Novel applications offered by Integration of Robotic Tools in BIM-based Design Workflow for Automation in Construction Processes

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Nowadays the integration between existent Computer Aided Design (CAD) and Building Information Modeling (BIM) software with robotic tools such as Robot Operating System (ROS) could represent the next step towards the correct design and application of automated construction processes in the Architectural Engineering and Civil Industry (AEC). The recent wide use of BIM improved significantly the quality and productivity in AEC field since it offers an always-updated model of the building with a structured, precise and shared database made up of detailed information about every phase of its lifecycle. This facilitates the mass production of construction elements ad-hoc to be automatically installed in addition to reducing errors and omissions due to a fragmented management of information. However, BIM by itself is not sufficient to achieve neither the complete and correct representation of complex modern buildings nor the direct planning of automated construction processes both off and on-site. There is still the lack of a specific software which can be fulfilled by resorting to the knowledge of Robotics Industry. In this paper the potentialities offered by the integration of CAD,BIM and ROS were analyzed with respect to the automated production and installation of precast timber modules for the refurbishment of existing buildings and to the installation of robotic tools for the independent living of elderly. The path towards such an integration is long and hard, many aspects have to be defined, since ROS was not conceived for AEC Industry but the potentialities in terms of money and time saving, of increased quality and productivity in addition to reducing damage risks are actually big. Thus, such an integration it's worth of further attention given that it allows to exploit an open source software with many available repositories and offers the opportunity of modeling every existing robotized system beyond to enable to test in various conditions with a realistic virtual environment thanks to the possibility of importing 3D models. In this way it is possible to find out both the best configuration and the most suitable robotic system to perform each required task.

Keywords: *BIM, Automation, Construction, ROS, Robotics, Building Technology*

INTRODUCTION

Until now it was a quite far idea to figure out the automation of the processes that concern AEC industry due to its various and fragmented system of managing the information about the project. This was ascribable to the many figures involved lead to very different fields of technique, each one requiring a project distinct from the others and fulfilled with incompatible software. With the advent of BIM the conception of the project in its core part is dramatically changed [1]. As a matter of fact designers have an always-updated model of the building containing all the necessary data concerning each step of its lifecycle and this is allowing to obtain exact information about the actual building, systematically organized and effectively corresponding to the project in addition to sharing them between all the subjects involved in real time. Thanks to this significant improvement, waste of time and money caused by wrong design and modifications during the execution phase are significantly reduced in addition to an improved productivity. Thus we are getting close to the easy automation of the off-site and on-site construction processes [2] [3] which require the exact location and dimension of all the elements, a methodically organization of the prefabrication and construction site over to the realization of accurate measurements.
BIM provides all these information into one file so that it's easy to handle them to design the building as to be realized by automated processes. But this is not sufficient by itself since it's also essential the exact planning of the construction process with detailed information about each required task as it is highlighted in previous studies [4]. Correa [5] underlines how BIM gave a big chance to automation in construction but also how it didn't provide direct opportunities for the use of robots in construction. In fact, BIM was conceived more for planning and managing phases than for automated construction processes. Hence there is a lack of a specific software to directly plan the automation of construction processes and to represent the complexity of modern buildings.
This lack can be filled by taking advantage of robotics tools such as ROS [6] so that its integration with existent CAD and BIM software could be the next step for the correct design of automated construction processes and verso the concept of "Active Building" of whom necessity was pointed out by Pan et al. [7] given that modern buildings must be easy adaptable to any change that occurs during their life-cycle, not fixed entities as it was in the past. Precisely for this reason the present research aims to explore the actual potentialities offered by such an integration.

Actual software limits

Even thou BIM represented a big improvement for the AEC Industry by providing us a really accurate model of the building that has made easier to handle all the information about the project, the now available BIM software are not able to give all the necessary information for the automation of the off and on-site construction processes. In fact they are not software conceived to directly plan automated construction processes and test robotic systems. Moreover the present BIM-based design workflow can't provide the dynamic design of the buildings as highlighted in previous studies [8]. It just offers a static representation of each aspect concerning the building which is a fixed "identity", not changeable during its life-cycle (Figure 1).

