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BETWEEN ARTIFICIAL INTELLIGENCE AND ROBOTICS: CONNECT-R

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Abstract

Questo trattato esplora le caratteristiche e le potenzialità di un progetto sperimentale - Connect-R - nato dalla sinergia di Intelligenza Artificiale (AI) e Ingegneria Robotica, finalizzato inizialmente all'impiego nell'industria nucleare, in particolare nella dismissione e smantellamento degli impianti.

L'idea che sottende a questo studio si basa su tre aspetti principali: stimare l'impatto economico sui contesti esterni di riferimento, descrivere il progetto sia dal punto di vista manageriale che tecnologico e infine illustrare i compiti svolti dal candidato in collaborazione col team incaricato dello sviluppo del progetto.

Più in dettaglio, nel primo capitolo si discute dello stato attuale e futuro dell'Intelligenza Artificiale e dei suoi effetti economici sul mercato globale.

Nell'ambito delle potenziali applicazioni di questa scienza, viene introdotta la presentazione di Connect-R, descrivendone nascita, finanziamento e partnership. I successivi argomenti sono la sua posizione nel panorama AI, lo scopo del progetto, la descrizione tecnica, un canvas business model e un benchmark con altre soluzioni tecnologiche esistenti. Sono, infine, trattate anche tutte le possibili aree di implementazione future: l'industria petrolifera e del gas, quella mineraria, quella agricola e quella aerospaziale.

Poiché la prima area di applicazione sarà la disattivazione delle centrali nucleari, il terzo capitolo affronta un'analisi di mercato del nucleare civile, al fine di individuare quali opportunità questo settore offre a Connect-R. Si discuterà pertanto dell'attuale fabbisogno di energia da rinnovabili e sulla sostenibilità del nucleare che comporta, tra altri, problemi come lo smantellamento delle centrali. Pur essendo già operanti in questo campo altre soluzioni robotiche, nessuna è in grado di offrire le stesse possibilità di Connect-R.

Nell'ultimo capitolo sono descritti i compiti tecnici di supporto alla progettazione che il candidato ha svolto all'interno del team di lavoro multidisciplinare della Royal Holloway University di Londra.

Le conclusioni del presente studio riassumono le considerazioni finali sui pro e contro del progetto Connect-R in termini economici e di mercato per valutarne le concrete potenzialità.

Abstract

This paper will analyze the potential of an experimental project born from the synergy of Artificial Intelligence (AI) and robotics engineering, Connect-R. Its first implementation will be on the nuclear industry, especially in decommissioning.

The idea behind this study has been structured in three main parts: estimating the economic impact of the related external contexts, describing the project both from a managerial and technological point of view and, lastly, illustrating the tasks performed by the candidate in collaboration with the team in charge for project development.

More in detail, the argument discussed in the first chapter is the analysis of the current and future AI state and its relative economic effects on the global market. Between all its current applications, Connect-R will be introduced together with the analysis of its birth, financing, and partnership. The following arguments are its position in AI panorama, the project purpose, technical description, a canvas business model, and a benchmark with other existing technological solutions. The last topic will regard other future implementations in different industries: oil and gas, mining, agriculture and space.

However, the first area of application will be nuclear power plant decommissioning. For this reason, the third chapter contains a market analysis regarding civil nuclear, in order to see which opportunities this industry offers to Connect-R. There is a discussion about the current green energy need and nuclear sustainability, involving problems like plants decommissioning. Many existing robotics technologies are already used for this purpose, but no one offers the same possibilities of this project.

Since it is still in development, technical tasks to support its progress have been realized by the candidate at Royal Holloway University Of London, and they will be analyzed in the last chapter. They are divided into two categories: graphical simulations and planning-problems software.

In the end, there are final considerations on the pros and cons of the Connect-R project in economic and market terms to estimate future project forecasts.

