Cable-driven parallel robot for curtain wall modules automatic installation

M. Taghavi[a], K. Iturralde[a], and T. Bock[a]

[a]Department of Architecture, Chair of Building Realization and Robotics, Technical University of Munich, Germany

E-mail: Meysam.Taghavi@br2.ar.tum.de, Kepa.Iturralde@br2.ar.tum.de, Thomas.Bock@br2.ar.tum.de

Abstract –

Recently, the accurate prefabricated Curtain Wall Modules (CWM) used as building facade are gaining popularity around the world. However, the conventional manual procedure for installation of CWM is dangerous for labour work. More so, it is a time consuming and expensive task. Automation of the CWM installation using a cable robot is an alternatively faster and safer method. The cost saved due to shorter installation time would compensate for initial investment costs of the robotic systems. However, for CWM installation, the cable robot and its modular end-effector (MEE) need to perform several tasks such as positioning within 1 mm accuracy, drilling, installing bracket (connectors), and handling and positioning the CWMs. However, there is no such robotic solution currently available on the market. As a probable solution to CWM installations, the European project "HEPHAESTUS" is designing a cable robot-based automatic system capable of 1 mm positioning accuracy, while performing other tasks such as drilling on the building. Meanwhile, it could carry nearly a tonne in payload in an outdoor environment. As a design phase in this paper, five different conceptual scenarios for such complicated automatic installation process conducted by a cable robot are introduced. The possible concepts are assessed using the Delphi method. Finally, the accuracy, safety, and installation time of the selected scenarios are comparable to the conventional manual procedure of CWM installation. In the future, these systems further improve within the HEPHAESTUS project framework.

Keywords –

Cable-robot; Construction robotics; Automatic curtain wall module installation; Delphi method

1 Introduction

The construction industry plays an important role worldwide. Many countries consider it as a large part of gross product, which supports high employment rates [1]. Although construction companies use numerous apparatus onsite and offsite to enhance productivity, still several duties remain for manual workers [2]. One of such tasks that requires high labour effort in construction sites is the installation of curtain walls. This task poses serious risks for manual workers, since this task is done on the edge and on top floors of incomplete buildings. In addition, manual curtain wall installation is a slow operation. Numerous labour forces working long hours make the manual curtain walls installation highly expensive as well [1], [3], [4]. Therefore, automatic installation of curtain walls increases safety and productivity [5] , [6].

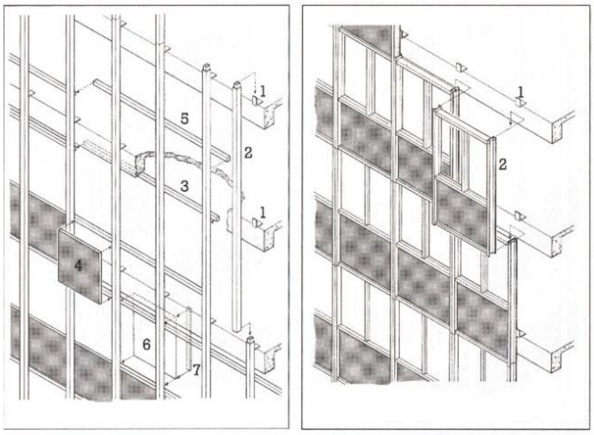
In the call for proposals from the European Union: *ICT-25-2016-2017 - Advanced robot capabilities research and take-up* [7], the *HEPHAESTUS* project [8] got founded in *innovation and action* scheme. The consortium of the project consists of three research institutes, one university and five companies. Nine members of the consortium are from different European countries namely Germany, Spain, France, UK, Italy and Norway. This project addresses novel concepts for facilitating the cable robots in the construction sector, which currently has a minor usage. The focus of the project is on curtain wall installation as a high risk and critical construction task. This paper is within the frame of the HEPHAESTUS project that aims to solve the challenges mentioned above.

In this study, we first discuss state of the art (chapter 2), followed by an introduction of the five possible scenarios for the automatic installation of curtain wall modules by cable robots (chapter 3). Next, the scenarios assessed using the Delphi method are highlighted (chapter 4). Finally, the assessment results leading to preferred scenarios are concluded.

