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AN OVERVIEW ON ROBOTIC APPLICATIONS FOR CULTURAL HERITAGE AND BUILT CULTURAL HERITAGE

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Abstract

Focus is an overview on Robotics application for Cultural heritage and Built Cultural Heritage (a term that includes all the Architectural, Archaeological, and generally constructed artifacts). In the field of analysis and restoration of Cultural Heritage and Built Cultural Heritage it is interesting to have accurate and efficient operating methodologies. Indeed, robots and robotic systems can be designed and used for these applications. The join between DART (Laboratory of Documentation, Analysis, Survey of Architecture and Territory), LARM (Laboratory of Robotics and Mechatronics) of Cassino University and the LAREA (LAboratorio di Rilievo E Architettura) of Tor Vergata University, it was an example in sharing different knowledges and competences and in developing innovative robotic applications, which are able to operate in Cultural Heritage and Built Cultural Heritage.

Keywords

Cultural Heritage, Built Cultural Heritage, Robotics, Architectural Survey, Restauration, Conservation

1. *Introduction*

Focus of this article is an overview of the results of collaboration between three Laboratories: the DART (Laboratory for the Documentation, Analysis & Surveying of Territory and Architecture), University of Cassino, the LARM (Robotics and Mechatronics Laboratory), University of Cassino and the LAREA (LAboratorio di Rilievo E Architettura), University of Tor Vergata Rome (DART, LARM, 2019).

Despite their seemingly diverse spheres of research, these three Laboratories have a long history of opportunities to discuss and share their knowledge, and to research issues on which to base practical, fruitful collaborations.

The contribution presents the report of the research activities carried out by the laboratories from 2002 to 2018 in the development of a robot for the knowledge of inaccessible cultural heritage, highlighting the evolution of prototypes in their main evolutionary steps, from a hexapod to a drone with legs.

Our aim is the analysis, documentation, conservation and restauration of Cultural Heritage and Built Cultural Heritage using robotic systems/applications/platforms. Despite Cultural Heritage and Built Cultural Heritage are apparently so far removed from the more general fields of robotics and mechatronics.

2. *Cultural Heritage and Built Cultural Heritage*

Italy has an extremely considerable number of Cultural Heritage: 43 UNESCO sites, about 4000 museums, 240 archaeological sites and over 500 monumental complexes (Ippolito, 2015).

In these scenes, the research on Cultural Heritage becomes essential not only in the field of survey but mainly in the development of the country, with a focus of various scientific skills and disciplines, technical, economic, and social competences with innovative points of view.

Our work focus on data collect and processing that will be used for their documentation. The research group consists of members with a varied pool of skills, who can guarantee a multidisciplinary approach. This will help the team to approach Cultural Heritage from various points of view and various scales of application, with a focus on Built Cultural Heritage (a term that includes all the architectural, archaeological, and generally constructed artifacts).

Our work focuses on data collecting and processing, for knowledge, analysis, valorization and restoration.

Procedures will be defined to guarantee the quality and integration of the acquired data, providing continuous access to the information collected and processed in digital format. Most of the data will be processed in the form of 3D digital models obtained through various technologies that will be consulted on off-line and web-based systems (Clini, Mehtedi, Nespeca, Ruggeri, & Raffaelli, 2015; Valzano, Negro, & Foschi, 2017).

Today, in terms of documentation, the tools available allow researchers to acquire a high amount (and quality) of data, manage and share them in real time with a huge audience, thanks to an increasingly widespread network infrastructure, with fast connections at economically insignificant costs. Our research focus on technological innovation, especially in terms of the opportunities offered by robotic platforms/systems /applications.

3. *Cases of study*

The very first collaborations between DART LARM and LAREA Laboratories started in 2002.

Since years Cassino DART team was working on analysis, documentation and survey of the abbey of Montecassino. The Abbey is an important case study because portions of a complex and articulated stratigraphy were highlighted after its partial destruction due to bombing during World War II. The photographic documentation of the restoration works carried out between 1948 and 1952 highlighted the signs of interventions of medieval origin, including large portions of flooring of the Byzantine school, considered lost (Cigola, 2012), now located to inaccessible areas.

