The use of BIM in TEATRO LIRICO restoration project

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Abstract

The paper deals with the employment of advanced methods for restoration project with the implementation of a communication code that focuses on the drawing up of the entire project documentation in a coherent way. It is possible by means of Building Information Modeling (BIM) in association with a structured project analysis such as Work Breakdown Structure (WBS).
The project of Teatro Lirico in Milan has been developed with this methodology for the first time in a restoration project, which requests the improvement of a specific communication code that can ensure congruence and efficiency as required by European Union Public Procurement Directive, with the addition of information about specific location of restoration interventions.
The WBS allows to locate and identify the restorative measures and interventions of the facades of Teatro Lirico. Following, the data of the WBS has been included in the BIM model of the theatre.
The purpose of this dissertation is to describe the methodology that allows to design the fronts of Teatro Lirico with the assurance of a good result through interoperability between BIM and WBS with restorative measures locations.
Finally the correct and coordinated application of Building Information Modeling and Work Breakdown Structure allows a considerable improvement, specifically in a restoration project, of the construction process.

Keywords: Building Information Modeling, Restoration Project; Project Management, Work Breakdown Structure, Restorative intervention location; Communication Code.

1. The issues of the conservation project

The complexity of the conservation project and its contents, its development through differentiated and in some ways heterogeneous moments, the reality of the restoration construction site that requires the installation of specific operating structures, identify actually a complex scenario that imposes the adoption of an information system and a communication code that should allow to face properly the terms and operational issues involved in the process in order to ensure the achievement of the objective and avoid irreversible loss of materials.
The design activity, the management of first information and subsequent choices, but also the operational provisions that will characterize the future construction site must find a support in organizational and management methods for improving the project documentation that exceed the traditional division of responsibilities (architect, structural engineer, plant engineer, quantity surveyor, ..., Director of works, site manager, ..., Manager), recognizing that efficiency in proceedings can only rely on information (see historical documentation geometric relief, relief, material, texture, can characterize the construction site, ...) and the modalities of this communication.
Therefore, the starting point for adjusting the design activity will necessarily be represented by contextual needs analysis, to proceed to their conversion into a generative process of choices, that requires the adoption of suitable tools to support communication, able, on the one hand, to transfer the information framework to all subjects who have an active role in the process, on the other hand allow feedback actions for continuous monitoring of results at all stages of the proceedings.
The uncertainty that may accompany the development of a conservation project and the drafting of relevant documents requires the designer to consider a specific methodology in order to minimize the errors and their propagation in flow of information.
The strategies in the design must follow a path that can create and develop interfaces and reports with which combine efforts for the success of the project, with the specific required knowledge.
Hiring tools able to govern a variety of efforts and fulfill multiple functions, makes it possible to carry out a constant adjustment of the action plan for the evaluation of the choices adopted, relative to the goal post and expected quality levels.

The elaboration of the methodological model is the first step for planning the design and evaluation of the effectiveness of the actions of process (⇆ best practices).
Design choices, the adopted solutions, the contents of documents, ..., require a coordination of the information flow within the project information system to ensure efficiency, effectiveness and risk minimization (for activities, tasks, division, resources, organizational model of the construction site, maintenance and management processes). At any time in the life of the project, the information must support the choices and the adopted solutions.
To manage the proper flow of information it will be required, through systematic and consistent actions, to acquire basic data on which will be developed the procedure in all its phases (feasibility ⇆ preliminary ⇆ final ⇆ executive ⇆ contractor's choice ⇆ execution plans ⇆ construction site ⇆ control actions, ...), to properly process the data to ensure the coherent development of the project, provide and communicate the results of the processing through the deepening of appropriate documents of various kinds: technical, economic, organizational, qualitative/quantitative performance, ..., (⇆ graphic documents, numerical, descriptive, contractual).
The need for an organic development of all design works would require the prior identification of a project analysis structure capable of ensuring the coherence of the management process. Within this process should be the relationship between:

- All content of design choices and technical solutions within the project compliant with the detection and encoding of the classes of technical elements that represent them,
- Classes of technical elements and cost centers (stratigraphy of CET) with identification of price items and their relationship with the adopted pricelist, through the identification of technical characters associated with these voices (BEST method 1.1) [1]
- All contents of the design choices and complying technical solutions (⇆ final, executive, operational design) with the detection and encoding of technical elements that represent them,
- Technical elements and cost centers with the identification and classification of work required through the identification of unit prices aimed at estimating procedures,
- Resources and work voices for identification of needs required for the development of construction site:
    - cost/price of non-ordinary machining (⇆ price analysis),
    - construction site times in applying synthetic or analytical methods,
    - time schedule,
    - correlation with the security and coordination plan,
    - correlation with the maintenance program.

All this implies the adoption of appropriate models for operating in what has been called **project analysis** or **structured analysis**. As we have already seen, this consists in identifying and structuring the management components, both in terms of prefiguration of reality to be obtained (⇆ project target) both in terms of the identification of all activities and all the tools necessary for its realization (⇆ project, race-based documentation, contract, construction site, result management).
The complex reality of conservation project requires that for the achievement of the predetermined results, with substantial satisfaction of all interested parties in the proceeding, we should adopt an information system capable of providing, to the involved division, a group of effective tools to manage all tasks, under a constant control of the quality of the result, the progress of the project and its realization, accumulated costs and support.
It is recalled that the planning of all development phases of a project comes loaded with complex problems that must find consistent solutions, but they are very difficult to manage for the large number of variables involved. In addition, production in the construction sector is characterized by a temporary organization productive structures and itinerant localization (⇆ site), it is necessary to proceed through operational managerial models, that can handle the complexity. This choice requires the acquisition of appropriate business logic through the adoption of an appropriate operation/organizational model.
An acceptable model must make available some general criteria on which to base the development of design dynamics to identify the tools and skills to use during the entire project life cycle and to rationalize the terms of internal communication and the development of a coherent management language aimed at:

- optimizing the design choices
- improvement of contractor choice mode
- consistent develop of all documents of the project
- support for the execution time and its control
- rationalization exercise and maintenance
- minimize the impacts the disposal phase

according to both the choices adopted and the objective to be achieved, within the limits imposed to the designer in terms of quality, costs and implementation times.

2. Optimization of design documentation

The objective necessity of operating a careful character recognition of project requires to develop and adopt a structure of analysis called WBS (Work Breakdown Structure) capable of representing the characters of the project and of the choices made. Through a reasoned decomposition of the project in subprojects or items more and more simple, it is possible to reach the desired level of detail in close relationship with the characters of design choices and design documents as these are provided by project level that you are addressing (preliminary, final, executive).