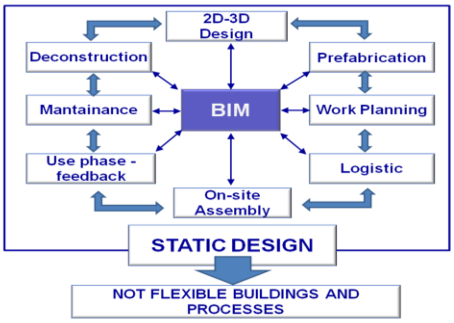

Figure 1. Graphical representation of actual BIM-based design workflow

At the present time there are interesting software like Autodesk Inventor and its Factory Suite that can be used to design and planning the manufacturing of the elements obtaining 3D models of the factory with all its work stations beyond to the most suitable work flow for the production. On the other hand, they cannot give a realistic simulation since they don't allow to program the robots or CNC machines or to dynamically test robot-assisted tasks.

Hence in the panorama of the construction software is still missing one capable of easily simulating these features. Nonetheless, such software should be well useful for simulating the implementation of different kinds of sensors, robots, end-effectors, actuators in a interchangeable and flexible environment that allows to adapt the planned process to any kind of production and building.

ROBOTIC TOOLS INTEGRATION IN BIM-BASED WORKFLOW

The exploitation of Robotic Industry software environments such as ROS is not a news in AEC field since other researchers have took advantage of this open source software in order to theorize the modeling and simulation of complex buildings [8] or to find out the best way to auto-mate installation of precast façades elements [9]. These previous studies showed the big potentialities of using software such as ROS in reducing time and costs for the planning of automated processes enabling to identify the best workflow and the more fitting robotic tools for each task as well to hypothesize a dynamic design of the building. This is allowed by the ability to simulate every change due to occurred new needs in occupant's life without having to test nothing in reality. However these just cited studies were previous to the recent wide use of BIM-based design by technicians from all over the world and they faced some issues such as having a structured and precise data base of information about the construction progress and updating it during its developing. Nowadays, thanks to BIM-based design, it would be easier to imagine the automation of construction processes and for this purpose it could be interesting take advantage of the potentialities given by BIM and ROS integration, exploiting the possibility to import detailed and structured 3D models in a dynamic simulation environment including all the necessary and updated information about the construction elements and process.

Exploiting the big availability of open-source ROS plug-ins it would be possible to simulate the implementation of sensors, control systems, cameras, robots and to test the automation of different phases of the building life-cycle such as prefabrication tasks, planning construction processes simulated in a virtual environment, implementation of control systems to monitoring the building that allow self-diagnose and opportune interventions, simulation of refurbishment interventions when new needs occurs and the planning of the deconstruction by testing different robots and systems.

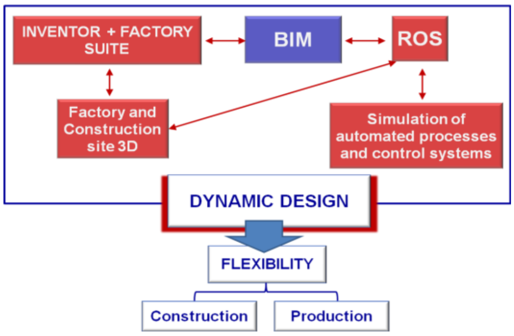

Figure 2. Schematic representation of new dynamic design approach with the integration between ROS, BIM and CAD

As a result of the integration between ROS, BIM and Factory Design Suite it will be possible to obtain a dynamic design of the building that allows to plan the automation of various phases of its life cycle without any expense or damage to the equipment or to the building itself. It is also possible to simulate potential interventions having an idea of the necessary tasks and tools to evaluate the actual convenience and to find out the best solution among the many offered by the automation industry in terms of time, efficiency and money expense. In this way the designed building process has a significantly improved flexibility both in the planning and in the production phases (Figure 2). It will be possible to change and to test different scenarios, process workflows, robots, machinery, end-effectors, construction layouts and immediately upgrading the BIM model with the information concerning the chosen solution. Another advantage could be that thanks to the information offered by BIM and simulation in ROS there is the possibility of obtaining a preliminary estimation about cost and time needed for each hypothesized automated process or intervention, in addition to the extrapolation of the best sequence to achieve them.

ROS-BIM IN MASS PRODUCTION OF CONSTRUCTION ELEMENTS

ROS and BIM can arise interest for the mass production of precast elements, since from BIM all the information about the dimension, position, materials and costs of each part are available and all the tasks which are necessary for realization are known.