2 State of the art

2.1 Curtain wall

A curtain walls is an exterior envelope of the building which does not carry the vertical loads of the building roof or floor. It sustains its own weight in addition to imposed loads such as wind, and transfers these forces to the building. It provides benefits such as daylighting and reduces the overall weight of the building [2]. There are two types of curtain walls shown in Figure 1.



Unitized and stick curtain wall system

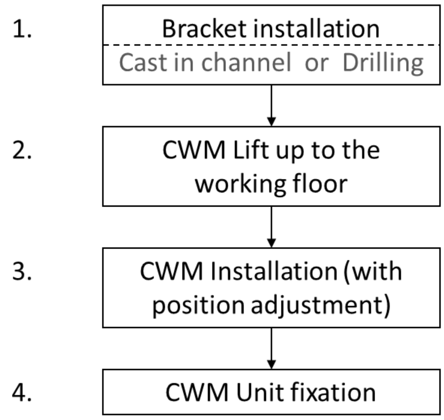
Figure 1. Left: Assembled on site, "stick". Right: Pre-assembled into rectangular panels, "unitized". [Picture rights: courtesy of AAMA [10]]

1. Type one is the stick system, where the installation of metallic frames and glass panels is carried out on site [9]. Most stick systems consist of horizontal rails and vertical mullions. When mullions and rails create such a grid on site, glass panels are often inserted, although other materials can also be used.
2. The second type is the unitized (modular) system. In a unitized system the curtain wall modules (hereafter called CWM) are pre-fabricated and assembled with pinpoint accuracy in the factory. The assembled module includes the rectangular aluminium frame and inner glass. A connecting part, i.e., bracket, will help to affix the module onto the buildings.

Figure 1 shows the two different types of curtain wall. The figure also shows that unitized system installation needs fewer steps on site. Therefore, the unitized system is selected for automation process and is the subject of this paper from now on.

2.2 Conventional CWM installation

The standard conventional CWM installation is a manual procedure, which occurs in four phases (see Figure 2). Step 1 of curtain wall module installations encompasses Bracket installation. There are two general ways of bracket fixation on the concrete slab of the building: cast-in channel and drilling. The Cast-in channel system is the most common technique for unitized system installations in new buildings.



Sequences of CWM installation

Figure 2. Conventional steps for a CWM manual installation process.

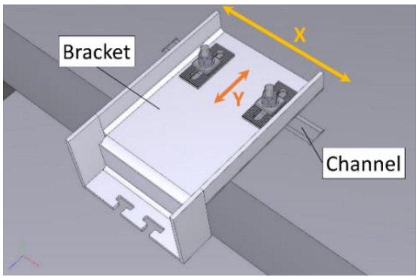
For the installation of cast-in channel systems, the first step is placing the cast-in channel on the framework, followed by welding it onto the steels bars before pouring the concrete (Figure 3 - up). The next step is manually removing foam from the cast-in channel (Figure 3 - bottom), followed by placement of the bracket (Figure 4). The adjustment of the bracket proceeds until its positioning meets the adequate pre-defined location.

Cast-in channel system

Figure 3. Preparation of cast-in channel system [Picture rights: courtesy of Focchi SPA [11]]

In a drilling system, the drilling points are first measured, and the absence of rebar under the aforementioned drilling points are checked before

drilling. If there is rebar under the drilling point, the drilling point will be changed accordingly while carefully considering the range of bracket adjustment allowance. Then, two holes are drilled in their proper positions. Finally, the bracket will be fixed using screws in the appropriate areas using anchors.
The bracket should be installed within an accuracy of 1 millimetre. In a cast-in channel system, the adjustment of the bracket position is possible in two directions (Figure 4). In a drilling system, the alteration is possible in only one direction because of the absence of a channel.



Bracket adjustment

Figure 4. Two possible direction of bracket adjustment while installing [Picture rights: courtesy of Focchi SPA [11]].

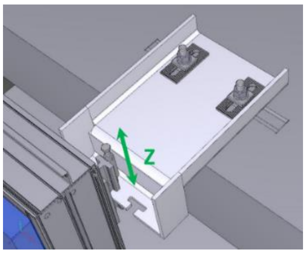
During bracket installation, its position will be controlled and checked by use of measurement systems such as a total station. In a manual setup, the placement of the bracket is critical because the final position of the CWM relies on the bracket location. The positioning of the bracket is likely not to be further re-adjusted.