To ensure effectiveness of the method, the WBS should be set so that each of the labels that will characterize the identified levels of detail, are relevant to at least one project document, highlighting at the same time, the specific technical skills that lead to the assignment of values to variables of compatible form, quality, cost and time, but also the identification of operational resources necessary to the implementation of the project (labor, materials, equipment). [1]

As we have already pointed out to do this, it is necessary to use appropriate organisational and managerial techniques to:

- locate for the project entities, attributes, associations and hierarchies that characterize the project database
- collect and sort all information related to the objective to be achieved
- propose an efficient information system
- enable integration points of responsibilities placed on a network (⇆ project network) where the project manager plays the role of server (⇆ receive and distribute information)
- prepare a planning system and integrated control, capable of supporting all phases of the project life cycle (from concept to disposal)
- coordinate and optimize efforts, resources and results.

The premise of each conservation project (⇆ restoration) is the identification and elaboration of a contextual situation, full of problems that require appropriate solutions, it must find a synthesis capacity to converge in choices consistent with the objective of protection of material stratification and operationally sustainable, in simple terms but exhaustive. For this reason, for the restoration project of the *Teatro Lirico* in Milan, it was essential to proceed through a preliminary stage of analysis, necessary to identify all issues that must be addressed and brought to the solution by adopting appropriate design choices.

From contextual analysis, mediated by exigencies framework indicated in the document preliminary to the design and to the state of building consistency, it is passed to the timely identification of methods of intervention. This phase will consist in selecting general areas that characterize the project, and adopting appropriate choices of detail that must necessarily take account of:

- strategic interest of the intervention
- operational feasibility of individual detail choices
- their compliance with quality levels
- respect of predetermined costs.

Operationally, the design choices have been identified based on the degradation level, the distinctive characteristics of the sub-layer material and the desire to maintain contextual aspects, whose indicators were addressed by the availability of information and the initial forecasts to be later refined, corrected and supplemented, in regard to necessary aftershocks feedbacks.

In general for a restoration project, the necessary actions for the development of the project must follow appropriate planning policy to coordinate and streamline all efforts: objectives and strategies must be put into operational terms through a series of rational choices, order and coordinates, depending on the result to be achieved.

With the planning job it has been possible to organize:

- activities and responsibilities closely related to the achievement of specific objectives
- tasks to be done
- required resources
- indicators to verify/check the progress and the quality of individual actions

From this point of view one of the most important activities in the planning phase of a project was its breakdown according to a structured scheme which enables an effective readability of the problems posed by design theme and whose solution is essential for the achievement of the goal post.

The scheme of representation that is usually adopted is the WBS, translating into a breakdown structure for project problems (⇆ interest areas, items, components, packages, activities, resources, ...) gradually more detailed (identifying ⇆ Work Breakdown Element WBE) interrelated by bonds which show hierarchical relationships that exist between entities that have been identified for this purpose and placed in a suitable position within the structure of analysis (⇆ coordinated and characteristic element of WBS).

The WBS finds its representation through a tree hierarchical graph, where the items placed on the right represent a deepening reason of the labels already assigned to the project. In fact, the substantial meaning of the WBS is to identify all the components of the project according to a scheme that does not neglect any possible appearance (cf. the rule of 100%). Normally in the WBS labels represent the necessary activities or the result you want to achieve in the following diagram.

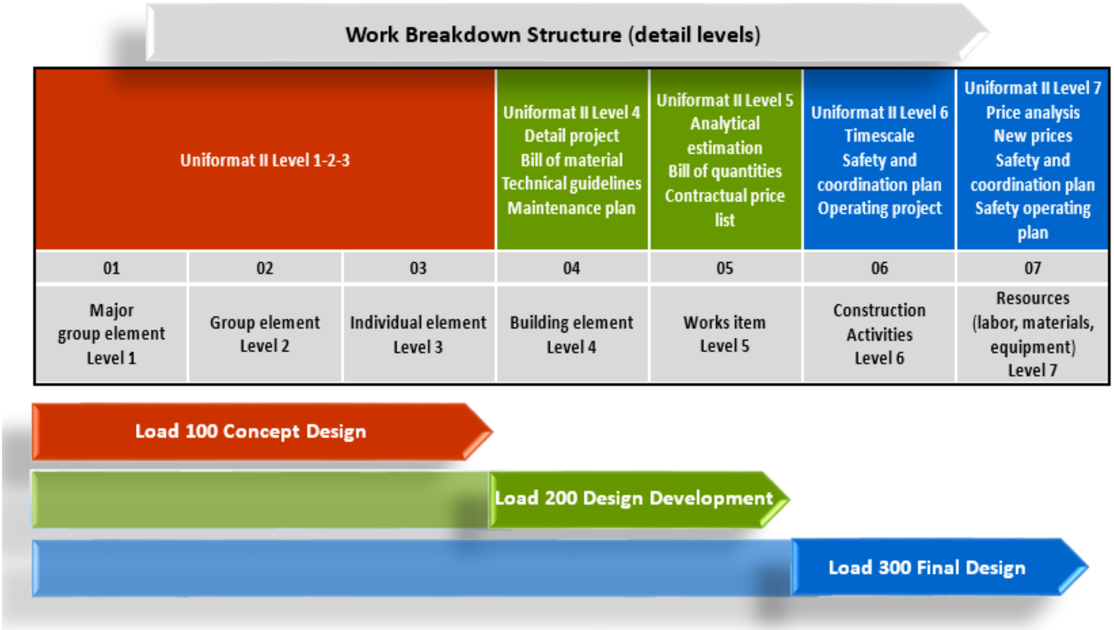

Figure 1: WBS, Work Breakdown Element, project documentation and design levels.

Based on the results of the structured analysis of the project, all the works are perfectly integrated with each other, to ensure consistency in the flow of information: all design documents refer to a single base, generating the project database.
Project documents return the same information: drawings, quantity calculation, price list, schedule, ..., present specifics of single information context (see project database) -perfected by the designer according to the exigencies framework highlighted by the design theme.
The WBS of figure 1 outlines the typical structure for a new construction project and follows the procedure in its evolution. Additional difficulties arising from the application of the method to the restoration works suggest a modified representation to take into account the characters of context on which you must act through the formal identification of consistency state of technical elements that constitute the primary components:

- degradation level and its specific location
- foreshadowing of interventions of conservation, maintenance, repair, restoration, ...

in order to fully identify price entries corresponding to proposed interventions in the preservation project. This involves the introduction of two WBS support levels to better characterize the intervention on the specific technical element according to the following scheme:

Uniformat II Level 1-2-3 (MasterFormat, OmniClass, ...)			Uniformat II Level 4 Detail project Bill of material Technical guidelines Maintenance plan			Uniformat II Level 5 Analytical estimation Bill of quantities Contractual price list	Uniformat II Level 6 Timescale Safety and coordination plan Operating project	Uniformat II Level 7 Price analysis New prices Safety and coordination plan Safety operating plan
1	2	3	4a	4b	4c	5	6	7
Technological Unit classes	Technological Units	Technical classes	Technical Elements	Technical element localization	State texture technical element	Conservation actions Price voices	Construction site activities	Resources (Labour Materials Equipment)

Figure 2: Detail levels of a WBS for the conservation project

As you can see from Figure 2, the WBS so set can identify its levels of detail with project documents and meet the needs of representation of the consistency state correlating the result of the survey with interventions that the designer will want to locate.
In fact the more general redevelopment requires more levels of integrated participation, levels that require coordinated development of:

- **conservation project**, maintenance to secure the existing and to better exploit its potential
- **architectural design**, functional to re-use and its optimization in accordance with the existing context and minimization of impacts
- **static consolidation project** to remove the structural weaknesses but also to ensure the load bearing capacity of structural elements to the new intended use
- **technological project** aimed at the prefiguration of the works necessary for the sustainability of the new intended use (⇆ habitability, viability);
- **project** for characterization of **fixed equipment and furniture**, functional to the new use

Everything can be interpreted as level 0 (zero) of the WBS type to associate with the more general project of redevelopment and reuse of built [2] [3].

3. From the preliminary design to the final design: advanced analysis and management techniques

During the design phase the project manager must identify, activate and carry on all the necessary tools and sources for the elaboration of the project documents required by statutory provision and in any case needed for the performed characterization of the work to achieve, the qualitative level of the expected result, the costs to be incurred, the necessary procedures for the execution of the work, and the contractual obligations assumed by the parties in compliance with the conditions of the contract.
The project phases are structured in specific moments that are normally recognized in four distinct project levels (pre-design, concept design, design development and final design). Actually facing the project phase in a dynamic that is more articulated than the narrow operating margins of the Procurement Code, the project levels that have to be deepened (implicitly or explicitly), because of the relationships that the specific level is called to govern, are: preliminary design document, feasibility study, pre-design, concept design, design development, final design, operative design, as built design.
To better understand the terms of a more responsible approach to design, that requires a further reflection to the characters of the necessary levels of detail, it must be recognized that the project is a reality whose complexity comes from the high number of variables that it has to manage and from the modalities in which these variables relate and interact between one another within its lifecycle. (see Figure 3)
To facilitate the management of its complexity in all the phases characterizing the process, the project contents must find a synthetic representation, through the assumption of a limited set of descriptors able to characterize the project, provide a strategy and an operative model able to govern and modulate efforts on the base of the needs that the level of detail requires.
The implementation of pre-design contents in its phase of study during the detail design must be accompanied by a reasoned discussion of the contents of the structure analysis of the preliminary draft that, from a simple classification plan based on the contents of the regulated classification plans (**UNI 8290, Uniformat II Level 3**), must enlarge the paradigmatic terms of the **WBS** (see top-down procedure) to satisfy the informative needs of the detail design. Since the pre-design is called to identify the qualitative and functional characteristics of the works that are to be achieved, the needs framework that the design choices are intended to fulfil and the costs to be supported; the tool to evaluate the project contents, estimate the cost value, and start the completion of project

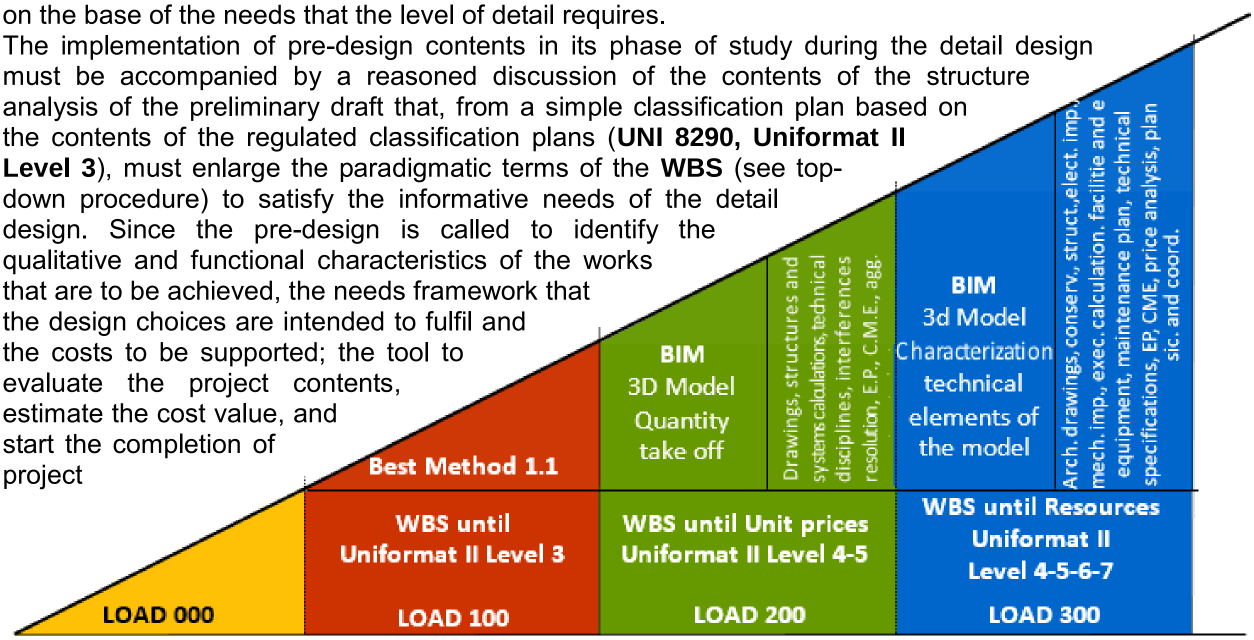

Figure 3: Management techniques in the procedure

documentation may be represented from the application of the **BEST Method 1.1**, variant of the BEST 1.0, specifically set up for the development of the preliminary design for interventions on the built. [1]
The transition to the detail design involves the adoption of techniques that enable to associate to each **WBS**' element the related characteristics in terms of geometry, formal characters and qualitative level, in relation to complying technical solutions prefigured in the project (design development and final design).
Passing from the pre-design to the detail design, it is no more possible to refer to synthetic methods, as the **BEST 1.1** method that estimates the quantities relating to the various **Classes of Technical Elements** with synthetic procedures and associates to each **CET** a technical stratigraphy deriving from a synthetic analysis which bases its assumptions on top-level data: historical drawings, archive drawings, cadastral maps, camera lines (the *detailed survey* can not belong to the draft design stage).
Moreover, during the development of the documents for the detail design the graphic works cannot be limited to the simple massing plan, even if integrated with complementary but still limited information: the survey, the representation of detail characters, the localization of conservation interventions, the formalization of architectural, structural and technological aspects cannot be marginalized (remember that the final design is also known as buildable).
The designer that has to develop graphic elaborates able to represent the goal to achieve:

- in terms of reasoned consistency with other project documents that will be required to express the same content, and
- in function of the contractual relation which will be finalized following the choice of the contractor and the obligations that the parties will assume with the procurement contract,

faces two possible ways: using traditional tools (drawing board, **CAD 2D**), or advanced tools that are catching on even on national level (**CAD BIM**).
The use of **CAD BIM** is particularly useful, as such CAD is able to associate, directly, to each element represented in the model, the geometrical, material and finishes characteristics, as well as the compliant technical solutions. Basically the CAD BIM enables the development of a 3D model that combines the geometrical aspects of the building (⇉ general representation) and of the single elements (⇉ detail representation) through which it is articulated, and the peculiarities of technical nature that characterize it. In this way the model goes beyond the mere formal representation of the result, assuming the non-trivial meaning of a linear combination of all the elements of detail characterized by specific attributes, associations and hierarchies, these properties are collected and organized in the **WBS**. The single elementary components of the representation act as bricks in a virtual Lego, each of which has its own specific characteristics and the combination of which results in the **3D model**.
The **CAD BIM** is therefore a powerful operational tool that allows you to load in the 3D model the prerogatives of all the building components to generate a **database** that essentially is the project database desired with the **WBS** construction. The **WBS** becomes so the essential instrument to rationalize the project ideas that will be later inserted in the **3D model**. By integrating the two techniques you can build a 3D model of graphic nature, in association with the choices already expressed in the **WBS** to realize the project **database** related to the context geometry. The **CAD BIM** organizes, collects and elaborates the data entered in a context that can return appropriate tables with numerical data resulting from the geometry of the context and the entered data: general geometry (⇆ building, floors, …) and of detail (⇆ technical elements, materials, …).
Simple elaborations of the data in the tables allow the development of project documentation for the specific design level (concept to final design) drawing from the sole **database** of the project which constitutes the guarantee of result. It should be stressed here that the transition from final design to detailed design always bases its assumptions on the contents of the same **database**; this is simply the most detailed (see **Figure 2**).
In fact, it should be remembered that the use of CAD 2d does not allow substantial correlation and automatic transfer reports of information from the general framework of the design choices to the project documents for as these are set in the Regulation (d.P.R. 207/10). In the best case, you can imagine the following relationship

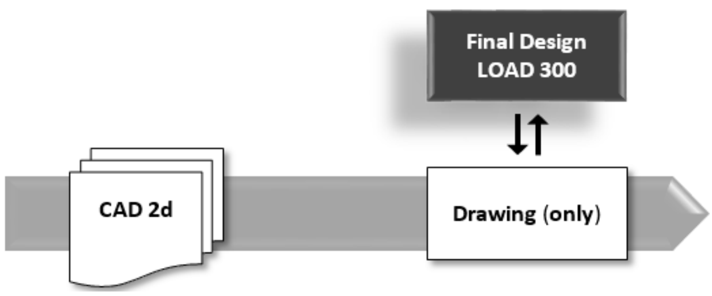

Figure 4: Report of weak correlation between traditional tools and project documentation (grey situation with latent errors).

Using **3D CAD** accompanied by an organizational structure of project ideas as the **WBS**, follows that the correlation is actually total.

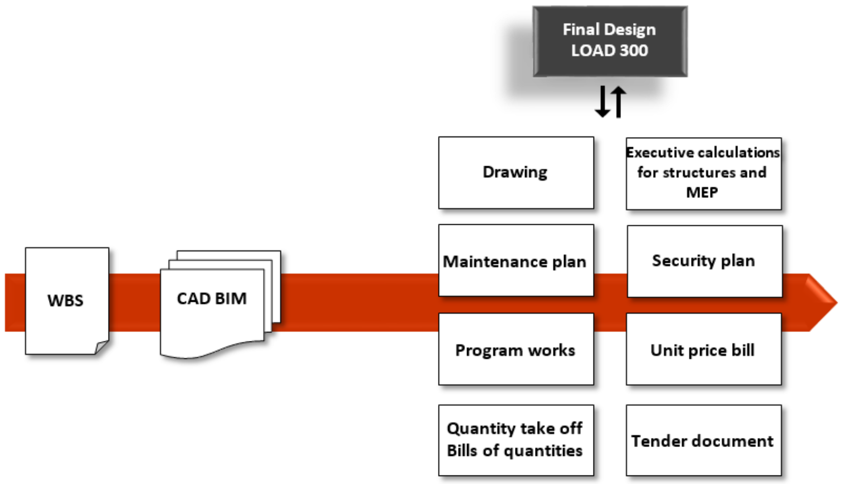

Figure 5: By adopting the proposed method (WBS, CAD BIM) the relationship of correlation between operational tools and project documentation is complete (colored situation, little or no errors: 100% rule).

Furthermore, since the **CAD BIM** are usually interoperable so that the information included in the **3D model** can be transferred to the structural analysis software, for the development of the technology project, the preliminary analysis of the construction site, …, it's possible to develop other design aspects within the same information framework with actions and retro-actions of adjustment they see the design activities not parcelled. In practice, rejecting the trivial idea that a **CAD BIM** can serve simply to give a representation in terms of future reality (□ rendering), in a purely logical management, you can ensure the proper flow of information that gives security in the result.

4. Operative WBS Cad BIM tools: the restoration project of the Teatro Lirico in Milan

The tools used for the development of the restoration project of the Teatro Lirico enabled to develop a project documentation accompanied by a comprehensive information framework and allowed to identify all the characters that found a solution in the design choices and a coherent representation in the project documents. All this has been possible by interfacing the project with operating procedure that refer to:

- **BIM** (Building Information Modeling), project contents organization to support communication, simulation and optimization of the results of a project.
- **WBS** (Work Breakdown Structure) project breakdown structure organized for increasing detail levels, able to give an exhaustive, efficient and effective representation of the project.

The availability of a project **database** allowed to prefigure a communication code common to all involved in the process, code aimed at improving the design documentation and to remove the latent lack of communication in the fragmentation of roles in the design activities.
Since the early stages of the adopted procedure, in order to ensure the project success, it was necessary to identify and characterize all the variables involved to create the conditions to ensure the proper completion of the intervention, conditions that allowed to ensure the reliability of the project forecast framework and the coherence between the detail and overall objectives, in close relationship with the documentation to developed as a function of the phase of verification and validation, subsequent phases of contractor choice and execution, in compliance with the statutory provision, according to the schematic of **Figure 6**.