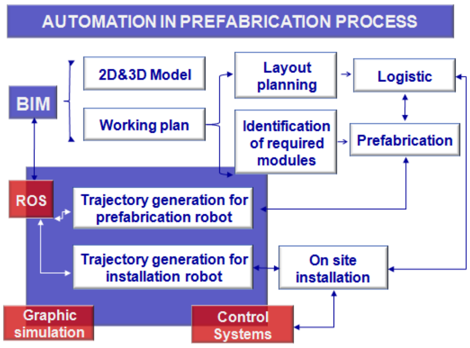

Figure 3. Schematic representation of ROS role in BIM-based design workflow for precast elements

Through such tool, designers can easily know how many elements are required, their shape and dimension. These information can be used in ROS for the off-line programming of complex assembly tasks and this enables to generate instructions for the automated manufacturing and installing process (Figure 3). Moreover, designers have the possibility to simulate the assembly tasks performed by different robots and end-effectors in order to find out the best configuration and they are able to implement control systems for the correct execution of the required tasks, checking the final results.

Starting from the standardization of the manufacturing of building elements, it would be possible to reach the final task of automated installation since it will be easier when the construction elements are designed and produced expressly to be installed by robots. Such a priori work might be not strictly necessary, nonetheless it surely would make simpler the manipulation of materials by means of robots.

ROS-BIM and the BERTIM project

The objective of the BERTIM project [10] is to establish a new methodology for mass manufacturing process of timber modules addressed to the upgrade of existing buildings so that it can be adopted by different companies with different production lines by means of an integration of robotic, automation, traditional and new technologies. It consists of three subsystems [11], the first concerns the exact 2D-3D modules configuration with the acquisition of the building model by means of a Laser scanner. From this first step starts the design and planning in a BIM-based environment of both off and on-site processes which gives the big advantage of having an always updated model of the building including exact and actual measurements also during the execution of the works. Thus the second subsystem concerns the manufacturing process with the implementation of some automated tasks, the third subsystem concerns the installation process by means of robotic tools and both of them will be tested by simulation with saving in terms of time and cost with respect to the traditional testing systems. In order to identify a general method the simulation environment has to be flexible and interchangeable, even the robots embedded for the automation of the process must be interchangeable and quickly re-adaptable with respect to the changes of the production line.

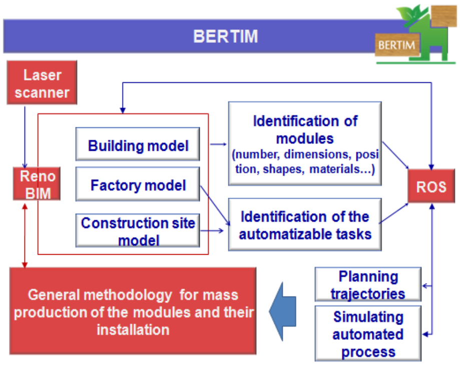

Figure 4. ROS and BIM integration in BERTIM project

This can be allowed by ROS. In fact, exporting the model of the factory, of the construction site and of the building in ROS, a company could test the real advantages (or disadvantages) of introducing automation in its factory without damage risks and any money effort, being also able to program and plan the ideal manufacturing and installation sequences (Figure 4).

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BERTIM off-site process automation

As assumed before, to allow the automated installation of any construction element it is required to design and fabricate it expressly with this intent. Thus, as a first step, it is important the accurate design of the connection elements and their exact placement on the modules. With regard to the connectors at the moment the first prototypes are being tested to identify the best solution, with regard to their installation the purpose is to find out an automated solution to increase companies' productivity and contemporarily improve quality of the process by making it quicker and more accurate. Relating to this last purpose, it might be interesting the use of an arm robot to pick and place the connectors on the panels by means of the factory 3D model designed in Autodesk Inventor and taking into account the characteristics of dimension and position both of the panels and of the connectors with respect to the existing structure.

Interchangeable scenario

In the BERTIM project the purpose is to find out a general methodology for mass manufacturing process of timber modules which can be adopted by different companies with different plant, not just suitable for the three companies involved in the project but for any company who wants to automate its production processes. ROS would be really efficient for this purpose, since it is possible to import in its simulation environments (i.e. Rviz, Gazebo, VRep) the 3D model of the factory designed with software such as Autodesk Inventor (Figure 6) and set them as "World". This means that it might be obtained an interchangeable scenario and to test the same automated process in different companies just changing the 3D file of the "World". Hence, a company could visualize directly what would be the new asset and how to integrate some automated tasks in its production line without any effort of money but just by means of the simulation in ROS virtual "World" capable of reproducing reality.