Architectural survey is made by a complex series of operations such focusing on collection, evaluation and interpretation of a big amount of data, not only concerning the morphology of a Built Cultural Heritage/Monument, but also data on its construction, structure, material, decoration, history etc.

All these data must be organized in graphic elaborations that identify all characteristics and peculiarities concerning the Monument, so it is necessary an accurate measurement.

On these assumptions our idea was to test interaction between Robotics and Built Cultural Heritage, in the field of documenting and surveying historical architectural elements, in a project specially designed for their analysis, conservation and restoration.

The interaction between DART and LAREA Team, experts in architectural surveying, provides the principal elements for designing a robot that

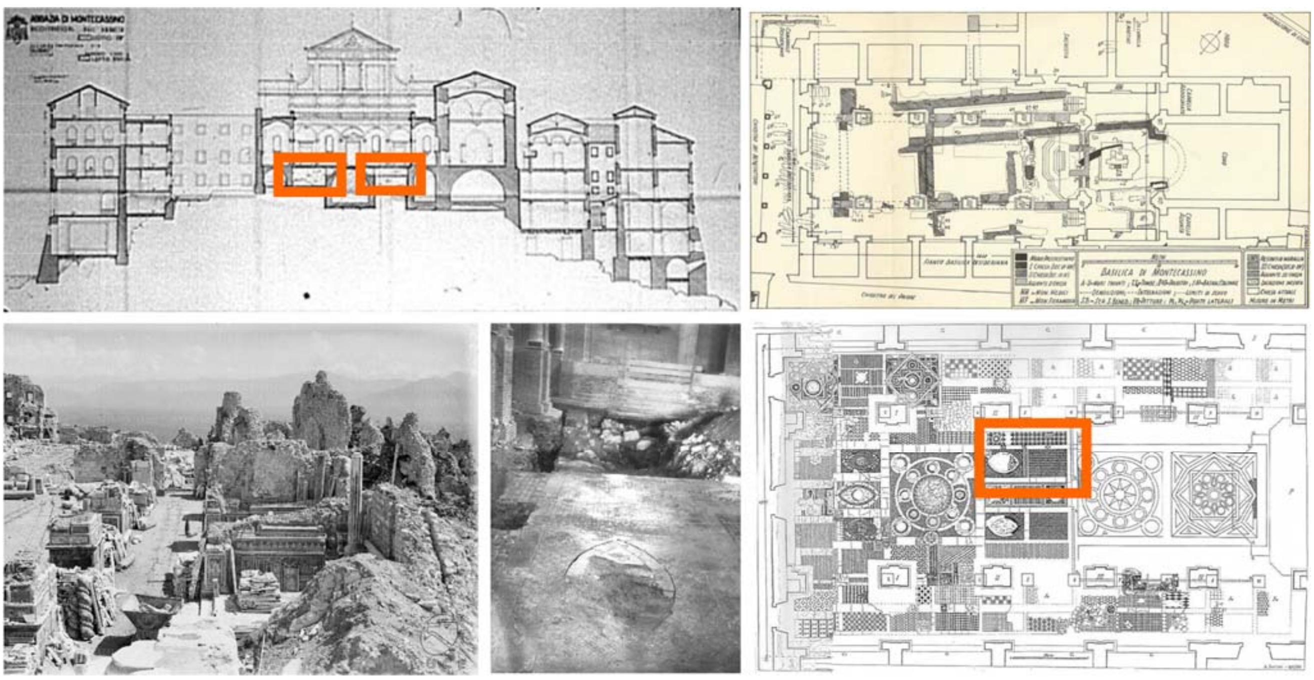

Fig. 1: Study area at the abbey of Montecassino. Cross section of the Abbey; the Basilica and some survey drawings before rebuilding

can operate inside the cavities beneath the Basilica. These indications were developed by LARMTeam, experts in robotized systems.

