploaded to its place and fastened. This paper proposes a Modular End-Effector (MEE) that hosts different End Effectors and Actuators. In order to evaluate the performance of the proposed MEE, a virtual simulation in SolidEdge© has been carried out. The results of the performance have been analyzed and compared with the traditional manual methods.

Keywords: Modular End-Effector, actuator, façade, upgrading, robotic.

1. Introduction and Research Question

In Europe, the general policy is to ameliorate existing building facades to improve the insulating properties of the existing building stock. (**1**). There is a big and potential market for the envelope upgrading process. The BPIE organization assumes that there will be around 38 billion m² useful floor area in 2050 (**2**). It has to be mentioned that there are already recent studies on using prefab-panels for ameliorating the exterior of the building (**3** and **4**). The general and usual technique for installing those prefab panels consist of fixing or anchoring a connector onto the existing façade first and mounting the prefab panel in the connector after.

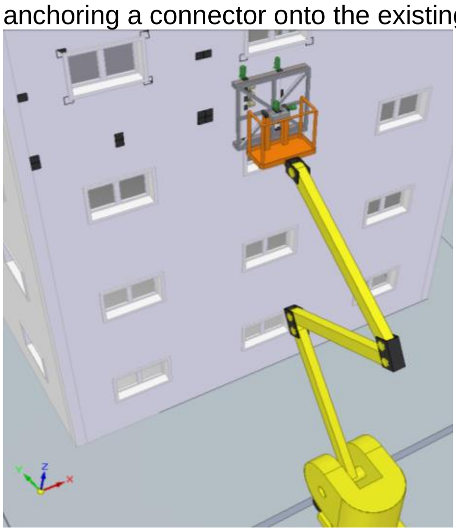
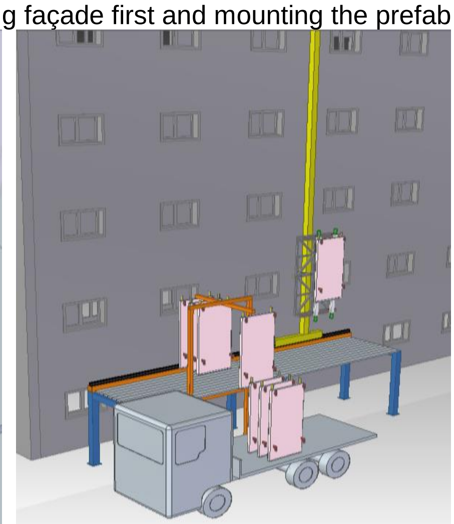
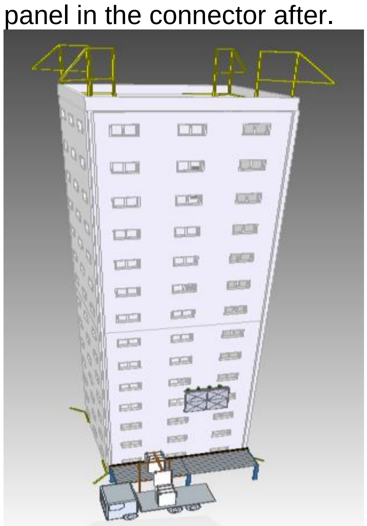




Figure 1(left): Connector fixation process with an Aerial Work platform. Figure 2 (middle):the MEE is used by an Automated Vertical Bridge crane. We can see the MEE elevating the facade component. Figure 3 (right): It also has been considered the choice of using the MEE as a cable suspended device.

There has been a previous study (**5**) to check that the proposed MEE is flexible enough for being used by different robot bodies. This previous study foresaw that certain robot bodies are more appropriate for certain building types. For instance, the Aerial Work Platform type of body (figure1) is more suitable for Single buildings, while the cable suspended devices are more appropriate for high rise buildings. Moreover, we can state that the proposed MEE can be used in different automation levels, from semi-manual (figure 1) to fully automated (figures 2 and 3). But some issues need to be solved in order to carry out the robotic and automated installation process. Within the preliminary definition of this System, we have considered necessary to check that first conception of the proposal do fulfill with some physical and efficiency requirements. So the research question here is, **does the proposed Modular End-Effector (MEE) System fulfill physical and efficiency parameters?** This preliminary evaluation of the MEE has focused on:

- Structural behavior of the proposed Modular End Effector system. The MEE is a mechanic construction that needs to fulfil some parameters. Basically, we ask to the MEE structure not to have big diferential displacements. A big displacement would produce errors on the accuracy of the performance of the End-Effectors while fulfilling a task. We need to know if the accuracy level achieved by the MEE is reasonable enough so we can manufacture and install the prefab component with sufficient tolerances.
- Operability performance of the Modular End Effector system. In order to carry out a successful research and posterior marketing about the MEE, we need to if the proposal is feasible in operability and efficiency terms. And derived from the efficiency, we can foresee, in the next step of the research, if the proposed MEE is competitive in the building facade renovation market.