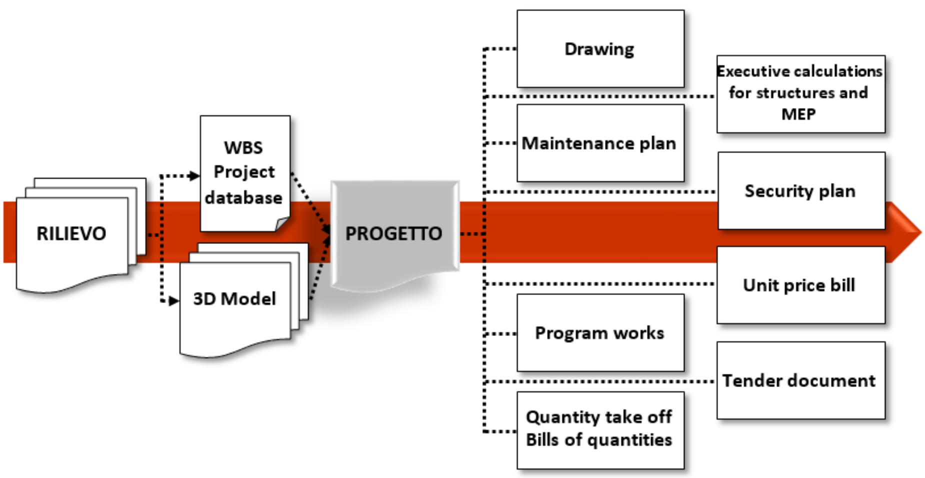

Figure 6: Flow diagram of the procedure adopted

The restoration project has based its assumptions (as is normal) on an accurate survey carried out here with Laser Scanner technology that can return a solid building image that formed the basis for the next phase of modelling developed by a **CAD BIM**. The survey phase acquired general and detail aspects to characterize accurately the building, since it should have been functional to the subsequent design tasks with **WBS** and **BIM** tools. From the point cloud generated by the survey, using the tools offered by the adopted **CAD BIM**, a solid 3d able to represent the geometry of the Teatro Lirico was developed. The model was then characterized, allocating to the various components the first level of specificity that distinguish them. The purpose of the first conducted operations on the model obtained from the point cloud has been to assign the specific distinctive character to the individual technical elements in accordance with the schematization of **Figure 7**.

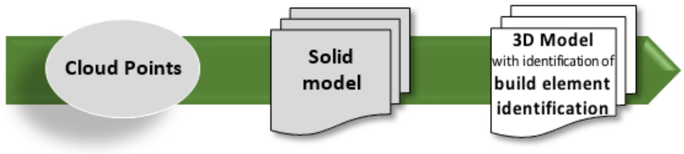

Figure 7: First step from the point cloud to the 3D model with the identification of the technical elements

Operation followed by a series of successive steps that allowed to associate the 3D model with both the features emerge from the survey and the action mode prefigured by the design choices but also by the changes introduced to the environment based on its re-functionalization. This operation brought to the recognition of project character rationalized in its structure analysis denoted in the **WBS**, and their inclusion in the project database as the **WBS** assumed assets of completeness and thoroughness. Following the pattern of **Figure 7**, it was possible to return the details of the status quo (in the first instance of geometric nature) in which have been identified the technical elements that make up the building's construction equipment.
After factoring the solid model (model technically not characterized) in the individual elements that make up the building for a system with a general effect (technical elements, location, rooms, floors) we proceeded to load their status in the **3D model** of consistency represented by the materials, their installation mode, the technological characteristics of single technical elements, the degradation level, the characteristics of finishing as well as the mode of action for the elimination of degradation as provided by the design choices based on data previously entered and properly organized in **WBS**, according to the principle diagram of **Figure 2**.

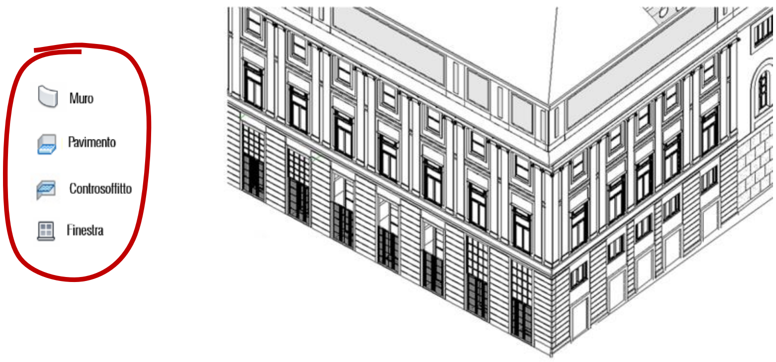

Figure 8: From the solid model (indistinct volumes) to the 3D model with the identification of technical elements that assume the specificities of competence (materials, finish, state of consistency).

With the next step, we proceeded to set up a coordinate system in order to locate the specific technical element in the complexity of the context. In this phase, to each technical element was assigned an identification code to associate it uniquely to a specific location within the building system that characterizes the **Teatro Lirico** (part of the building, level, room, wall, ceiling, floor).
With the support of a detailed photographic survey that accompanied the contextual analysis of the theater, it was possible to detect and classify the state of consistency and to implement the **3D model**, associating to each technical element, conveniently located, the specificity of degradation against which the design choices are set. Remembering that the peculiarities of the choices that inform the project are characterized from belonging to the world of design documentation (ex ante) and subsequently to the real world of the execution or the use of the results (ex post), the articulation of the design choices must necessarily lead to the formulation of a management system that bases its assumptions on the identification of elementary units organized in coherent sets (see **WBS level 5**). In the present case, the price components are identified individually for each technical element, for each of which has been established what was the necessary work in order to satisfy the needs expressed by contextual analysis.
The identification of characters of single conservation/repair interventions brought to the identification of specific price components (see **WBS level 5**), which allowed the adjustment of the project interventions

through the correlated action of emerging needs and contents of the Price List used (see **Pricelist of the City of Milan**). The result of such action generated a fundamental document as part of what will be the next contractual relation with the contractor: the **list of unit prices**. It should be remembered that the processes identified in the prices list represent the obligations that the contractor will have to pay by signing the contract. Facing this, the descriptive contents of the work items had to include all the information necessary to identify

- the qualitative level of the result,
- the direct and complementary obligations that the contractor is going to take.