The focus was to plan a robot capable to perform many of the operations related to analysis and monitoring into an inaccessible area in remote control. It could improve procedures and results in terms of speed, precision and execution. To obtain this result, a robot was designed with the ability to move in various directions, with "vision capacity" and a high degree of versatility in order to adapt to the various sites in which it can be used (Architectural and/or Archaeological).

The research was developed in two phases:

The first phase concerned the development of remote-control prototypes compatible with use within the Cultural Heritage. In this first phase, the experimentswerecarried out inside the Abbey of Montecassino (Fig. 1).

The second phase (Heritagebot Project) concerned the development of integration. In terms of technological equipment for the survey.

In this phase, the experimentations have been extended to the territory, focusing on archaeological areas within the Archaeological Area of Cassino (Fig. 2).

The first phase (2002-2017) carried on the design and construction of a series of prototypes (Fig. 3a).

With the first prototype, the study focused on the theme of operability and manoeuvrability, with attention to the management and planning

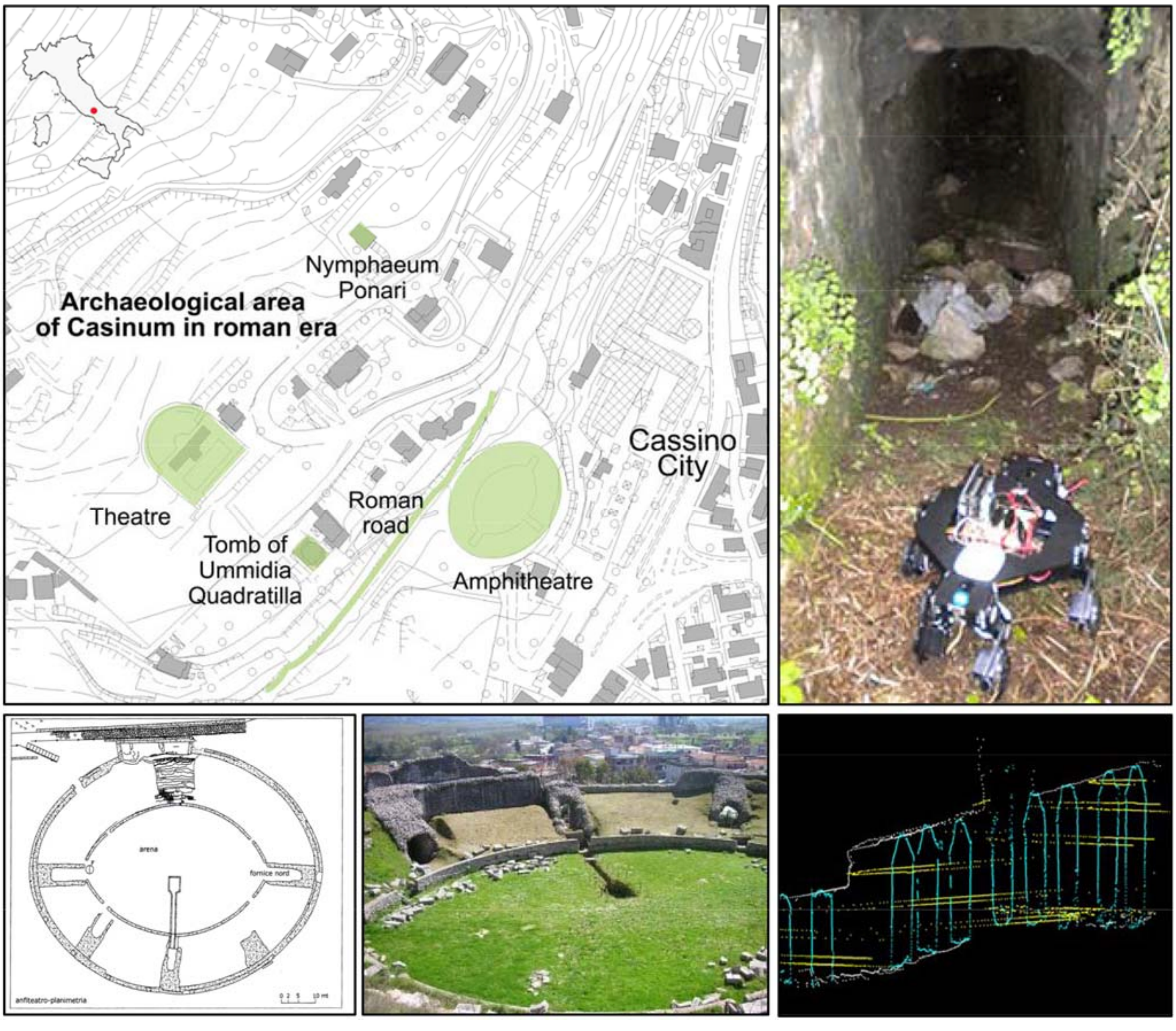

Fig. 2: The archaeological area of Cassino, a field of experimentation for the "Heritagebot Project". Analysis of the amphitheater tunnels.

aspects of the movement capacity. They were identified the parameters and the equipment - related to the scanning operations- that could be appropriate and possibly integrated with the available robotic system and assess whether and how the device itself could meet the specific requirements.

At the same time, protocols have been defined regarding the compatibility of the equipment with Cultural Heritage to ensure its conservation.

The collaboration between the DART, LAREA and LARM laboratories has been continued with the design and construction of other two prototypesof exapod robot (Fig. 3a, 3b), by solving some problems encountered in the previous model and by optimizing both the mechanics and the components, always using COTS optical hardware and software, to significantly reduce the costs of system manufacturing and management.