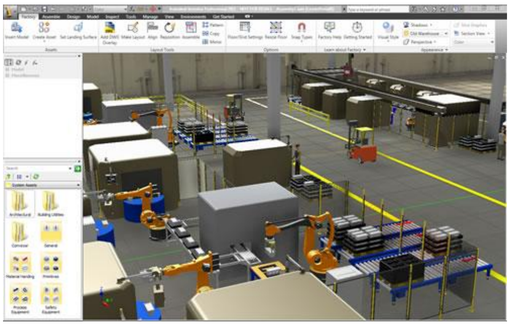

Figure 6. Example of 3D factory model in Autodesk Inventor (Image from http://www.tenlinks.com/)

This opportunity enables to evaluate the feasibility of the upgrading in the assembly line by means of automated processes and its actual efficiency without physic costs and saving a lot of time. It is just necessary a 3D model of the factory which could be designed with any CAD or BIM software and then imported in Rviz [12] or Gazebo [13] in collada (.dae) or STereo Lithography (.stl) format. Once they will be defined, there will also be available the BIM models of the panels and of the connectors, thus it will be possible to bring them in ROS and testing some automated tasks with the actual construction elements such as the already mentioned process of connectors' pick and place by means of an arm robot. In a reasonably short time it would be possible to try the embedding of a robot in the production line of each of the three companies involved in the BERTIM project, looking for a system that fits for all of them but without testing in reality, thus saving time and money and preventing any damage.

In future developments of this work the 3D model of each involved company will be supplied so as to obtain a simulation environment as realistic as possible. Design the 3D model of the factories involved in the project was beyond the scope of this paper which mainly deals with the evaluation of potentialities offered by the integration of robotics tools in BIM-based design environment and wanted to focus more about the actual feasibility of automated production and installation processes thanks to such an integration. However, it must be said that having a CAD file of the factory plant makes the design of the 3D model very quick and simple given that it's possible to import it in Inventor and obtain a base on which arrange various work locations.

Evaluating the installation of an arm robot in the assembly line

With respect to the objective of installing the connectors on the panels by means of an automated process so that the production time decreases and the quality of the products increases, it has to be considered the exploitation of a robot such as the Kinova Jaco arm (Figure 7) on the assembly line of the factories in the previous location with respect to the one where the windows are installed (Figure 8).

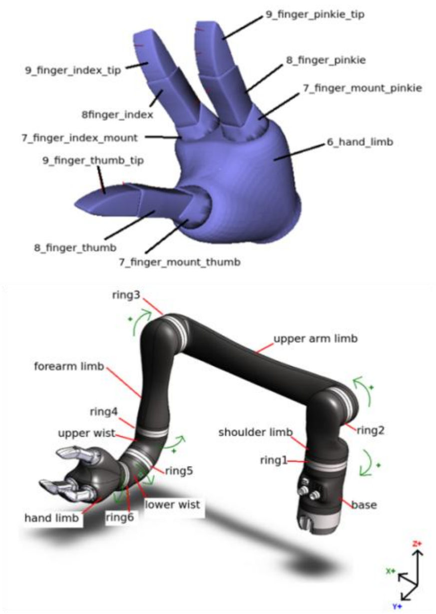

Figure 7. Images from Kinova website with indicated joints and links used in the URDF file

Within the available robot for the present study, Jaco was taken in consideration due to its high adaptability so that it could be reused for various automated tasks in different assembly lines and due to the fact that there are many available repositories online.

There are diverse available repositories for Jaco: the official Kinova package (i.e. Kinova SDK) which is useful just to move the real robot once it is connected to a terminal and it is not customizable and the ROS official package for Jaco [14] which has some issues in reflecting exactly the actual behavior of the real arm. Thus it was necessary a different approach that was found in the repository realized by a robotic researcher [15] and represented a great starting point to create a customized package for the integration of Jaco arm on the assembly line of the three companies involved in BERTIM project and let the robot pick and place the connectors on the modules. Two planners are essentially required: one for the motion planning (i.e. Moveit! [16]) to reach the arm out to the position so that it can grasp the object and one for the grasp planning (i.e. Graspit! [17]) to grasp the object with the joint sate determined for grasping that particular object.