In order to carry out properly our research, first we have analyzed the existing technology on End Effectors and tools used for construction. We have excluded from our research field techniques related to Additive techniques, such as 3D printing or Carbon Fiber Layup. We find very interesting to apply these techniques, especially for creating customized connector directly fabricated on the surface of the façade, but we leave this option for a future research project. If we analyze the Actuators and end Effectors on a fully automated and robotic product assembly line (for cars, household appliances or even ships), it is obvious to conclude that we cannot extrapolate directly these techniques to the fixation of the components in existing external and vertical building skins. It is needed a co-adaptation of the existing tools and façade components, in other words, a coordinated development is necessary. There are some other proposals for the Automation of Façade installation processes (**6**), but maybe those are not suitable for the renovation of existing buildings. We have to take into account that our tasks must be undertaken from the exterior of the building; therefore, the strategy for carrying out the task is different and diverse depending the building typology.

Evaluation of existing Tools and End Effectors used for the fixation of elements.			
Type	Automated Scredriver	AutoFeed ScrewDriving System	Powder actuated tool
Size	Variable	Similar to a crewdriver	Around 450 x 80x 180 mm
Weight	High	From 2 to 7 Kg	From 2 to 10 Kg
Feeding system	Apart, needs a feeding unit	Integrated	Integrated
Operating time	Moderate	Moderate	Fast
Operative in Concrete	No	Yes	Yes
Reaction forces	Low	Low	High
Power	Electric	Electric	Chemical propellant charge
Used in Automation	Yes	No records	No records

Table 1: As we can see in the table, the performance of the different tools varies from one to another.

Previous to this research, we have analyzed several existing End Effectors (**7**). We have to focus on three main tasks: drill, fix and temporary grip. Some research on flexible drilling heads can be interesting to implement in the construction field (**8, 9**). Besides, on the field of fixation of elements, we can find Screwdriver End Effectors that are used either manually or by Industrial Robots (**10**). In this case, the feeding mechanism is separated from the screw-driving unit, which in principle, it is not desirable for our case. Besides, we can consider this system too heavy for our proposal. For our purposes, it suits better the so called AutoFeed ScrewDriving System (**11**). Those are based on a Cartridge and a Magazine, this last is normally flexible band. Both equipments are attached to the screwing unit. This type is very common in Construction, but unfortunately there is no record of using this system in automated procedures. And finally, we have the Powder-Actuated Tool or nailing gun (**12**). This tool can be considered as extremely fast as it doesn't need a previous hole, not in the connector, not in the wall, the nail is inserted directly. But it can generate to the MEE a heavy reaction force, which in principle it is not desirable. As we can see in table 1, probably the most convenient type of End Effector for our purpose is to use or adapt the AutoFeed ScrewDriving System.

In order to provide stability to our system, we are looking for a way to temporary fix the MEE in order to gain accuracy while performing. The suction fixtures do not provide enough gripping force. Therefore we would look for mechanical solutions. Some climbing robots are quite explanatory and appropriate to fulfill our task (**13**). Somehow, as we are using robot bodies that differ reasonably from one to another, we need to find a type of fixation that is adaptable. In principle, the best and simpler solution would be to hold the proposed MEE to be handled in two single points.

Besides, the Robot Oriented Design (ROD) has guided the conception of the façade connector and component. The previous works (**14**) must be used as an example to conceive the components to be installed (figure 10). Concepts such as Clear and Simple Design, Easiness of Orientation, Compliance or submissive design, and Facilities for component transportation have been put into practice and therefore a redesign of existing building elements has been approached. A good example is the SMART (**15**) system, where the main construction elements where modified in order to facilitate a rapid assembly on site. The design of the façade component and the joinery system must be oriented to the robotic fixation onto the façade.

2. Methodology

The methodology itself can be considered as an adaptation and simplification of the TRIZ method (**16**). We have chosen TRIZ because it is a suitable tool for technological development. We have customized it for our own research. Following the method, first there has been a Definition of the tasks the Actuators and end Effectors must fulfill. This can be considered as the ``ideal situation´´ that the TRIZ method proposes. In this ideal situation, there are no physical constrains. As said before, the proposed installation process foresees some steps. It starts with the fixation of a connector, which is basically a plate that needs to be attached to the existing facade. Once the connector is fixed, the facade component that has been delivered to the site must be uploaded to the proper place and clipped onto the connectors. How can we achieve the technology to fulfill this process? In order to Develop the Actuators and End Effectors, we need to define different sub-processes.We have considered that each sub-process will be carried out by a different End Effector. Those sub-processes must be solved separately. We have considered that the connector needs to be screw-drived with fasteners. The first sub-process is to drill four perforations. After that, within the second sub-process, another End Effector places and holds the connector in its proper place. Simultaneously, a four headed screwdriver with automated feeding inserts the fastener with its own wall plug. The next sub-system is to upload and clip the component, which in principle seems simpler. But it is needed a specific End Effector for holding the component while uploading and clipping process.