Each prototype represented an improvement in terms of reliability, lightness and maneuverability while maintaining the principle of leg-based movement.

Once the necessary know-how had been obtained, it was possible to access regional research funding (FILAS) with which the project moved on to a more structured and articulated second phase of work (2018) named Heritagebot Project. The funding allowed an important evolution of the prototype with the modification of the leg structure that passed from 6 to 4 and with the addition of a drone module.

The second phase had as its testing ground the territory and in particular, the Archaeological Area of Cassino (Cigola, Gallozzi, Paris, & Chiavoni 2018).

4. *Phase I: Prototypes*

First prototype designed by our teams (Fig. 3a) was Cassino Hexapod I developed in 2006 (Carbone, Shrot & Ceccarelli, 2007). The control architecture was implemented by using an on-board commercial PLC. An external DC power supply was used to provide power to the hexapod. Size of the robot was 0.6x0.6x0.5 m. and weight was 21.6 kg. The main problem of this prototype was represented by the weight and specially the high-power consumption originated mainly from the high number of DC motors adopted.

A new prototype was proposed in 2012 with the name of Cassino Hexapod II (Fig. 3b).

It was simpler in mechanical way by using low-cost components and commercial thermoplastic alloy (Delrin) (Tedeschi, Cafolla, & Carbone, 2014). Its maximum size was 0.36x0.27x0.2 m. and was powered by 18 RC servomotors, 12 of which were used to give mobility to the legs, while the other six were used to drive the wheels. Control system was based on a commercial, low cost platform Arduino Mega 2560. Customized software has been developed to allow operation and remote-control interface has been developed by means a Wi-Fi Arduino shield.

The high-level control, implemented on PC, has been developed in a Java environment and allows the task planning through Wi-Fi network. A Li-Po battery, 7.4 V-2200 mAh provides power to the control board and the actuators (Carbone & Tedeschi, 2013).

We proposed a novel solution in 2015 to improve second prototype in terms of walking speed, load capacity, stiffness, survey activity with the name of Cassino Hexapod III (Fig. 3c).