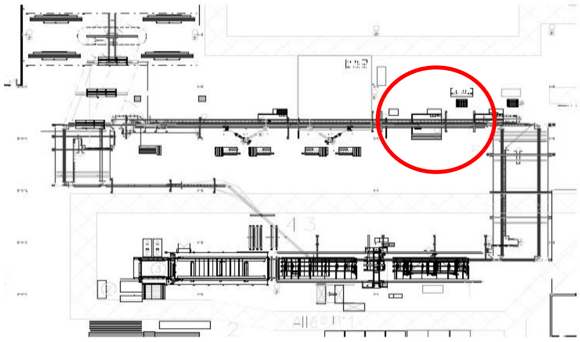

Figure 8. POBI factory layout with red circled the hypothesized Kinova Jaco position

As a first try, Jaco was putted on a table and it was attempted to let him grasp a cube and place it in another position (Figure 9). In order to do this, many ROS nodes are required (Figure 10): one for the motion planning, one for the simulation in Gazebo, one to spawn the cube on the table and one to grasp and ungrasp it.

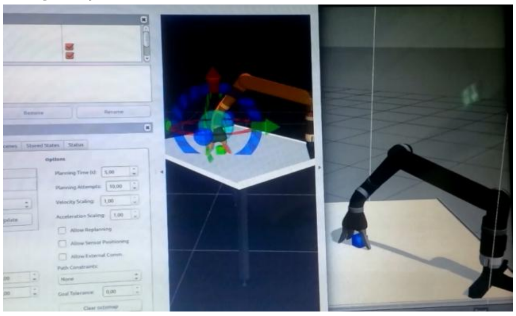

Figure 9. Screenshot which shows the recognition of the cube

At the present time all is under developing but in the future steps of this project it will be possible to substitute the table with a part of the assembly line designed in Autodesk Factory Suite and inserted in the 3D model of the factory for the realistic simulation of Jaco's tasks. Beyond this a camera sensor will be added to the robot, get the panel's and connector's models from BIM and simulate the application of the connection elements on the panels to find out the best solution in terms of costs and time.
As previously said, many ROS nodes are necessary to simulate the Pick and place task with Jaco: Moveit and Rviz to visualize and plan the motion, Gazebo for the simulation and implementation of the real scenario, Graspit to grasp objects. This makes all complicated, thus one of the future objective is to write a code for the automated execution of the pick and place task, avoiding the use of so many nodes contemporarily. Furthermore, now there are lot of issues to solve since sometimes Jaco lose the grasp, other times the cube slides away and sometimes there are no reasons but simply it doesn't work or get stuck.

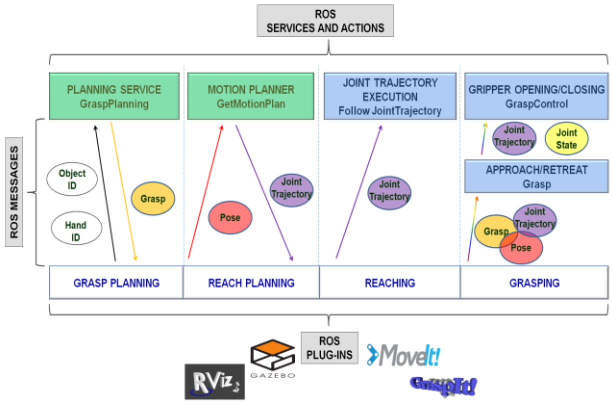

Figure 10. ROS nodes and plug-ins required for grasping with Jaco

There are also other matters to be solved in future work, since to let Jaco be useful for the automation of the off-site production process the robot has not just to pick and place the connectors but it has to execute many others tasks. In fact, Jaco must be able to recognize the environment from whom is surrounded and the dimension of the modules to execute the correct trajectory to install the connectors. Then it has to grasp the connection elements and apply the right trajectory to place them and, finally, it has to check the final result by means of sensors that check the correct installation. With regard to the first objective of letting Jaco recognize the world which surrounds it, the better solution could be the installation of a camera which allows also the recognition of the objects in the environment. Try to find such a solution with ROS is not so complicated since there are many available plug-ins for Gazebo that allow to implement different types of sensors. Within them there is the “Camera” plug-in which provides ROS interface for simulating cameras by publishing Camera Info and Image ROS messages and it is sufficient to incorporate the description of the camera in the URDF (Unified Robot Description Format) file of the robot. Regarding the second purpose, Jaco has also to recognize the object (i.e. the connector) and the position where it has to be placed. This can be achieved with a scanner embedded on it and a smart tag or a barcode both on the panels and on the connectors. In fact, the panels are different for dimension and for the stuff installed on them, consequently the right position of the connectors will not always be the same and it has to be planned a trajectory that Jaco must follow. However the combination of possibilities are finite and the right trajectory could be recognized from Jaco by reading the smart tag or the barcode on the modules since to each code it will correspond a trajectory for the exact displacement of the object. If there were four kind of panels of different dimensions and with different surface characteristics, there will be at least sixteen tags or codes to distinguish them (one for each panel and one for each corner of the panel). This codes will be read by the scanner on the robot which then has to find the correspondent connection element with the same tag and apply the relative planned trajectory to displace it in the correct position. The panels are not all equals but at least they are not infinite, so there is the possibility to give a finite number of trajectory to the robot, one for each panel type and then it can recognize the right trajectory by reading the codes and consequently place the connectors in the correct position.