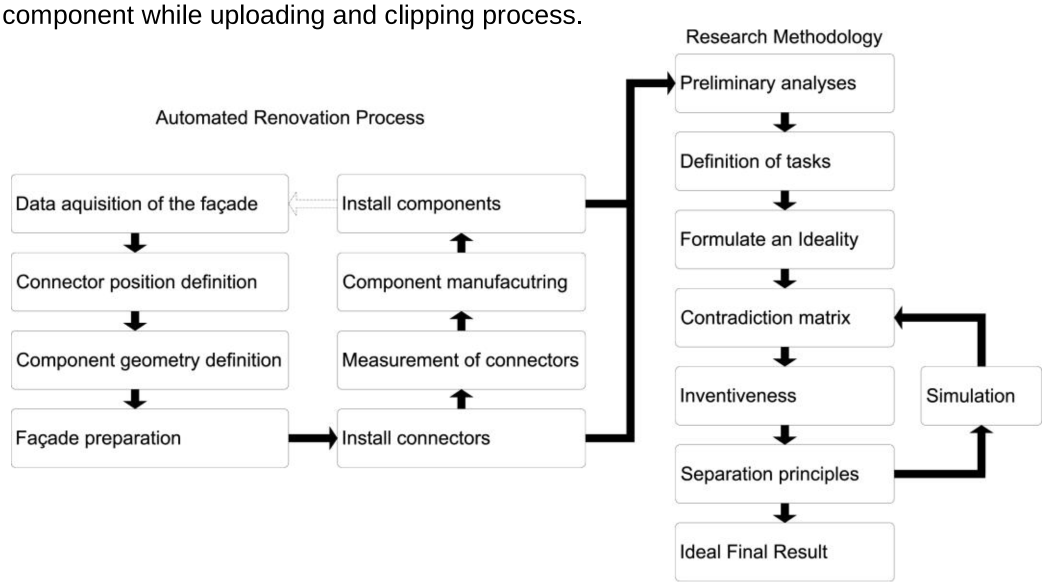


Figure 4:Brief scheme of the research method and its connection to the Building facade Renovation process.

There has been an ``inventive´´ process for conceiving new solutions. As in every new technical conception, each of the adopted solutions may generate a ``contradiction´´ which needs to be solved. The TRIZ method considers different type of contradictions. In our case, we will focus for now in two aspects. One is the Physical aspect, related to the physical properties of the solutions. The other is related to the Performance or

efficiency; we must know if the solutions are feasible in terms of operability. In order to check that the proposals work properly, the adopted solutions need to be simulated. For that purpose, the software SolidEdge© has been used. This software offers the possibility to animate the 3D model, which is very necessary for measuring the time required for the installation process. Besides, the SolidEdge© can test the physical properties of the elements and components of the adopted solution. The results generated from the simulation have been analyzed. In the case of the efficiency tests, the results have been compared to manual methods. In the case of the physical properties, the stress and displacement of the component has been checked. Especially the displacement of the elements is a quite important issue, if want to achieve the accuracy of the End Effectors and Actuators.
During the conception of the proposals, some of the solutions have been refused due to their non-optimal operability o unsatisfactory result due to physical restrictions. Therefore, we will focus for now in more down to earth solutions. In the end, the final solution can be considered as the most optimal and feasible gathered until now.

3. Development of the Modular End-Effector

As said before, some different Actuators and end Effectors have been conceived. These actuators are not single tools that actuate individually in a separate robot body, but they actuate coordinately in a common MEE. This MEE can be considered as the gathering of multitude of interrelated subsystems. The MEE will be moved all over the façade surface by the robot body (see figure 5). This MEE is basically a Gantry that operates in a vertical plane and that is placed by the main robot body according to the coordinates in the façade. The Actuators have been designed to be common in all cases, let's say for every project. The MEE has been conceived mainly for improving the time of connector fixation. Once the robot body is positioned, it can fix several connectors. For that purpose, the MEE or structure enables the movement of the End Effector within the x, y and z directions. It has to be said that the Fixture (see figure 7) between the MEE and the robot must enable the fixation of various bodies. This fixture must also facilitate two degrees of freedom in order to facilitate the picking up of components.