Summary

Introduction

Only recently, our society has been invaded by AI new inventions, and now it is the moment when these types of products are entering the business market. New autonomous technologies will not have just an economical direct impact on their segment, but they will affect industries indirectly where will be adopted with the result that can be positives or negatives. For this reason, it is relevant to understand what AI really is, in which forms it comes today, and which effects will have on the relative environment. Then, it is introduced Connect-R, one of these new technological solutions: a project with the goal of providing structure in unstructured environments. Innovate the UK has funded it, the government agency evaluating, promoting, and financing innovative ideas and start-ups in the United Kingdom. This particular project is still experimental, and it is in collaboration between various universities and companies. These are the Royal Holloway University of London and the University of Edinburgh from a side, and Barrnon, Ross Robotics, Jigsaw Structures, and Tharsus from the other. All of them operate in robotic contests, like AI, cognitive robotics, and intelligent control. This project aims to provide an autonomous and robotic alternative to a human operator in hostile working environments, where complex tasks and operations must be executed. In this scenario, risky situations where workers can damage their health will be substituted by a robot capable of building structures and deploying tools. Consequently, not only automation but also an improvement in job security will represent Connect-R benefits and advantages. The range of possible executable actions is extensive, and this explains why many possible implementations in different sectors are supposed for the future.

Moreover, it is essential to evidence project participation of the UK Atomic Energy Authority. Although Connect-R purpose is to be applied for the construction, maintenance, and operating in more than just one industry, its first adoption is in development for nuclear power plants. Therefore, it will be under the nuclear examination market and its perspectives in order to understand which earnings forecasts and success Connect-R will be able to obtain from its first usage. Despite public opinion had a bad reputation about this energy source in the past, currently, many governments are deciding to invest in nuclear. This event is happening since the need to finds out green energy source alternatives to traditional fossil-fuel ones is more urgent day by day. CO_2 emissions must be reduced as soon as possible, and nuclear will be analyzed to understand if it will have the right features to become the new primary worldwide energy source.

The last part will debate tasks related to Connect-R performed at the Royal Holloway University of London during the last six months, to help researchers in its progress and development. The subject of this project participant is about planning-problems and how to program what robots will do. First, this is the reason why a graphical simulation of the problem was needed to provide a tool to understand better what was happening and not just imagining it. Second, it has been wondered if the approach adopted at present to realize the plan was the best, and it has been subsequently compared to an ad-hoc and alternative resolution system.

To sum up, the Artificial Intelligence it is spreading more and more quickly, meaning a break with the past and, probably, upsetting the global economic balance. For this reason, this generational change must be managed with care and attention. One of the levers of this change will be Connect-R, an innovative project aimed at automating risky manual tasks for a human operator in hazardous environments. Although the possibility of implementing this solution in various areas is concrete and is the goal for the future, the prototype is being carried out for nuclear plants. Finally, Connect-R will be analyzed from a technical point of view, defining tasks performed for its support during the experience at the host university. It is clear how the experimental nature of this project poses many challenges and, at the same time, opportunities to reach not conceivable targets until a few years ago. The purpose of this elaborate is analyzing all these aspects, in order to evaluate the effective impact that Connect-R will bring on the market and in our society.

Chapter 1: Artificial Intelligence

Before the start of a Connect-R in-depth analysis, it is crucial to evaluate the context where it is born. In this way, the Artificial Intelligence concept will be introduced, evaluated both from a theoretical and practical point of view. Subsequently, the market for this new branch of technology will then be studied, trying to quantify the impact it could have on the current economy. Finally, predictions will be estimated regarding the future implementations of these technologies and where they would be able to bring better efficiency. For each of these steps, the relative positioning of our project will also be identified.

1.1 State of Art and Connect-R position

One of the main features of current technological research is the implementation and study of automation methodologies and techniques, i.e., those processes and sequences of actions structured independently and continuously that are attributed to the Artificial Intelligence (AI) branch. Nowadays, it is possible to see a worldwide deployment of these technologies as never in the past: they have become an essential part of all the various areas of activity like automotive, navigation, banking, medic, research, mailing, communication, and many other ones. In this panorama, AI mechanisms are the core of each new technology and idea, from fundamental to complex processes. For this reason, when it comes to Artificial intelligence is not possible to provide an unambiguous and shared definition since it is a concept that includes an outstanding argument amount. The result is that when it is requested to provide an AI proper statement, comprehensive of every aspect, it is needed to simplify its formulation, giving a general and trivial description and leaving out fundamental points. Therefore, Artificial intelligence can be described as the subject that studies how to project, develop, and realize mechanisms and systems capable of simulating human reasoning, skills, and behavior. Despite all this, a much-debated question connected to AI scenario is if machines can actually be able to think since there is an enormous difference between passively applying rules stored in memory and programming robots that can really understand a problem by themselves. For having, as a result, a proper information comprehension, robots do not have only to respect and submit to what they have been programmed to do, but they need to elaborate in an autonomous way information retrieved by the external environment making their own conclusions.