CWM installation

Figure 5. Conventional installation of a CWM, possible dangers for labours - the number of workers involved in the installation process [Picture rights: courtesy of Focchi SPA [11]].

After the production, assembly, and control of the curtain wall modules in the factory, the modules are transported to the construction site and stored. At this step, it is assumed that the brackets are already fixed in their planned positions and are ready for hosting the CWM. In step 2, cranes lift the CWM to the working floor. The CWM can also be elevated to the working floor using an elevator (if available on site). Nevertheless, cranes handle the CWM's weight during installation, while workers manipulate the CWM and adjust its position accordingly (step 3, see Figure 5).

Workers on the site guide the CWM into the bracket and adjust the CWM's height via a specific part of the CWM (Figure 6). Finally, when the correct position of the CWM is confirmed, it will be fixed (step 4) and the installation of the next CWM starts.



CWM level adjustment

Figure 6. One direction of CWM adjustment during installation [Picture rights: courtesy of Focchi SPA [11]].

Each bracket hosts two adjacent curtain wall modules while bearing half the weight of each CWM, and each CWM is supported by two brackets, i.e., each bracket handles the full load of one.

2.3 Automated CWM installation

Multiple types of automated equipment for automatic curtain wall installation exist. One good example is a patented method by Brunkeberg Systems AB [12], which uses a dedicated railing system and a specially designed CWM to install the façade from the outside of a building. However, rail installation is conventional in this method. S. N. Yu *et al.* [2] used a mobile robot from the inside of a building to automate façade installation. However, they only managed to automate step 3 (Figure 2) of the standard CWM installation. J. Činkelj *et al.* [4] developed a telescopic hydraulic system that reaches the building façade from the outside followed by nailing of the façade panels to the building. This tele-operated system is specialised for sandwich panels, but not for CWMs. K. Iturralde *et al*. [13] proposed a Modular End-Effector (MEE) concept for use in automatic panel installation. Nonetheless, the proposed MEE is still at the conceptual level. These robotic systems, nevertheless, have some limitations.

In the HEPHAESTUS project (a subject of this paper), all the four steps (Figure 2) in CWM installation are considered to be fully automated, but not tele-operated. To reach this novel goal, a cable driven parallel robot (known also as cable robot) hosting a modular end-effector is the selected robotic system. A cable robot system has several advantages: (a) it could carry heavy objects based on cable load capacities, (b) the workspace is a design parameter and could be chosen big enough to cover the whole side of the building. Moreover, other features of cable robots such as the degree of freedom, speed, and adaptability could be beneficial [14]. In cable robots, flexible cables are used as actuators of parallel manipulators. One end of each cable is connected to a platform hosting the MEE, and the other end is reeled in or out by a motor-driven winch. The MEE is a specially designed mechatronic system, which moves to different floors of the building by the help of a cable robot. Briefly, a cable robot carries the MEE to the desired position and the MEE performs the rest of the tasks (e.g., drilling). Figure 7 shows a conceptual cable robot and the platform hosting the MEE. However, the Figure does not reveal the details of the MEE.

Cable robot

Figure 7. Conceptual view of a cable robot (Orange) working on a building. The platform hosting the MEE is coloured red.

2.4 Development process

In the HEPHAESTUS Project the requirements for the system together with existing technologies have been studied. The HEPHAESTUS Project revealed that the series of tasks in CWM installation is one of the critical issues that need to be addressed. Therefore, in this paper, mainly the sequence of the tasks is researched. In order to find the most suitable workflow procedure, first, five possible scenarios were defined and analysed by the Authors. Secondly, these five scenario were introduced to the whole project consortium. Next, based on the Delphi method for gathering expert opinion, all project partners participated in an assessment process. Finally, as a result of the assessment process, the preferred scenario is introduced in this paper.