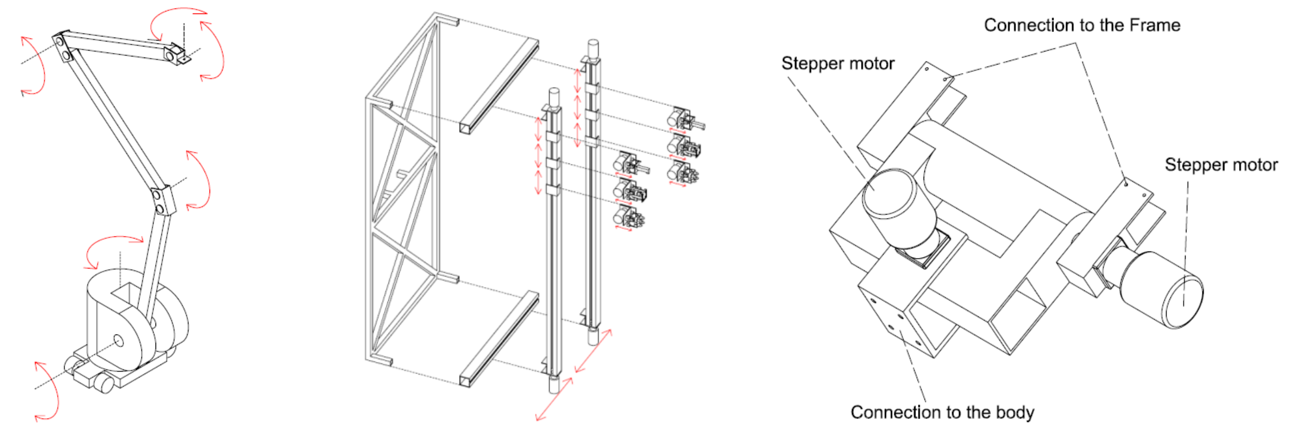
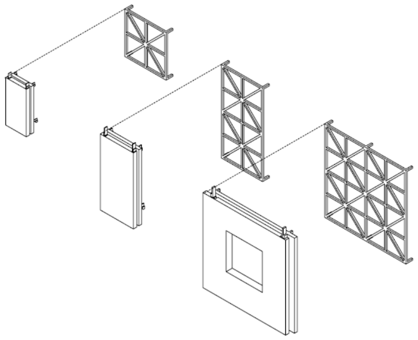
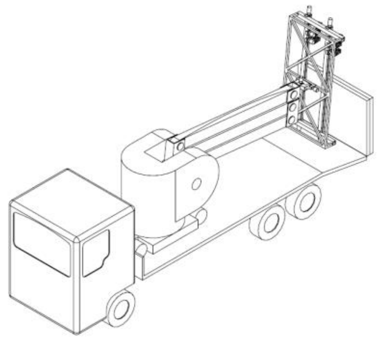


Figure 5 (left): Exploded view of the robot body, MEE. Figure 6 (middle): Exploded view of the MEE. Figure 7(right): fixture that connects the robot body with the MEE.

Regarding to the mechanics, the more flexible way for making move the axe along a guide in our case is to use a linear system based on rack and pinion for moving the moving the main axes parallel to the façade (see figure 6). This way we can gain flexibility on the positioning of the connectors. For the End Effector system that needs to work on an orthogonal direction to the façade, we will use a linear actuator that pushes the End Effector towards and backwards. During the course of the research, then definition of the mechanic elements might change depending on the future simulations and experiments with prototypes. Besides, it is important for the connector fixer to work right away the driller, and it has been pointed out as necessary that both actuators must be in the same axe. This will avoid the double positioning of the actuators; the connector fixer must only follow the path that has accomplished the driller. Besides, the MEE must be flexible and modular in size, in order to be adapted to different sizes of prefab façade component and to different building typologies. The size of this MEE is a factor that will depend on the size of the facade component and the geometry existing building. The Minimum size of the MEE, let's say the minimum module, is limited by the size of the actuator and End-Effector. The MEE must at least have around 150cm for 150cm (figure 8). There will be a second MEE size of 150cm*300m. The maximum size for the MEE will be limited by structural and mechanical reasons. For now, the maximum MEE considered has been of 300cm*300cm. The size of the MEE and the component will have a direct relation with the performance of the installation process. In principle, the biggest the MEE is the more effective in time. It has to be said that the size of the MEE must be taken into account in terms of operability and transportation (figure 9).