Rationalizing information framework and collecting data in a sort of transformed **WBS**, it was possible to improve their representation by providing the pattern of **Figure 14**, where the relationship between the ratio of price items and needs collected and documented by **WBS** is clear; relation establishing the design choices, coordinating with it the contents of the **WBS** with the geometrical aspects of the technical elements for such as these are characterized in **3D model**.

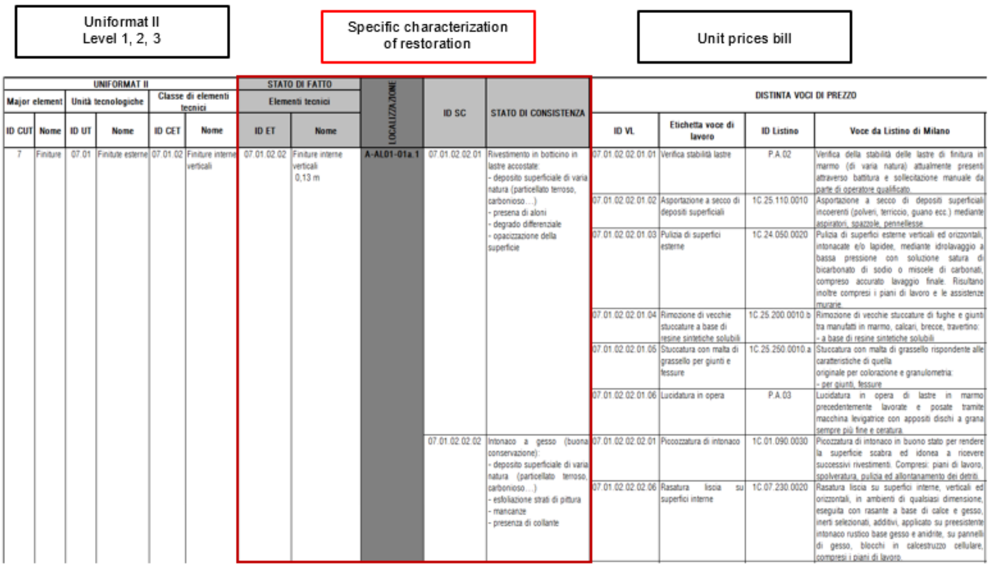

Figure 9: WBS with inserted the columns of the location and status of the consistency of the technical element with the directions of the work items needed to eliminate the degradation.

After completing the **WBS** and loaded its data in **BIM** model it was possible to extract the information, which rational manipulation led to the development of each project document according to the diagram shown in **Figure 6**. The CAD BIM in fact allow to release data organized through extraction filters for fields and specific regulations.

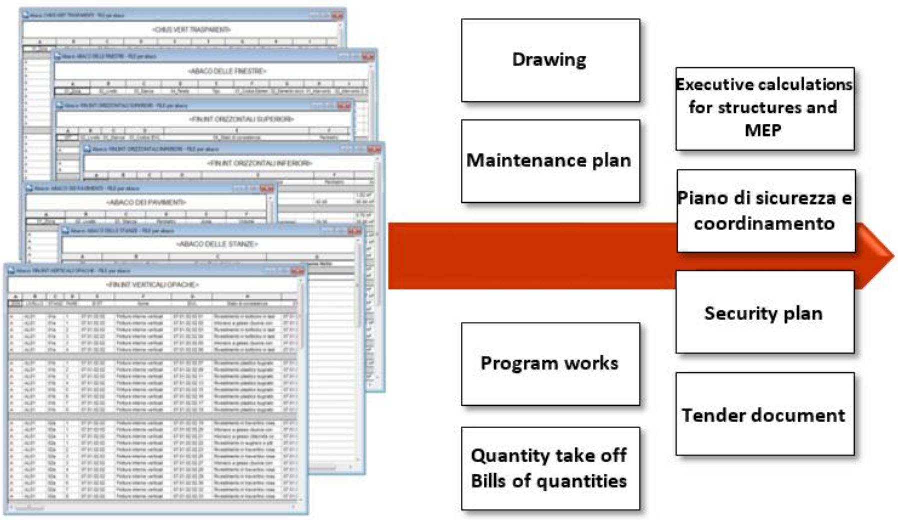

Figure 10: From schedules to project papers.

On the basis of the statement of the technical elements, their technical characteristics and the way the conservation work is articulated, it was possible to proceed in the organization of the contents of the maintenance manual.

5. Conclusions

On the basis of the contents arranged through structured analysis of the project, all the elaborates result perfectly integrated with each other, ensuring consistency in the flow of information: all project documents refer to a single generating base, documents that have found support in the **WBS** and in the **3D model** developed with **CAD BIM**, in adoption of a management, planning and control process of the project, able to sustain the flow information throughout its lifecycle from service architecture, the presentation of the offer, to run and to its control, use and management of the results.

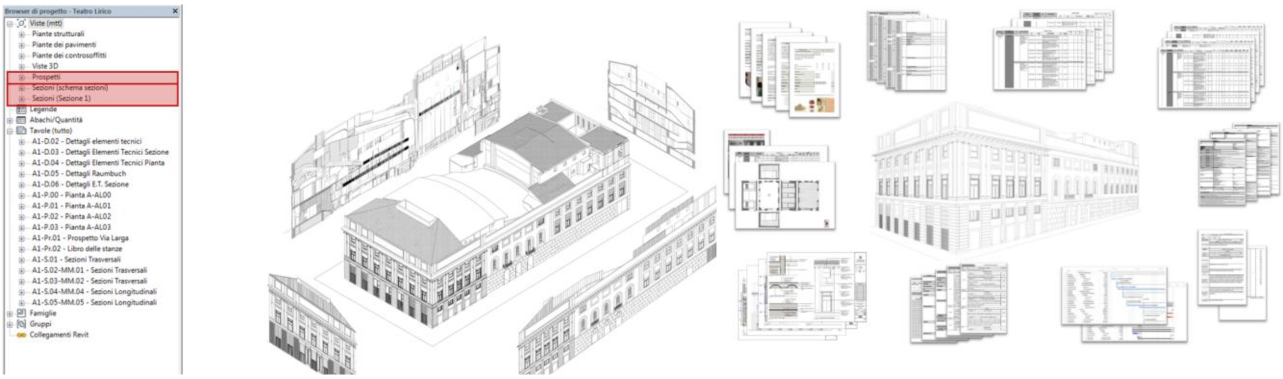

Figure 11: From the model to the drafting and the virtuous cycle of information functional to the project documentation

The tools used have therefore allowed the consistency of the information framework of the project, optimization of operating times, information sharing, automatic updating of the changes, the certainty of validation to ensure the 5 zeros of the production process, or zero errors:

- in the design,
- in the estimated cost of construction,
- in the logistics,
- in the implementation phase,
- in the delivery of the work,
- in the facility management.