BERTIM on-site process automation

Once the automation of the off-site construction process is planned, by means of BIM, Inventor and ROS it might obtain construction elements built ad-hoc for automated installation thus also the on-site installation process that represents the third subsystem in the BERTIM project could be automated (Figure 11). Thanks to the detailed information stored in BIM that offers us the exact dimension, geometry and position of the elements and exploiting the realistic simulation provided by ROS where the models of the building and of the panels (with the connectors embedded) can be imported, it could be possible to identify the ideal workflow for each construction task, tested to avoid any clash and to identify also the respective appropriate robot with the more suitable end-effector. Hence, this could enable to automate also the on-site installation process.

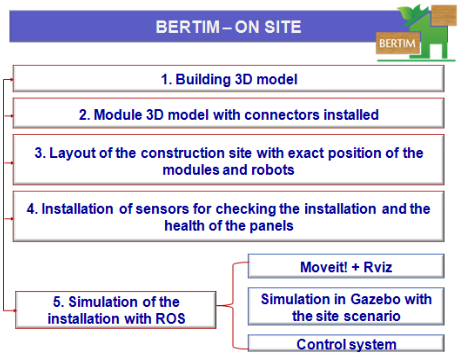

Figure 11. Steps for the automation of on-site construction processes

It can be hypothesized also to insert some sensors in the panels for the future monitoring of its health state, being able to intervene before there are visible damages and also to check the correct installation of the panels with respect to the existing building and to the other panels (being sure that they don't move too much or that they load on the existing building). All these things could be made possible by the simulation in ROS integrated with BIM and CAD models.

ROS-BIM IN LISA-HABITEC PROJECT

ROS could be an interesting tool also for projects like LISA-Habitec (Habitats, Bits and Technology in an Ageing Society) [18] that concerns the implementation of RmRs (Robotic Micro-Rooms) [19] to allow the independent living of elderly people.

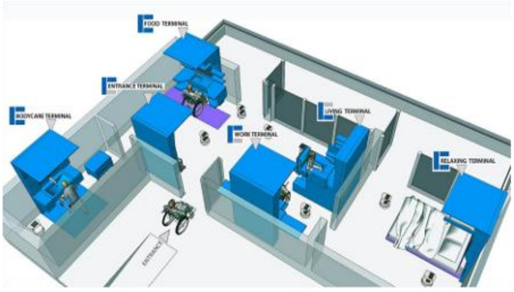

Figure 12 . Example of apartment with RmRs installed (Image from br2.tum.de)

The implementation of new technologies such as sensors, assistance devices and robotic systems requires costly and long processes to test them and find out the best arrangement. In addition, it usually requires that elderly move to another accommodation and this often is the reason to give up the idea of installing assistance devices. This could be overtook using ROS since it might be imported the model of the existing house and try to integrate LISA terminals in a virtual but realistic scenario so that the elderly can visualize how their home will look after the interventions not only in an architectonic sense but also with respect to the visualization of how robots move in the house, without any physical approach and expense. Moreover many different kind of sensors, actuators and robots as assistive technologies could be tried by means of simulation in Gazebo and Rviz without any cost and risk. Exploiting ROS it could be possible to import the LISA 3D model and testing different control or assistive systems.

JACO arm in LISA bath terminal

It is a matter of fact that old people have problems even in carrying out the simplest daily activities and bathing process is one of the most problematic. In fact it requires a certain physical strength and agility to access the bath tub, two capabilities that many old people lost even if they are also required to avoid slippages or falls.