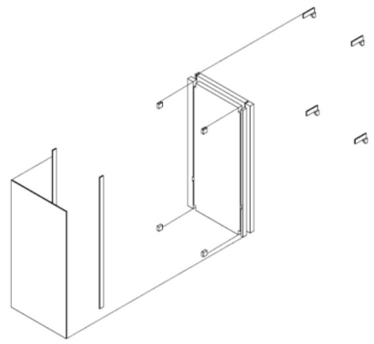
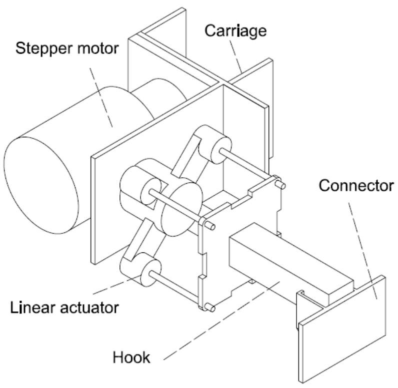
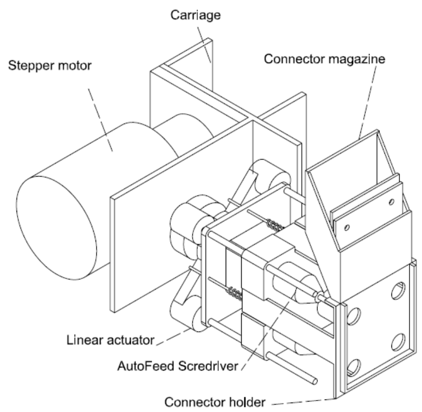


Figure 8 (left): Modularity of the MEE and adapatation to different component size. Figure 9 (middle): operability of the Frae under standard traffic rules. Figure 10(right): The component must be sefigned according ROD principles.





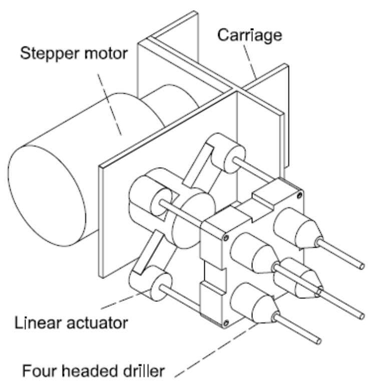


Figure 11 (left): End Effector for Temporary fixation of the MEE to the wall. Figure 12 (left): End Effector for connector fixation. Figure 13 (left): End Effector for drilling.

For the fixation of the panel, we have forecasted two main End Effector types that perform two main tasks: fixation of the connector and fixation of the component. In principle, those two types won’t be hosted at the same time, simultaneously, within the MEE, but separately.

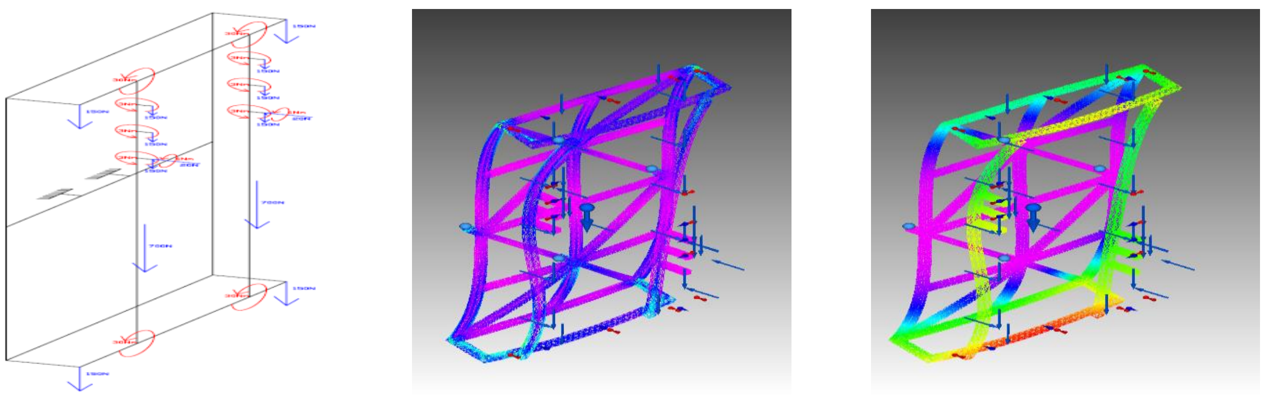
- There is an End Effector for providing stability to the MEE. This is a temporary fixation to the existing wall. It is based on a hook that is inserted on a previously fixed connector. Every MEE needs at least to be fixed to three non parallel connectors, and as precaution measure, four will be used in two different axes or bridges. This fixation will be used also for checking that the connector has been fixed properly and that it supports the required loads.
- Probably, the most complicated among the End Effectors is the connector fixer. This End Effector is mainly based on the existing assembly lines. It consist of several sub End Effectors. First there is a magazine hat stores the connectors and feeds them when needed. There is another magazine that stores the fasteners and a feeder. The screws do already inserted have a plug that will expand when being screwdrived inside the whole. The screwdriving unit is similar to the driller.
- The Driller will perform the second step among the End Effectors. The drilling of the existing wall is performed by of four drillers that work simultaneously.