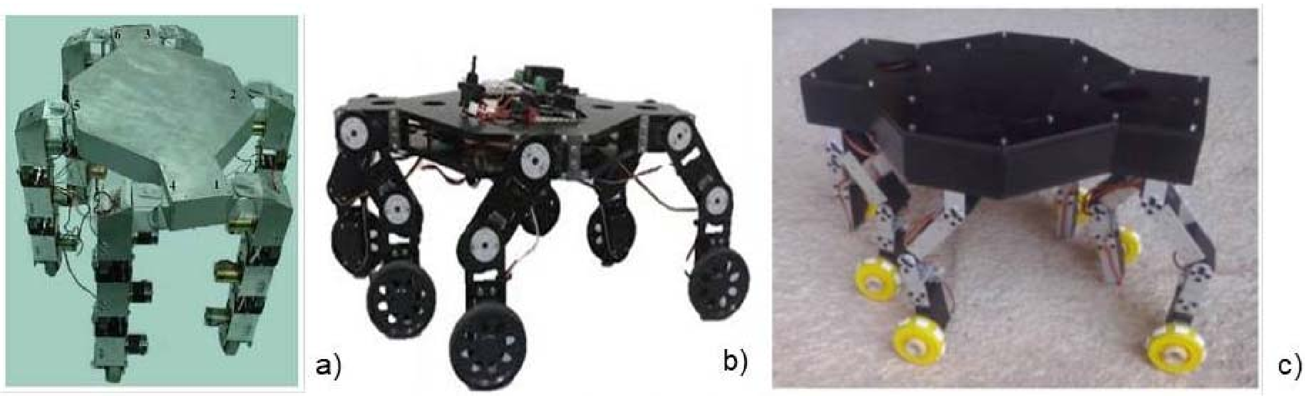

Fig. 3: Prototypes of Cassino Hexapod. a) version I of 2006; b) Version II of 2012; c) Version III of 2015

This third prototype has been equipped with omni-wheels in order to improve the strategy for turning left and right. Each omni-wheel has a diameter of 60 mm and it is driven by an independent continuous rotation servo. A suitable control strategy of omni-wheels allows the robot steering. The legs operation has been carried out by means 12 digital servomotors with an output torque of 1.5 Nm.

During the research, the working group also carried out some further upgrades to the basic prototype. These include:

A robotic arm on the upper base of the hexapod, capable to support, measurements tools like laser scanners (Carbone, Cigola, Tedeschi & Gallozzi, 2015).

An application called MuseBot system (Cigola, Gallozzi, Ceccarelli, Carbone, De Stefano & Scotto, 2017) which focuses on the use of robots for visiting a museum during closing time. A visitor connected to the robot through a computer/ smartphone/ tablet can control and "drive" the robot visiting a museum. The visitor can also get a simple or extended view of the picture/sculpture etc that he/she is looking at, through a specially prepared multimedia database (Gallozzi, Carbone, Ceccarelli, De Stefano, Scotto di Freca, Bianchi & Cigola, 2017) (Fig. 4).

5. Phase II: The HeritageBotProject

HeritageBotwas the last phase of the research. The prototype, starting from the knowledge acquired by its predecessors, was an important evolution not only for the mechatronic approach of the mouvement capability, but more for the integration of survey's instruments.

HeritageBot was a research financed by FILAS Regione Lazio (Italy). It was carried out by the Department of Economics of the University of Cassino and South Latium that engage the laboratories DART, LARM, IMPRENDILAB and FINLAB.

The research had two focus. First one is to verify and test the limits and operative possibilities of the robotic system. Second one is to define an operative protocol of experimentation

Fig. 4: MuseBot architecture diagram system

for acquisition and check metric and colorimetric data (Ceccarelli et al, 2017).

HeritageBot robot platform has been designed by a multidisciplinary team with expertise in Robotics, Architecture, Entrepreneurship and Finance aiming to achieve a system that can be attractive, useful and affordable in Cultural Heritage.

The design process has started by defining the market requirements and needs. First market analysis has identified some potential in a device for documentation, exploration, conservation, restorations, monitoring Cultural Heritage and Built Cultural Heritage especially for non-easily accessible environments.

Existing solutions are mostly limited to crawlers/wheeled mobile robots or drones that show some limitations. Crawlers can easily damage the operation surface. Wheeled robots cannot overcome high obstacles. Drones are not suitable for exploring narrow spaces.