Here is where Connect-R is positioned, a robotic solution addressed to substitute human operators in unsafe and hostile working environments. For performing these types of tasks, AI techniques will be involved to provide an efficient execution, capable of analyzing and processing every step autonomously. Connect-R will offer a large number of possible actions all needed to build structures and to deploy tools in hazardous environments, typically of difficult intervention for a human being. Possible application fields can be identified in Nuclear plants construction and decommissioning, which is for what has been developed, but also in others like Oil and Gas, Mining, and Space. With this project, previous barriers of auto-manufacturing will be overpassed, meaning a milestone in AI progress and deployment. In fact, the Artificial Intelligence term has a meaning that has not been wholly achieved yet since understanding automation is still far from implementation in everyday life. In each case, hopes remain and are continuing to increase, making our society more and more futuristic through many projects still in development, having the purpose of remodeling our everyday life, as Connect-R is trying to do.

In current days, Artificial intelligence comes in different forms that have been developed and improved during many years and experiments. It has been distributed in various application fields, and it is now used to solve different types of problems. However, to offer an efficient and effective service, AI needs also support technologies since it is not possible to create a functioning mind without a fit body to execute the actions.

Another relevant matter regarding AI is how it should be categorized, distinguishing between systems only capable of simulating human thinking and systems having cognitive skills comparable to human ones. The first category is the most common and easy one since machines act as if they would have consciousness, but it is only a set of algorithms looking for an answer to a problem. For finding this answer, machines process a significant amount of data and compare many solutions until they find the optimal one. In this category, then, algorithms are not able to fully understand human cognitive processes, and for this reason, this type of machine is called "*Weak Artificial Intelligence*", or Artificial Narrow Intelligence (ANI). Differently, the second category is not yet mature, and it is difficult to find its application in everyday life. Here are located those kinds of machines that, from an assumed as true proposition goes to a second one, following deductive or inductive logic, i.e., deducing a truth from a previous event. These skills are comparable with human logic, and its core is natural language comprehension since there is no real intelligence without a full environment understanding. This category is, then, called "*Strong Artificial Intelligence*", or Artificial General Intelligence (AGI), and for now, it is easier to see that in a movie than in real life, requiring a technology level not yet reached. This classification has been claimed for the first time by John Searle, an American philosopher that in 1980 showed his idea in an article. Even if "Strong Artificial Intelligence" seems far looking at these possibilities, technological development grows fasts, and before we know it, these machines will be around us.

According to this categorization, currently, machines are not able to generate by themselves cognitive skills but to emulate humans ones. Although this is a limit of technological progress, these robots can process complicated calculations and can elaborate an enormous amount of data and information finding out relations that difficultly a man could have found. Since these machines are upgrading human calculation and optimization possibilities, a new definition has been claimed to define Artificial Intelligence as "*Augmented Intelligence*". This is the reason why computers expand human knowledge capability, and its usage is preferred in many contexts.

1.2 History

Since ancient history, human beings have always shown a great interest in the dream that inanimate objects could be truly capable of producing thoughts. Even if in recent years research has made its main progress about this topic, first signs of autonomous intelligence systems employment can be found in ancient civilizations like Greeks, holders of many myths regarding robots, as well as Egyptian and Chinese, both automatons builders from their cultural origin. Since that moment, many years have passed until arriving in the XX century, where can be located autonomous intelligence modern birth. In fact, despite Artificial Intelligence has been studied for decades, it remains a nebulous and vast argument with an infinite number of growth possibilities. AI foundation can be identified in describing human thinking through a symbolic system, considering, in this definition, a broad range of different applications. These implementation ideas were coming from a new way of thinking that was affecting the generation of mathematicians, philosophers, and scientists due to a wind of change and innovation brought by 20th science fiction movies, representing artificial intelligence and futuristic robots.