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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 <u>Modular End-Effector</u> (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.

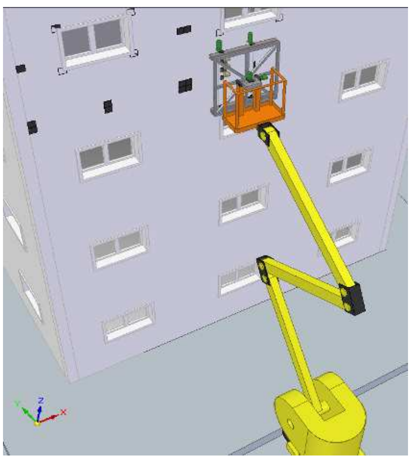
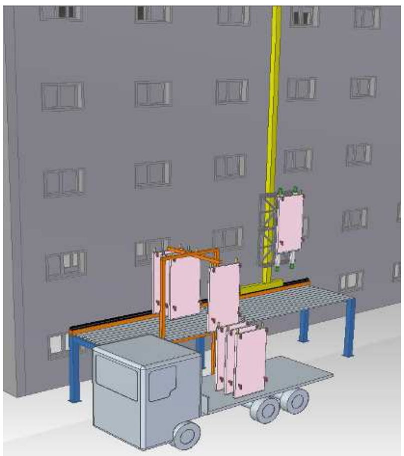
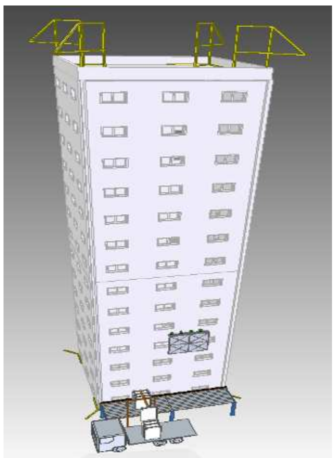




Figure 1(left): Connector fixation process with an Aerial Work platform. Figure 2 (middle):the MEE is used by an Automated Vertical Bridge crane. We can see the MEE elevating the facade component. Figure 3 (right): It also has been considered the choice of using the MEE as a cable suspended device.

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.

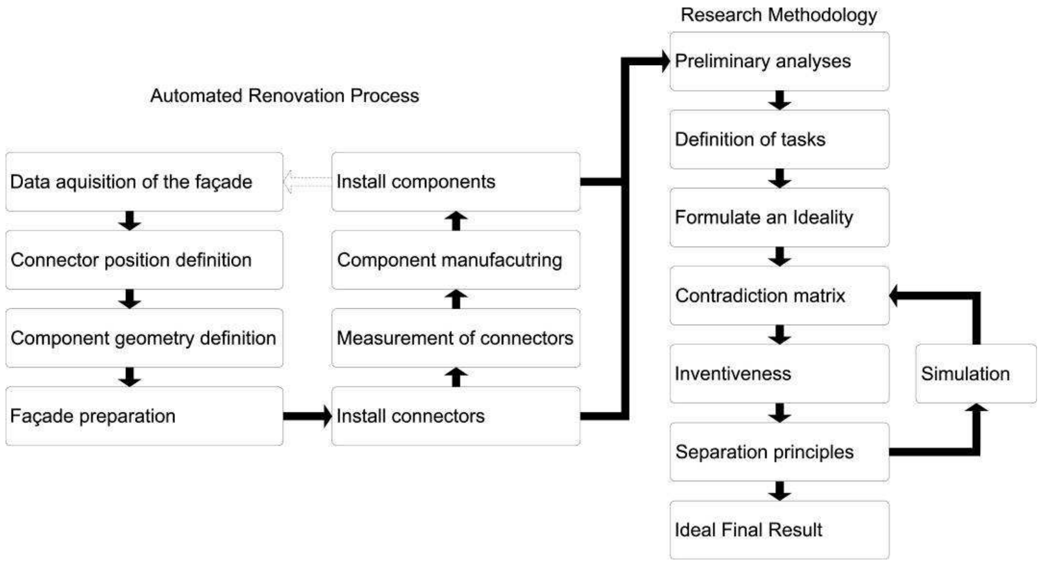


Figure 4:Brief scheme of the research method and its connection to the Building facade Renovation process.

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.

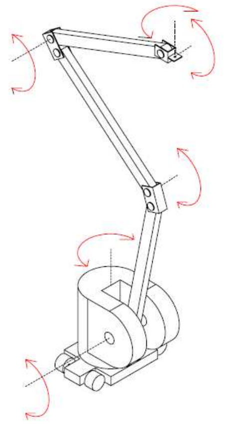
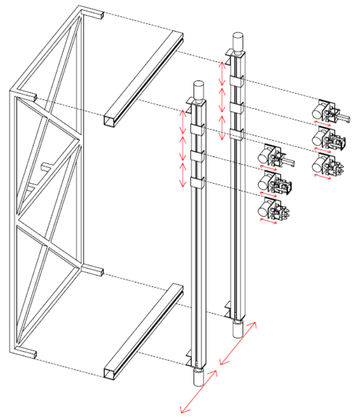
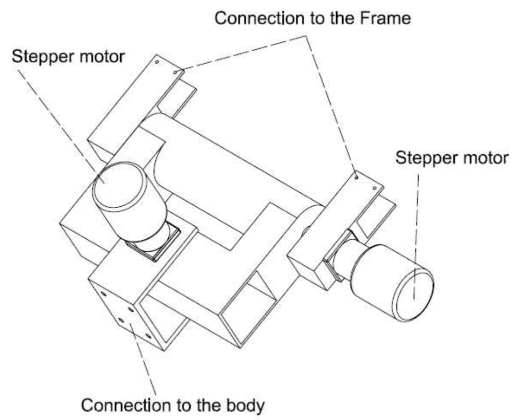




Figure 5 (left): Exploded view of the <u>robot body</u>, MEE. Figure 6 (middle): Exploded view of the <u>MEE</u>. Figure 7(right): <u>fixture</u> that connects the robot body with the MEE.

Regarding to the <u>mechanics</u>, 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 <u>flexible and modular</u> 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).