HeritageBot robot platform was designed to overcome the above-mentioned limitations also by considering specific features requested by experts of Architectural survey. So HeritageBot design has been planned with a modular structure that can provide specific features and equipment according specific application and functionalities that are asked by the users.

Three modules have been designed in collaboration by robotic and survey team (Fig. 5).

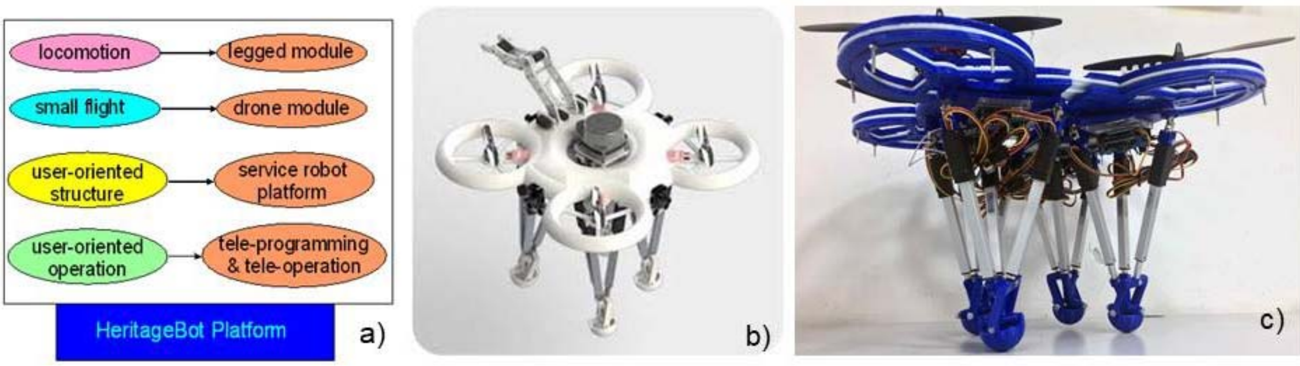

Fig. 5: Design of HeritageBot. a) scheme; b) CAD Design c) LARM prototype with leg module

The first hosts the control and operation architecture (including batteries and communication hardware) as well as the specific sensors and instrumentation needed by users.

Second module was a quadcopter-like system that can perform a small flight to avoid obstacles and to increase its payload/stability capacity. More propellers could be added to achieve larger flight heights, but we decided it unnecessary in Cultural Heritage frameworks.

Third module has a tripod parallel architecture (patent pending by LARM) (Russo & Ceccarelli, 2017). Its main features are the very high payload to own weight capacity as well as a wide step range. HeritageBotcan operate in narrow spaces, in presence of obstacles comparable with its platform size while avoiding high pressures or damages on the operation surface.

Focus of DART Team was developing a suitably sensorized robotic platform with mobility, locomotion and a low flight capacity that is managed wirelessly for Built Cultural Heritage monitoring and restauration operations. The device can capture data with on-board storage capacity and has high operational autonomy, also thanks to its intrinsic characteristics.

The platform's structure was modular, especially as regards its instrumentation geared towards Architectural and Archaeological Built Cultural Heritage monitoring and intervention operations. The modules were designed to be independent structures, which are however integrated so that the platform can easily adapt to various of applications. Any additional sensors can be used for various functionalities, using commercial or specially developed solutions. The demonstrative prototype includes sensors for monitoring and recording through a camera and LIDAR sensors.

The device project includes an initial phase to assess the prototype's potential. To simplify the verification process, specific tests have been programmed: test on locomotion in a controlled environment to simulate typical problems of Archaeological sites and identify any difficulties in movement and data acquisition; test of the sensors; test of an operative procedure of acquisition, processing and data analysis in terms of geometric quality and ability to provide the necessary photographic information relative to the case study. In order to assess the HeritageBot prototype's functionality, an "Experimentation Field" was specially designed and created by the DART laboratory.