Finally, regarding to the End effectors for uploading, placement and fixation of the faced component, a set of grippers will be used. The most critical step will be to clip the component once it has been delivered to the site. For now, we are using very simple and standard grippers, there has been no adaptation for now. The authors propose that there must be a storage system near to the site that can be placed at the sidewalk behind the building. This is for facilitating the robot the recognition of the component. Each component also

needs to be identified so the robots knows where has to be placed. The façade component and the connector have been adapted to facilitate the gripping. Basically, the component needs four rebates in order to be gripped properly. The details of the component have been developed in another phase of the overall research.
We can say that there are two positioning systems, one rough or approximate and another more accurate. The first will be referred to the gantry MEE. This can be considered as a temporary fixation of the MEE to the previously placed connectors. Once the MEE has been positioned and locked to a previously fixed connector, the actuator will be accurately moved within the gantry and placed to the projected x,y,z coordinates in order to perform the task. It can be said that the MEE works as a base link (x,y,z). We are still working on the simulation. In the real future robot, the approximation of the MEE will be controlled by an accelerometer, odometer and some other sensors. Besides, the Positioning of the bridge within the gantry MEE will be controlled by linear encoders. There might be a conflict between the two positioning systems, the rough and accurate, so for the future prototype, an algorithm will be used to solve and merge the information received from different sources. The first fixed connector within the façade will serve as a base (0,0,0) or Initial position for the operating robot. So the question here is, who will place the first row of connectors, in order to serve as reference? For now, we will consider to fix it manually. This first connector (or connectors) will serve for calibrating the robot and perform correctly the planned path on the façade. Once a connector has been placed, its position must be recalculated so when the MEE will be gripped to that connector, the MEE knows where to position the next connectors. Basically, it will be needed to Publish and subscribe the position every time, and when the connectors are fixed. To avoid problems derived from unexpected placement of the connector (unexpected coordinate and angle respecting to the facade), the component and the connector must be designed in a way that small adjustments can be fulfilled rapidly and not stop the process. The simulation show that the overall geometry, won't be necessary to re-calculate or re-shape it, only the position on respect to the connector/component. This aspect has been developed in another phase of the research.

4. Simulation

The simulation has been carried out in two levels, the Structure Behavior and the timing performance. For that purpose, we have used the software SolidEdge©. This specific program doesn't consider the interaction with humans, but we have supposed that for the robot is performed by one main operator, and another operator will help and check some other tasks, such as security of the pedestrians and traffic, the control of the arrival of the components and similar. Basically, for now, we have considered that level of automation: two persons per robot unit. Besides, we have considered that the façade to be upgraded is around that 480 square meters, 12 meters high and 40 meters wide. For this specific simulation, the chosen robot body has been the cherry picker type (**5**); the use of this body is limited to 500 Kilograms load, which is a fact for configuring the MEE and the size of the panels.



Figures 13(left), 14 (middle) and 15 (right): Schenme of the forces that are applied on the MEE The figure 8 shows the MEE under stress. The figure 9 shows the MEE's displacement graphic.

Simulation of the structural behavior of the MEE.
One of the main concerns while developing this system has been if the robot and the proposed MEE can bare the foreseen loads, forces and torques. For that purpose, there has been a study of the needs physical,

geometrical of the MEE. In order to simulate the structural behavior of the MEE, we have used the tool called Nastram within SolidEdge©. This tool is based on the Finite Element Method. The structural needs of the MEE are limited by the weight of the end effectors and the weight of the components, the weight of the MEE itself, and the forces of the different elements while performing. For now, we have developed a **Static Analysis**. Those are the forces we have taken into account: For the simulation and its calculation, it has been easier to consider a more simple profiles made out of steel. Rectangular 50mmx50m*x5mm profiles have been used. For this case, the MEE itself would weight around 242,25 Kg. Regarding to the Façade component, approximately, we have considered a component that weights 20 Kg per square meter. For this experiment, as we are using a cherry picker type robot, we will consider a weight of 100 Kilograms for the façade component. The weight of the End Effectors has been estimated in 15 Kilograms each. In total, we have considered a total weight of 90 Kg for the end effectors. The Actuators produce another load to take into account. We have the rack guides Rodless Mechanical Cylinder and linear actuators that create of a load of around 20 kilograms per lineal meter. We have taken a load of 30 Kg for each of the Horizontal actuators. Vertical actuators are 70 Kg each. In total we have 200 Kg for the Actuators. The Torque generated on the drilling process has been considered quite low, 1Nm. The torque generated by the movement of the End Effector and the Vertical actuator are 3Nm and 30Nm respectively. The Horizontal thrust created by the drilling process will depend on the speed of advance of the drill, in the hardness of the material and the diameter of the hole. Thrust reaction forces should be equalized. The MEE as well as the robot body must bear the stress. We have considered a force of 20N. In our process, there are two main load scenarios. One is when the MEE is fixing the connector. And the second is when the panel is uploaded. For the calculation, we have considered necessary to create a virtual load test scenario applying all the forces described previously. This is a very secure driven option, but for now, we will proceed this way. After that, we can optimize the loads, materials and forces.