3 Description of the installation Scenarios

The previously defined scenarios distinguish themselves in their different workflow of tasks. Although all the five different scenarios fulfil the CWM installation requirements, they require different technologies and provide various outputs. Table 1 shows the different steps to be taken in each of the five scenarios. All these phases are automated by the use of a robot unless mentioned otherwise.

Table 1. The sequence of tasks undertaken in the different Scenarios

	Scenarios				
	1	**2**	**3**	**4**	**5**
Steps					
Drilling the hole in precise location		1			4
Drilling hole with rough position			1	1	
Placing anchor in bracket	1	2	2	2	
Adjustment of bracket position	2	3	3		
Placing bracket	3	4	4	3	
Placing anchor in building					5
Fixing the bracket on the building	4	5	5		6
Measurement			6	4	
Creating interface bracket (Manual or by external device)			7		
Adjustment of CWM connection part (Manual)				5	
Mounting Bracket on the CWM(manual)					1
Placing and fixing interface bracket			8		
Placing CWM	5	6	9	6	
Placing CWM and bracket together					2
Adjustment of CWM and bracket together					3

Following, in this chapter, those scenarios are defined and their advantages and disadvantages are discussed.

3.1 Scenario 1

The first conceptual scenario follows the same workflow as the conventional installation process; for installing the CWM in new buildings, the placement of a "cast-in channel" before pouring the concrete is necessary. Afterwards, a bracket is accurately placed and adjusted. Finally, the curtain wall module is draped over the bracket. The accuracy of installing the façade relies on a precise bracket installation.

Advantage: This is the closest scenario to the existing installation methods. Therefore, solving this scenario would mean getting closer to the needs of the current market.

Disadvantage: The complexity of the tasks is considerable. The MEE system would need to achieve several tasks such as levelling of the bracket's nuts simultaneously.

3.2 Scenario 2

In the second scenario, it is considered that there is no cast-in channel available. Hence, drilling is required. First, the drilling position is calculated, then the robot will check if there is re-bar under this planned position. If this is the case, the position will be adjusted considering the bracket adjustment range. If there is no re-bar, the drilling process does not require an additional recalculating step. After this recalculation, two holes for each bracket are drilled automatically by the robot. From this point onward steps are similar to the scenario 1.

Advantage: It improves the adaptability and versatility of the system, because a cast-in channel system may not be provided in all constructions (assuming e.g., renovation process or steel construction), but drilling could be used in almost all constructions.

Disadvantage: There is some additional complexity. Attention to re-bar of the concrete, which should be recognized before drilling, especially if slabs are post tensioned.

3.3 Scenario 3

This scenario is based on using a correction interface for (mostly) each of the brackets. It is an alternative to have the adjustment flexibility in the fixing or drilling process. The idea is first installing the bracket roughly, and then with help of an interface, correcting any small misalignments. Considering the construction nature, (for example, concrete slabs are not always well aligned) some misalignments are hardly avoidable. Therefore, this scenario solves it by using a uniquely made interface for each bracket.

Advantages: This is a rapid installation case if the interface can be ready on-time. Furthermore, drilling position is selected roughly.

Disadvantage: It is Expensive. CNC or an additional machine on-site would be required. Other rapid prototyping methods such as 3D printing for the manufacturing of the interface may not be strong enough. Challenges of rebar recognition on drilling process exists, too.

3.4 Scenario 4

In this scenario, similarly to scenario 3, the hole is drilled roughly in range of a few centimetres. And the bracket is installed within that rough position precision. The adjustment for the exact position of CWM is handled by an adjustment module on the CWM. On the CWM, there is a part to be connected to the bracket. This part normally is fixed on the CWM, but in this scenario the CWM is re-designed to make this part adjustable. After rough placement of the bracket, its position will be measured and the connecting part on the CWM will be adjusted manually on the ground to correct the misalignment caused by rough installation position of the bracket. In contrast to conventional installation methods, adjustment capability transfers to a connection part of CWM. In conventional methods, adjustment happens directly on the bracket.

Advantage: The advantages are same as in Scenario 3.

Disadvantage: Adjustment module on CWM could not be mechanically strong enough to carry the load. It is better to have it fixed and not adjustable, considering mechanical stiffness. There might be a problem during the placement, hence non-parallel movement of the CWM may be necessary, which can jeopardize the fitting process. Challenges of rebar recognition on drilling process exists, as well.