In it various and suitably designed obstacles allowed for the verification of the prototype's ability to move and maneuver in tight spaces, as well as its remote control, LIDAR data acquisition and photograph capabilities (Fig. 6).

Experimentation field was a closed three-dimensional space with different types of obstacles that the prototype must face using movement strategies either independently, or in combination.

integrated data, capable of geometrically and perceptually describing the explored locations. In this first phase of the project we used low cost sensors simply available on market. Sensors evaluation was carried out with the aim to define the level of uncertainty and the degree of approximation of data. (Apollonio & Gaiani, 2012).

6. *Conclusions*

The collaboration between the DART, LAREA and LARM laboratories will continue enriching itself.

Currently, in fact prof. Marco Ceccarelli (former Director of Cassino LARM) is Director of LARM 2 at University of Rome "Tor Vergata" and prof. Giuseppe Carbone (former part of Cassino LARM Team) is Associate professor at University of Calabria.

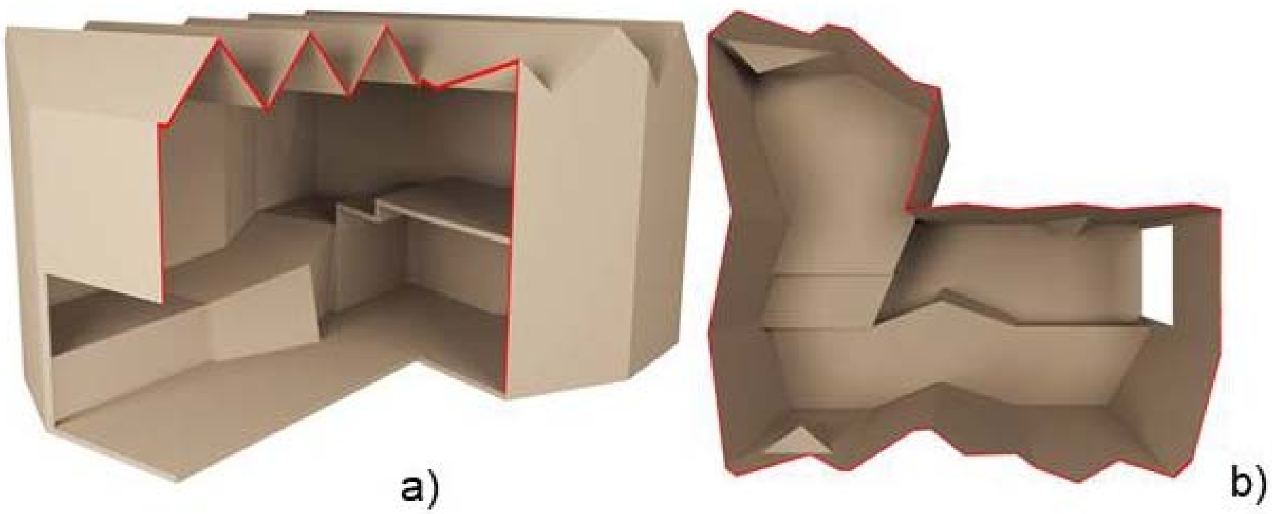

Fig. 6: Experimentation field. a) project three-dimensional model cross-section; b) top perspective view

The obstacles were designed to simulate a natural bumpy surface in a limited dimensions space. In this way was tested the possibilities of locomotion, the prototype's overall dexterity and its ability to provide the operator, maneuvering in remote, the data to identify various problems concerning the surface. The structure was designed as a sequence space with individual characteristic planned for evaluate prototype's capacity to overcome each type of obstacle.

The first HeritageBot prototype was equipped with two types of sensors linked to collect

We worked together for more than 16 years, and we together reached important goals developing some robotic platforms/systems /applications for Cultural Heritage and Built Cultural Heritage (Fig. 7).