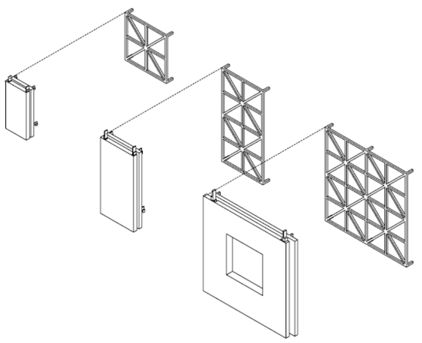
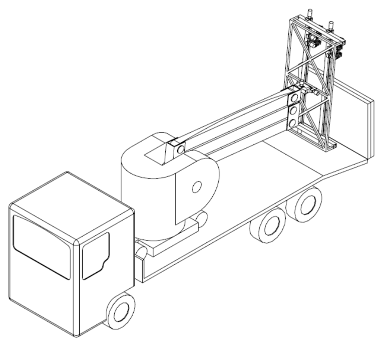
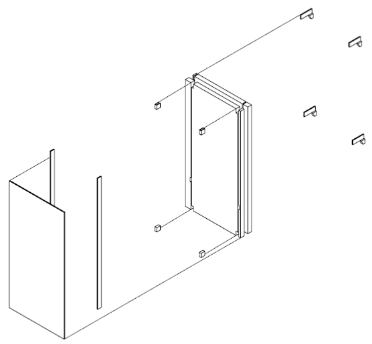




Figure 8 (left): Modularity of the MEE and adapatation to different component size. Figure 9 (middle): operability of the Frae under standard traffic rules. Figure 10(right): The component must be sefigned according ROD principles.

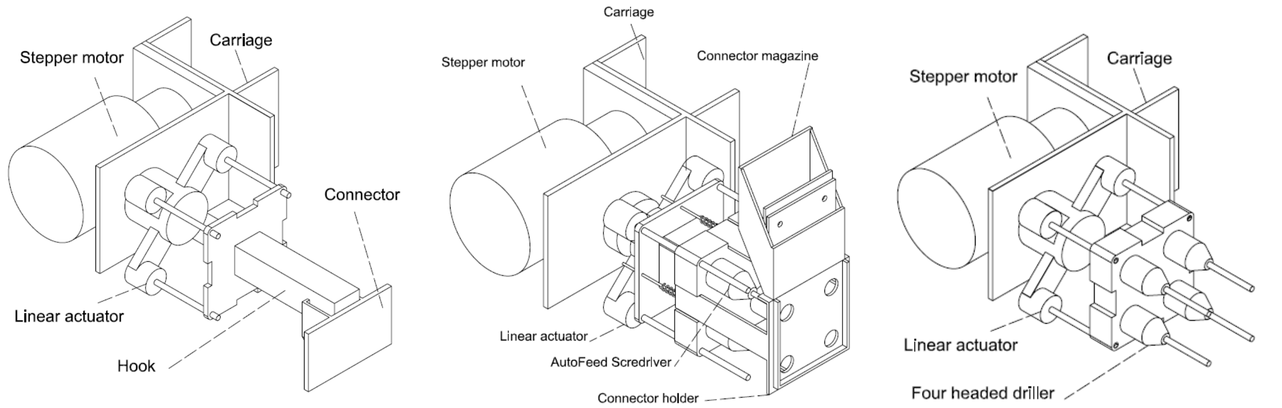


Figure 11 (left): End Effector for Temporary fixation of the MEE to the wall. Figure 12 (left): End Effector for connector fixation. Figure 13 (left): End Effector for drilling.

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.

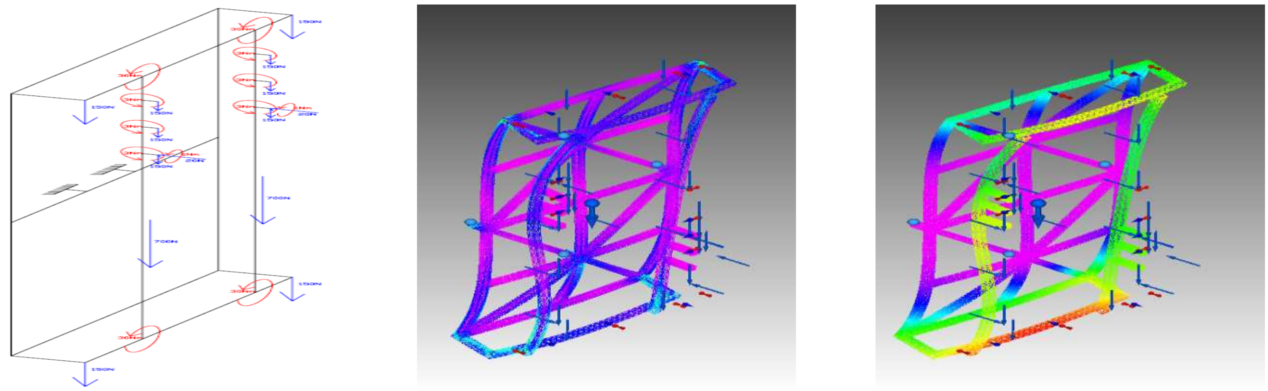
Finally, regarding to the End effectors for uploading, placement and fixation of the faced component, a set of grippers will be used. The most critical step will be to clip the component once it has been delivered to the site. For now, we are using very simple and standard grippers, there has been no 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.

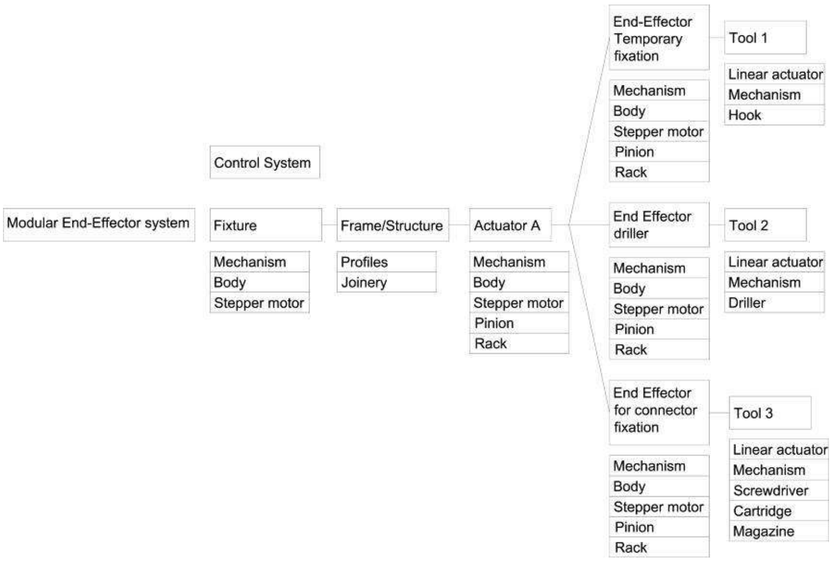


Figure 16: General product structure of the Modular End-Effector

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.

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.

Discussion

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 €), 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 aluminum, 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 inclemency 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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