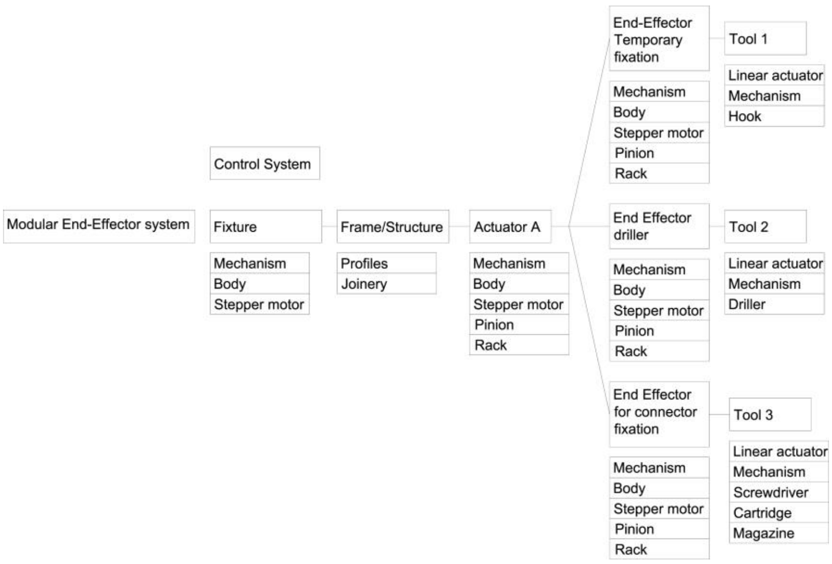


Figure 16: General product structure of the Modular End-Effector

The simulation won't take into account the temporary fixation of the Actuator and End Effector to the existing wall. The Simulation of the structural behavior show that the MEE is strong enough for hosting the loads that have been prescribed. Though, clearly the shape of the MEE must be improved. Besides, there are displacements on the structure that on the worst of the cases reaches 2 mm. This is a critic point that must be solved. The overall weight taken in the simulation gives a total of 632 Kg. So we need a cheery picker type of body that can lift that weight. We can find in the market several, even many, Aerial Work Platforms that, do accomplish that features. We have to take into account that the Aerial Work Platform would work without the platform itself. The shown MEE type was the middle size or double moduled. The reason is that it is the module who suffers bigger loads per linear distance on the supports. On the tests, the results of the small and big seized MEEs have been better under the same circumstances.

Operating time and productivity

The simulation of the performance has been also tested using the program SolidEdge©, for this purpose, the MEE gantry, the actuators and the end effectors have been animated in SolidEdge©. We can see that the time for drilling and fixing a connector is around 2 minutes, including the movement of the MEE all over the facade. This means that in sixteen hours, we can fix a facade of around 480 square meters. This is only related to the fixation of the connector, not taking into account the transportation and placement of the robot body with the MEE. The fixation of the panel can be done just before the finalization of the connector fixation, but for now, we have considered that it is needed an adaptation of the initially predicted geometry of the component.

EVALUATION of MEEs	Big sized	Medium sized	Small sized
Instalaltion time hours/square meter	0,085	0,17	0,255
Component size	3 x 3 meters	3x1,5 meters	1,5x1,5 meters

Table 3: This table shows efficiency and suitability of each MEE for the different size of components.

So at the component manufacturing site, the panels will start being produced once the connectors have been fixed and the accurate coordinates of them have been measured. Or at least, these components can be pre-manufactured and once the accurate coordinates are known, these can be re-adjusted. Therefore, we have considered that the component fixation won't be carried out just after the connector fixation. The time of the fixation of the component within the facade will be some factors. One is the size of the component. The bigger the component, the less time is necessary for covering the whole facade. We have considered here panels of around 3 square meters. For each panel, the simulation has revealed that the component can be installed in around 10 minutes. Therefore, with a single gantry MEE, we will need around 27 hours. The results are quite satisfactory. Comparing to traditional manual methods, we can see that for a square meter, we need around 1.5 and 2.5 working hours per square meter depending on the type of material we need to use (**17**). For the proposed system we need around 0.17 hours per square meters. Therefore there is an improvement of the installation process of around 10/15 times faster, just considering the installation process, not the manufacturing of the component. This doesn't take the time on site. But a fully automated component manufacturing process is arranged, the manufacturing time per square meter is around 0,3 hours. We have tested that the efficiency of the biggest MEE is 50% higher than the middle size, while the smallest module is 50% lower. Therefore, for the future, it will be very important to choose the adequate MEE in order to gain efficiency. As said before, this will be a matter of the building typology and façade component size.