The traditional bath tub design doesn't help elderly to easy access it, thus there are many commercial solutions designed with this purpose and previous studies considered the elderly problems connected to bathing process but their solutions, even if valid, have the difficulty of requiring always an assistance (Figure 13) or an invasive upgrading work of the existing bathroom that has to be completely refurnished [20] (Figure 14).

Figura 13. Example of existing assistive device

Figura 14. Futuristic bathroom ideated by professor Thomas Bock et al. [20] (Image from the paper)

Thus, as final part of this preliminary study, it was tried to integrate Jaco arm in the LISA bath terminal (Figure 15) with the intent of helping elderly during the bath and doing all the connected activities safely and independently with low impact interventions. With this purpose Jaco could help elderly in getting up from the bath tub or reaching objects in high shelves or preventing falls. Another interest application could be the installation of waterproof sensors in the bath which are able to signal a long-time inactivity of people. In fact they could had a problem or fell asleep or, in the worst case, they could felt sick and be in life danger. The sensors must be able to call for help also in the case that the old person falls down and isn't able to getting up by himself.

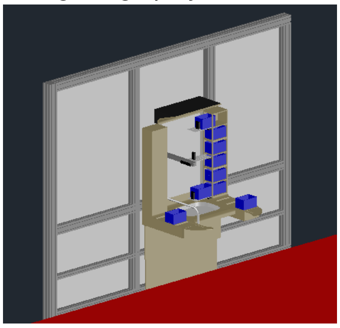

Figure15. LISA bath terminal

Coming back to the first purpose of installing Jaco in the LISA bath terminal, its 3D model was converted in stl binary format by means of Autocad “Export” function. and then two ways of importing it in ROS were tested: first directly in Rviz by means of the “Import file” function, In this way it might have have the stl model in the scenario and drag it in the correct position, being also able to change its scale and orientation. The second method considers of embedding the binary code in the Gazebo launch file but it is more complicated even if more precise, the first tries were intricate, thus for the moment it was exploited the first method which gives a good integration (Figure 16) even if it wasn't possible to visualize the real colors of the meshes even trying with a collada 3D file.

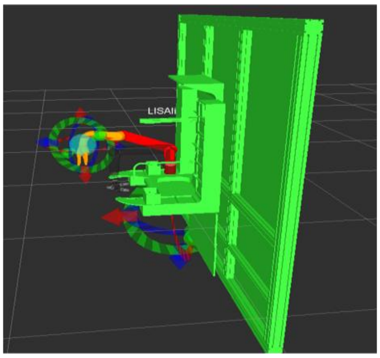

Figure 16. Screenshot of LISA bath terminal with Jaco arm installed directly in Rviz

However, to simulate and visualize the installation of robotic tools it is more than sufficient. In future work it has to be considered another approach that is to divide the model in different meshes and then connecting them as links in the URDF file, in this way it might be more simple but also more accurate.

HVAC systems control by means of interaction with elderly

Another interesting application for LISA-Habitec that could be tested by means of ROS and BIM, might be the interaction between the terminals and elderly to achieve the control of internal environment conditions (i.e. air quality, temperature…) and of the elderly life itself. As a matter of fact old people have problems of dehydration or they could have memory problems that don't allow them to understand exactly when it's time to turn on or off HVAC systems or when it's time to change the air, over that it would be interesting also to monitor how long the old person didn't go outside (Since solar radiation is important to fix vitamin D for the bones) or how long he/she was seated or laying to avoid blood flow problems and so on. This could be possible taking advantage of the already implemented function of reading vital signals within LISA-walls, adding other sensors to check the activities of the person and measure air quality or control HVAC systems basing on the actual need of the person in addition to monitoring of energy consumption, being able to reach the desired condition of both thermal comfort and energy saving.

Terminals health monitoring system

Finally, in a project such as LISA-Habitec it could be really useful a monitoring system embedded in the terminals to check their health-state for various scopes. In fact, it is known that elderly are not so familiar with technologies nowadays, thus a sensor networks capable of signal in real time possible operation problems or the necessity of maintenance works could be important to intervene in time, without waiting for the evident damage. This could really facilitate the independent living of old people since in this way it is possible to intervene in time, with minor costs and less impact on their life once they are used to have these assistive functions. Hence they could live in tranquility knowing that their precious assistance systems are constantly controlled and if there will occurs a problem the assistance will be instantaneously active. These kind of sensor networks can be tested in ROS before the real implementation on the terminals without any expense of time and money.