The link between Cultural Heritage and Robotics is always mandatory for us. A binomial that has been in recent past, is currently and in the future will be essential for the analysis, preservation, restoration and valorization for the Heritage of our Country

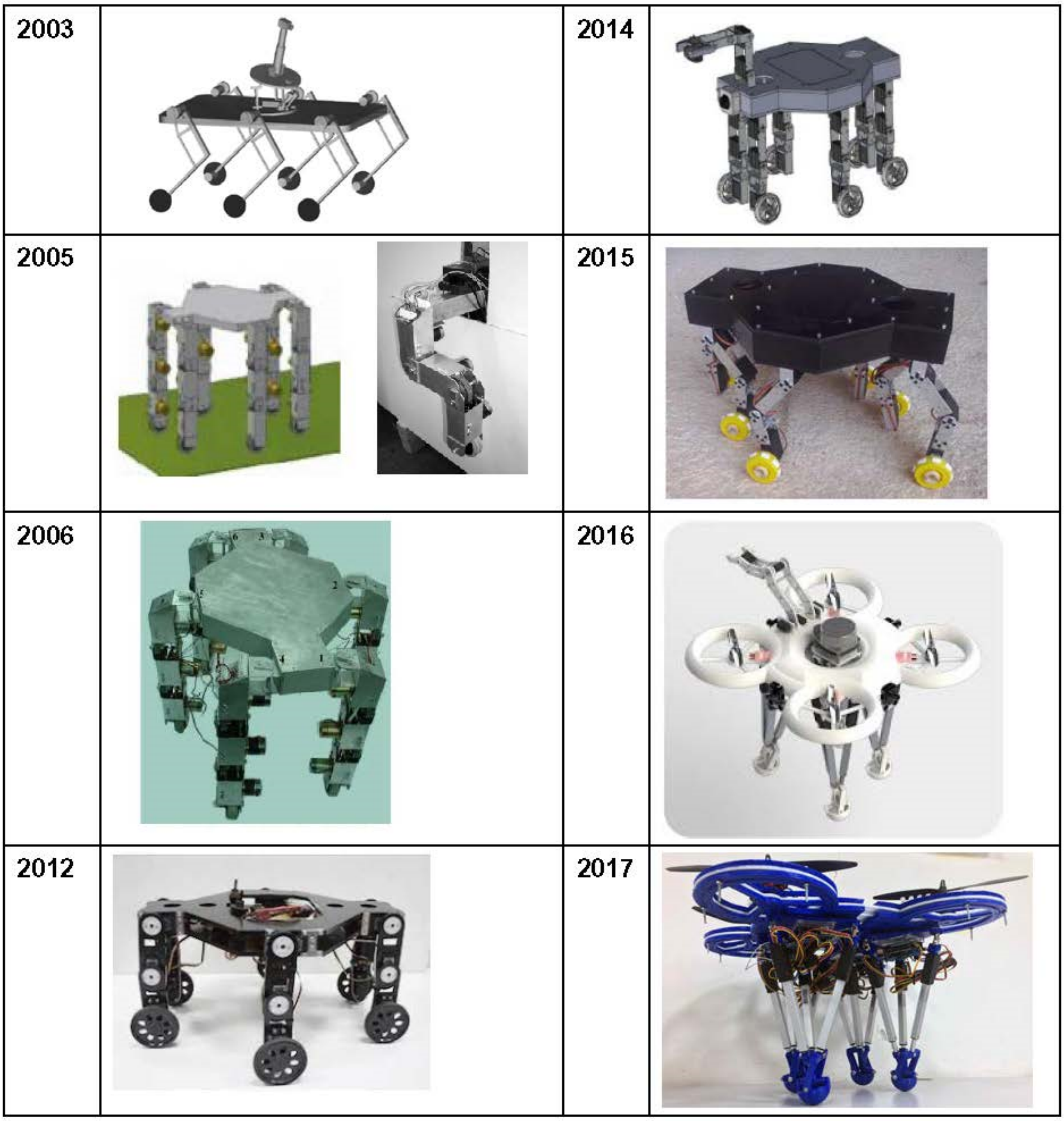

Fig. 7: An overview and synthesis of DART and LARM designs for robots applications for Cultural Heritage and Built Cultural Heritage

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