3.5 Scenario 5

In this scenario, it is given that the bracket and the CWM first combine with each other, which could be considered as one module hereafter. Secondly, the combined modules are carried to the desired position by the cable robot, and next they are adjusted on their correct position within 1 mm accuracy. The further steps: drilling, placing anchor and fixing the bracket finish this scenario. When the bracket is installed on the building, it is carrying the CWM, which is the main difference of this scenario from the others.

Advantages: The CWM module is used as a physical pattern.

Disadvantage The slab's current geometry is unknown. Therefore, it may be impossible to level the bracket. Challenges of rebar recognition on drilling process exists, as well.

4 Assessment

After presenting five scenarios, one of them should be selected as the preferred scenario. To select the most profitable one regarding the requirements of the system, an assessment process is carried out in this research. In this chapter, first the assessment methodology is introduced then the corresponding procedure and results are presented.

4.1 Methodology

The assessment process and the selection of the preferred scenario in this project is a decision-making problem. In many decision-making cases, the decision needs to be taken based on multiple attributes to select an alternative from the feasible ones. This is the principle of Multiple Attributes Decision Making (MADM). It contains multiple decision attributes and multiple decision alternatives. The aim of the method is to make the decision considering all attributes [15][16][17]. One of the methods to do so is the Delphi method developed by Helmer and Dalkey [18] (around 1950s) to systematically use the expert's opinions. Decisions based on several experts' opinions are usually more precise than the individual opinion of each of the expert [19]. The Delphi method is a group communication process, which gathers the experts' ideas via survey letters or, in our case, via an assessment table. In contrast to other methods, Delphi applies multiple iterations (uses feedbacks) to develop a consensus of opinion concerning a specific topic [20]. The Delphi method begins with sending the same open-ended questionnaire to each of the Delphi participants (experts) and asking for their first thoughts and comments about the questionnaire. This is the first round. After collecting responses, this data will be converted to a well-structured questionnaire to be used in a second round. It is acceptable to start the method from round two if such well-structured questionnaire is already available [21]. In the second round, each expert receives a new questionnaire and is asked to review and sometimes to rank it in order of priority. In this round, area of diversity among opinions are identified and some consensus starts forming. In round three, each expert receives the questionnaires that includes opinion and rating of other experts in the previous round. They are asked to revise their rating and specify their reasons. In round four, usually the final round, the consensus of opinion, and any remnant of items exists, is presented to the experts. It should be mentioned that the number of Delphi iterations could vary from three to five.

In this paper, the Delphi method is used to assess the previously proposed scenarios. The group of experts as Delphi participants are project members. On behalf of each organization of HEPHAESTUS consortium, one person represents the organization's thought. So, nine experts are involved. First, an assessment table is provided as a questionnaire, where scenarios could be assessed by provided indicators.

In the first round, the assessment table and the scenarios' explanations were sent to experts and they were asked to share their first thoughts on the scenarios and indicators of assessment tables. After receiving the first comments, they were considered and included in the scenarios and the table. In round two, new well-structured table and scenarios returned to the experts. The experts shared their new revised ratings in the assessment table while they knew the others' opinions, as well. Finally, in the fourth round the final assessment table based on consensus of experts' opinions was presented. All experts agreed on that and it was accepted as the result of the Delphi method.

The following section presents indicators, which are used in an assessment table. The section after next describes the assessment table.

4.2 Indicators

The cable robot must perform certain tasks. The main task is to install a CWM in a building structure. For that purpose, some specific criteria for the cable robot were marked:

- **Cost of the proposed systems**
  Initially the presented solutions must rely on the possibilities of the end-users, the CWM installers and the contractor companies. It should compete with conventional manual installation.
- **Simplicity and ease of accomplishment**
  There are several ways to perform each task to make the overall system work. The simplest way is preferred, because it eases the design process and makes the job for an end-user simpler.
- **Technological availability**
  The proposal must rely on previously tested technologies. However, scientific development is required in cases such as a specific visual system for bracket placement. The extra developments should be avoided as much as possible.
- **Accuracy and Repeatability of the robot's path**
  The cable robot is responsible for the CWM installation. Therefore, its position accuracy plays a key role in installing the bracket and the CWM correctly.
- **Adaptability to different construction sites**
  The cable robot should be adaptable to multiple construction sites. The target buildings are commercial and office buildings. In such cases, they are made of steel or concrete structural frames with on-site concrete slabs. The cable robot system will be designed to install the curtain wall panels in facades without balconies, as it is the case of most commercial and office buildings. Indeed, a cable robot is well-known for easy reconfiguration, since pulleys and drums can easily be placed in different position and are adaptable to complex systems.
- **Matching to conventional unitized CWM**

products
If scenarios require major changes in the current product (the Curtain Wall Module and bracket) for being installed by the cable robot, this might be a problem for future marketing of the robot. Therefore, matching the system to the conventional bracket and the CWM system will ease the future marketing and is considered as an indicator of the most successful robot.

- **Possibilities of Multi-functionality (cleaning, repair, etc.)**
  The cable robot should be configured for accomplishing multifunctional tasks, the project primary task (installation of CWM) plus possible optional tasks (such as cleaning or painting). The optional tasks are generally easier compared to the primary task.

4.3 Assessment result and preferred scenario

In order to assess each scenario quantitatively, each indicator has a specific maximum value as seen in Table 2 in parentheses.

Table 2 Assessment table of the Scenarios

		Scenarios				
	Indicator (max- value)	1	2	3	4	5
Demonstrators	Cost of the proposed systems (20)	15	15	10	10	15
	Simplicity of the system and ease of accomplishment (20)	10	10	10	15	10
	Technology availability (20)	15	15	10	15	10
	Accuracy and Repeatability of the robot´s path (20)	15	15	10	5	5
Future feasibility	Adaptability to different construction sites (10)	5	5	5	5	5
	Matching to conventional unitized CWM products (5)	5	5	2	2	5
	Possibilities of Multi-functionality (5)	5	5	5	5	5
	TOTAL (100)	70	70	52	57	55

The indicators are divided into two types: demonstrators and further feasibility. Since demonstrator is the primary goal of the HEPHAESTUS project, the respective indicators have a greater maximum value. If the project is successful for the demonstrator task, it could fit for simpler applications as well (e.g., cleaning). The weights (maximum value) of indicators are mentioned in parentheses. The maximum value represents the maximum score a participant could give a specific scenario. The higher the value, the better the project goal in terms of that indicator. For instance looking at Table 2; scenario two has higher value compared to scenario three considering first indicator, which means scenario two better fits to the project goal regarding costs. Simply it could be translated such that: scenario two is at the end cheaper by experts' opinion compared to scenario three. The sum of the weights is 100. Each scenario finally will gain a total value between 0-100, the closer to 100 the better the scenario fits the project goal considering all indicators. All consortium partners in the HEPHAESTUS project have participated in the assessment process by the Delphi method. Table 2 is the final table of round four using the Delphi method confirmed by experts.

5 Conclusion

The results in Table 2 show that scenario 1 and 2 achieved the highest value and are the preferred scenarios. However, the MEEs in scenario 1 and 2 need further development in the direction of modularity. Ideally, the MEE should be modular enough for both situations, despite the need for some modifications. Additionally, scenario 2 is interesting from a technical point of view; it makes use of drilling, and can therefore be used for renovations on old buildings with no cast-in channel. Another aspect of the preferred scenarios is to perform bracket installation and to carry the CWM, distinctively. The modules in charge of moving the CWM and the ones responsible for installing the bracket do not have to be run at the same time by the cable robot, therefore reducing the typical load carried by the robot.

In the next research phases of the HEPHAESTUS project, the authors will further improve and develop these selected scenarios.

It is worth noting that the details of the "detail how to do systems" will be defined in the next stages of the project, which deal more with the design of the system. After completion of the design, the system will be built and tested in a real world.

6 Acknowledgement:

The research leading to these results has received funding from the European Union's H2020 Programme (H2020/2014-2020) under grant agreement n° 732513.

References

[1] Stone W. C. National institute of standards and technology (NIST) construction automation program, report no. 2. In *NIST Construction Automation Workshop*, Gaithersburg, Maryland, 1996.