CONCLUSION

This paper tackled the problem of how designing and test the introduction of automated processes and domotic systems in AEC industry since there still missing a specific software that enables the direct planning of such systems. It was highlighted how BIM can give an help in this sense but also that it is not sufficient by itself, thus it was evaluated the possibility to take advantage of robotic tools typical of robotics industry and apply them within the BIM-based design workflow. In fact, there is the need of a specific software for the dynamic simulation of construction processes that allows also the planning of a detailed and precise workflow for each required task, avoiding clashes for a successful automation and the realistic representation of complex modern buildings which have many new technologies embedded that cannot be represented with classical CAD or BIM tools by themselves. This lack could be covered with the integration of a powerful instrument such as ROS in BIM-based design workflow which can give a strong push to automation in AEC industry, allowing to simulate any construction process or domotic system in a virtual ambient without risking both the construction and the robotic tools. This means having not expensive planning for automation and not losing money in tools that in the future could reveal useless or too complicated, moreover there is the possibility to visualize the process, plan it in a safety way and visualize also the final product avoiding errors or accidents both in the planning and realization phase with a consequently improvement of productivity.

In the present research it was showed many possible applications enabled by this integration between BIM and ROS which offers a lot of potentialities even if the road to reach it is not so simple. In addition to the difficulties exposed that just require time to study and try better solutions, another issue will surely be the lack of already available URDF for traditional construction machinery but it can be realized ROS packages also for them by creating a mesh file for visual representation and the URDF description to define links, joints and kinematic.

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REFERENCES

1. Eastman et al. "BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors", John Wiley & Sons, 2011
2. Zhang J., Long, Y., Lv S., Xiang Y., "BIM-enabled Modular and Industrialized Construction in China", Procedia Engineering 145, pp. 1456-1461, 2016.
3. Ding L., Wei R., Che H. "Development of a BIM-based Automated Construction System", Procedia Engineering 85, pp. 123-131, 2014.
4. Lee S., Isaac S., Bock T. "An Ontology for Process Information Modeling", in *Proceedings of the 32nd ISARC*, June 15-18, Oulu, Finland, 2015
5. Correa F., "Robot-Oriented Design for Production in the context of Building Information Modeling", in *Proceedings of the* 33th *ISARC*, July 18-21, Auburn, AL, 2016.
6. Gerkey B., Conley K., Faust J., Foote T., Leibs J., Berger E., Wheeler R., Ng A.,"ROS: an open-source Robot Operating System Morgan Quigley", *ICRA Workshop on Open Source Software,* Vol.3, 2009.
7. Pan W., Lee S., Bock T. "Active Building Structure and Envelope", in *Proceedings of the 32nd ISARC*, June 15-18, Oulu, Finland, 2015
8. .Linner T., Shrikathiresan A., Vetrenko M., Ellmann B., Bock T., "Modeling and operating robotic environments using Gazebo/ROS", in *Proceedings of the 29th ISARC*, June 26-29, Eindhoven, NL, 2012.
9. Iturralde K., Linner T., Bock T., "Comparison of Automated and Robotic Support Bodies for Building Facade Upgrading", in *Proceedings of the 32nd ISARC*, June 15-18, Oulu, Finland, 2015.
10. http://bertim.eu
11. Iturralde K., Linner T., Bock T., "Development of a modular and integrated product manufacturing-installation system kit for the automation of the refurbishment process in the research project BERTIM", in *Proceedings of the* 33th *ISARC*, July 18-21, Auburn, AL, 2016.
12. http://wiki.ros.org/rviz
13. http://gazebosim.org/
14. http://wiki.ros.org/Robots/JACO
15. https://github.com/JenniferBuehler
16. http://moveit.ros.org/
17. Miller A., Allen P.K., "Graspit!: A Versatile Simulator for Robotic Grasping", *IEEE Robotics and Automation Magazine*, Vol.11(4), pp.110-122, December, 2004.
18. http://www.br2.ar.tum.de/index.php/research/projects/8-home/153-l-i-s-a-habitec-living-independently-in-suedtirol-alto.
19. Linner T., Guttler J., Bock T., Georgoulas C., "Assistive robotic micro-rooms for independent living", *Automation in Construction*, Vol.51, pp.8–22, March 2015.
20. Bock T., Georgoulas C., Linner T. "Towards Robotic Assisted Hygienic Services: Concept for Assisting and Automating Daily Activities in the Bathroom", *Proceedings of the 29th ISARC*, June 26-29, Eindhoven, NL, 2012.