<u>Discussion</u>

Once we have gathered the results of the simulation, the next question here is if the proposal is feasible in economical terms. The intention is that these optimal solutions will discussed by several agents that work on the industry of building façade renovation. For that purpose, we would build a mock up to test that this optimal solution is technically feasible and that can be adapted to the needs of the market. For that purpose, we have listed the elements that are part of the system and estimate their price (table 4). For the first mock up, we will consider a tele-operated, in order to avoid sensors and excessive control systems.

Budget Estimation for the middle sized Mockup,	Number	Unit type	Price per unit	Price
MEE, middle size	243	Kgs of steel structure	40 €	8.240 €
Linear systems, with rack	10	linear meters	300 €	3.000 €
Pinions	10		100 €	1.000 €
Stepper motors	10		400 €	4.000 €
Linear actuators	6		200 €	1.200 €
Drilling system	2		400 €	800 €
Screw driving system	2		500 €	1.000 €
Magazine and its automation	2		1.000 €	2.000 €
Temporary fixation gripping system	2		1.000 €	2.000 €
Fixture to the robot body	1		2.000 €	2.000 €
Controlling system	1		6.000 €	6.000 €
			Total cost	**31.240 €**

Table 4: This table shows the number of elements needed and a rough estimation of the cost for building a prototype of the MEE.

These quantities have to be taken as an estimation and will reviewed in the near future. The cost of build the MEE and joining all parts together is not considered. Neither is the cost for programming the controllers. For a single module MEE, the cost would be slightly lower (25,620 euros), as the main variable would be the Kgs of structure and the linear meters. For the bigger sized, the price would vary ostensibly (39,840 €).

5. Conclusion

In the way for looking a robotic and automated installation process of façade component within existing buildings, this work has been an exercise for checking that the proposed Modular End-Effector system can be applied in real life. On the structural aspect, even though there are displacements that have to be taken into account, we can say that, according to the simulation, structurally the MEE responds adequately to the required solicitations. The next work related to the structure will be to optimize the shape and geometry of the MEE. In that sense, we need to choose adequately the profiles, assembly or joinery system and materials that form the structure for gathering an efficient solution. We will choose among materials and elements that already exist on the market, not only steel or alluminium, but also Carbon Fiber.

Besides, if we look in the aspect of the performance efficiency, the simulation shows a satisfactory result. Therefore we can conclude that the proposed MEE has been a good approach on the direction of gathering an Automated Installation process. For now, we can consider that the viability of the MEE in economic terms is positive. Thus, on the future, we need to define and specify more each of the elements that work on the MEE. And once the elements are totally defined, we need to check that the proposed system works correctly under different circumstances. Some of the issues that should be solved are next:

- There will problems generated due to outdoor conditions. We must consider that the MEE needs adequate protection against weather inclemencies such as rain, snow and strong wind.
- High hardness of the existing façade might be an obstacle for drilling. The End–Effectors must be able to drill properly at least the majority of the façade types.
- Lack cohesion of the existing façade might cause that the screws are not fastened properly, which can generate the loosening of the connector.

To check in real life that the issues related to the structure and operability are correctly solved, a Prototype must be built. First, we are considering to create a manually actuated MEE. In other words, this first prototype will have a low automation level. With this prototype we can experiment that the device works properly under several terms such as structural stability and accuracy of the positioning of the End-Effectors. The experiments will be approached in different physical conditions of façade hardness and cohesion. Besides, some samples of the façade connectors and component will be thoroughly designed and manufactured in order to be used on the experiments. If the results of this Manually Activated MEE are optimal, we will insert in this prototype the Actuators and Control Systems that will make move the End Effectors according to a previously defined code. For the prototype, a specific Robot System Architecture will be designed and put into practice. The current work of the author is being held on simulation using ROS, Gazebo, Moveit and some other specific software. This work will be convenient for defining the controlling system of the automated MEE.

The application of the output of this research within the real life could suppose a step forward on the way for achieving a fully Automated Process for the Building Envelope Renovation and upgrading. The process's steps could be totally linked. Besides, security and efficiency will be gained on site, during installation process.

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