[2] Yu S. N., Lee S. Y., Han C. S., Lee K. Y., and Lee S. H. Development of the curtain wall installation robot: Performance and efficiency tests at a construction site. *Autonomous Robots*, 22(3):281–291, 2007.

[3] Kahane B. and Rosenfeld Y. Balancing Human-and-Robot Integration in Building Tasks. *Computer-Aided Civil and Infrastructure Engineering*, 19(6): 393–410, 2004.

[4] Cinkelj J., Kamnik R., Cepon P., Mihelj M., and Munih M. Closed-loop control of hydraulic telescopic handler. *Automation in Construction*, 19(7):954–963, 2010.

[5] Cusack M. Automation and robotics the interdependence of design and construction systems. *Industrial Robot*, 21(4):10–14, 1994.

[6] Lytle A., Saidi K., Stone W., and Gross J. Report of the NIST workshop on automated steel construction. In *Proceedings of the International Symposium on Automation and Robotics in Construction (ISARC)*, pages 247–253, Washington DC, USA, 2002.

[7] EU CALL, ICT-25-2016-2017 - Advanced robot capabilities research and take-up. On-line: http://cordis.europa.eu/programme/rcn/700616_en.html, Accessed: 12/01/2017.

[8] HEPHAESTUS WEB PAGE. About the project. Online: http://www.hephaestus-project.eu/, Accessed: 12/01/2017.

[9] Ochshorn J. LECTURE note 2614/5614, Curtain walls and glazing systems. Building Technology. Wall sections: I: Materials and Methods. On-line: https://courses.cit.cornell.edu/arch262/notes/11b.html, Accessed: 15/01/2017.

[10] American Architectural Manufacturers Association, AAMA. Curtain Wall Design Guide Manual (AAMA CW-DG-1-96). Picture rights: courtesy of AAMA. The figure reprinted with permission from AAMA, USA. On-line: https://aamanet.org, Accessed: 12/01/2017.

[11] Picture rights: courtesy of FOCCHI SPA, Italy. www.focchi.it, Accessed: 12/01/2017.

[12] Falk J. H. and Augustinson D. F. Brunkeberg Systems Ab. Method for mounting façade elements on a multi-storey building. *US Patent*. US8695308, 2014.

[13] Iturralde K. and Bock T. Development and preliminary Evaluation of a concept for a Modular End-Effector for automated/robotic Facade Panel Installation in Building Renovation. In *10th Conference on Advanced Building Skins*, Bern, 2015.

[14] Izard J. B., Gouttefarde M., Michelin M., Tempier O., and Baradat C. A Reconfigurable Robot for Cable-Driven Parallel Robotic and Industrial Scenario Proofing. *Cable-Driven Parallel Robots part of Mechanisms and Machine Science Book*, volume 12:135-148. Springer, Berlin, Heidelberg, 2013.

[15] Yue Z. Approach to group decision making based on determining the weights of experts by using projection method. *Applied Mathematical Modelling Journal*, 36(7):2900–2910, 2012.

[16] Durbach I. N. and Stewart T. J. Using expected values to simplify decision making under uncertainty. *Omega*, 37(2):312–330, 2009.

[17] Wang X. and Triantaphyllou E. Ranking irregularities when evaluating alternatives by using some electre methods. *Omega*, 36(1):45–63,2008.

[18] Hsu C. C. and Sandford B. A. The Delphi Technique: Making Sense Of Consensus. Practical Assessment, Research & Evaluation. 12(10), 2007.

[19] Burkov E.A., Lyubkin P. L., and Paderno P. L. Intellectual Systems – the Future of Expert Assessment. In *Proceedings of the XX IEEE International Conference on Soft Computing and Measurements (SCM)*, pages 34-36, Saint Petersburg, Russia, 2017.

[20] Ludwig B. G. Internationalizing Extension: An exploration of the characteristics evident in a state university Extension system that achieves internationalization. *Doctoral dissertation*, The Ohio State University, Columbus. 1994.

[21] Kerlinger F. N. *Foundations of behavioral research book*. Holt, Rinehart, and Winston, Inc, New York, 1973.