Artificial intelligence history in calculation can be subdivided into several main phases:

- The first one can be located in the seventeenth century because concrete traces of AI can be found when first scientists were studying this subject, like Blaise Pascal and Gottfried Wilhelm von Leibniz, have built new tools able to make automatic calculations. It was precisely the 1600s when modern science was born, although from a conventional point of view it is to be attributed to the year 1543 when it was published "*De Revolutionibus Orbium Coelestium*" by *Nicolaus Copernicus*;
- It is needed a jump in time of almost 250 years to reach the second phase when the analytic machine by Charles Cabbage was created. This device was a prelude to modern calculators, anticipating their main characteristics. Together with this, there is the second phase Alan Turing work, considered as computer science founder and located into 1930.
- Only the third step will be laid the foundations that will allow artificial neural networks to born. It was in 1943 when Warren Sturgis and Walter Harry Pitts stated the three logical elemental operations NOT, AND, OR that can be mixed to simulate the human neuronal system. To claim this concept they made a comparison between the binary system and neurons.
- To trace the very birth of the term AI, however, it is needed to arrive in 1955: at the Dartmouth's conference was shown for the first time a problem-solving program capable of simulating human logic. Its development is attributable to John McCarthy, Nathaniel Rochester, Marvin Minsky, and Claude Shannon, famous computer experts and mathematicians. Moreover,

they created the “Artificial Intelligence” word definition by compiling the conference report.

- The period between the years 1950 and 1965 was full of new vital events that happened with rapid succession. From a chronological point of view, in 1950, Alan Turing published “Computing machinery and intelligence”, a report regarding machines’ truly thinking capabilities. Never a question like that was proposed before that moment, and for this reason, Turing ideas represented a tear with the past. In 1958, instead, Franck Rosenblatt, an American psychologist, claimed the Perceptron. This fact was the first example of a neural network scheme, structured through input, output, and a learning rule depending on error minimizing. Rosenblatt's idea was initially created just for shapes classification and recognition. In fact, in that period, Artificial Intelligence previsions were exciting, attracting each kind of area of interest and applying different concepts to see AI from different perspectives. A significant milestone was also reached in 1958 again with LISP language development by McCarthy. His code language was used for a long time as a reference to Artificial Intelligence implementations. After this, McCarthy focused his attention on developing programs not strictly connected to mathematicians’ problems in order to expand the AI application field.
- Although AI’s growth spurt seemed unstoppable, it came to a halt after 1965. In fact, despite all ideas proposed and in development, until that moment, no one positive result was achieved. All mathematics models theorized in those years were a failure with a consequent breakup of a dream. One of the main reasons slowing down collective excitement was machines’ limits to develop and obtain a semantic knowledge, i.e., correlating and processing different meanings, due to automatons were able to calculate relations depending on stated rules, i.e., a processor limited to a syntactic knowledge. Moreover, in 1969 distrust in neural networks spreads, led by Marvin Minsky and Seymour Papert, which were not convinced by Rosenblatt Perceptron.
- Only twenty years later, new trust signs were shown when, in 1980, McClelland and Rumelhart changed the scenario through their researches. From that point, a new growth without any slowdown is happened until now, evaluating and analyzing the future potential and possible developments.

This result is how the artificial intelligence is presented today: born of a dream, continued through hopes, slowed down by unachievable goals, and progressed via man's deep desire to confront a new type of reality and never give up before to new challenges. Connect-R project is one of them and represents something that in the past was only theorized as the opportunity of completely automatize construction, maintenance, and dismantling in scenarios that could be risky for human operators. However, despite Connect-R and many other work-in-progress projects purposes of renovating society, AI is still far from reaching its mature phase, and only with the passing of time all the benefits that it will bring will be shown.

1.3 AI types and applications

Currently, the artificial intelligence definition corresponds to a substantial number of different forms. Many experts express their belief on what the actual types, applications, and categories are and what differences exist between them. According to the most trending opinions, there are four main types and eleven applications that can be found. In this definition, the concept behind what a type is it is equivalent to machine capabilities of autonomous thinking since this particular target has not been achieved yet. For this reason, four different types have been theorized depending on the self-consciousness degree. After their argumentation, applications will be discussed, too, while categorization has already been debated in the previous paragraph. The types are the following:

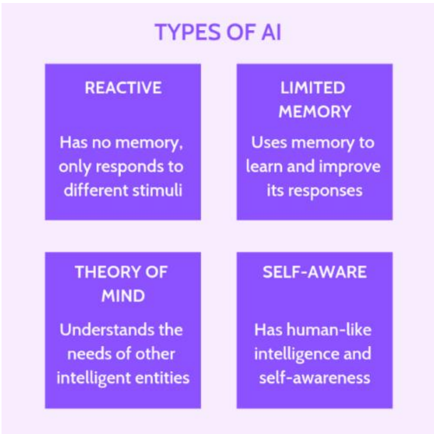
- Reactive machines
- Limited memory
- Theory of mind
- Self-awareness[1]

Before starting the discussion, it is essential to note a gap that separates these four types. As for the first two, they are characterized by being performing limited actions and, therefore, they correspond to those currently existing. On the other hand, the last two define a level of automation not yet reached, establishing only the bases on how to continue developing these machines in the coming years. More in detail, Reactive Machines are those

[1] Hintze, A. (2016). *Understanding the Four Types of Artificial Intelligence*. In Government Technology.

systems capable of executing necessary actions, not being provided by a storage memory. Their programming is addressed to build just a reactive framework, not learning from the past and without a place where to store information. In this way, when they receive a determined input, they perform the following action, repeating this iteration forever and with never a change. An example of these machines was the famous Deep Blue, a chess-playing supercomputer from IBM that has been developed in the second half of the previous century. This event is gone down in history due to the defeat received by Garry Kasparov, a Russian international chess grandmaster, in favor of this old pc, signing the first time where a machine has won on a human. The limit behind Deep Blue, and this first AI type, is the inability to save the information and the restricted fields of actions since these robots cannot switch easily from an activity to another. For what concerns the second type, the situation is not changing so much except for storage memory adoption. However, the information amount that can be absorbed is not infinite, and this is because this type is called Limited Memory. Through data saving possibility, these machines can elaborate on past actions and, thanks to machine learning models, can learn from what happened previously. This skill allows computers to create by themselves their knowledge with many growth possibilities. An example of these robots can be identified in autonomous vehicles. To have a successful execution, these have to perceive data from the environment and to elaborate on them to find the right path. This fact means how not only the road will be analyzed but also other vehicles and pedestrians during the way. Even if these results are amazing, this AI type has barriers that cannot overpass since all learned information is used just in that particular moment and is not stored for sequent experiences. Data acquired will not become part of the machine's mind, and the effect will be temporary. This classification can be found Connect-R since as similar technologies, it is not recording as experience what is perceived from external signals but just using it for calculating the path at the moment. After this point, the limit from what is currently existing and what is only theorized will be marked: human research until now has reached only these two previous AI types, while the other two are derived just from many hypotheses claiming technologies not yet invented. In the next future, machines will become able to understand people's intentions and emotions, being able to act in social interactions. This skill is a must required to perform cooperative work between humans and these new inventions that will fulfill our future. For this reason, this third type is called the Theory of Mind and is not yet actually exist. Nowadays, technologies did not yet achieve a so high level required to create these robots, and much time will have to pass yet. Despite this, sooner or later, machines will become able to interact with humans, comprehending emotions, and adjust their behavior on what is perceived. In these previsions, there is also the last AI type that is even more futuristic and far from our reality, corresponding to Self-Awareness. This event is a step ahead of the previous type since it is a broader version of the Theory of Mind. In fact, from the consciousness understanding capabilities programmed by experts for the third type, machines will be characterized by their one. Programmers will not be anymore who define how to perceive input from the environment and to elaborate an output depending on a pre-existent rule but will define a real consciousness able to process output by its own and without external bits of help. These two last types are not existing yet, but in order to reach them as the next steps to walk, research now will have to focus on the second type, i.e., Limited Memory systems. These are the most advanced technologies for now, and to progress, it is needed to expand their memory capacity, allowing them to take more and more decisions and becoming more similar to humans.

Figure 1



[Source: Joshi, N. (2019). *7 Types Of Artificial Intelligence*. In Forbes.]

Despite this classification in four types, in our society, the AI comes in many different applications. These subsets are all positioned in the second type previously stated, the Limited Memory. It is possible to define several applications so high that they could reach eleven subsets in this particular moment. They can be listed as follows:

- Computer Vision
- Robotics
- Natural language processing (NLP)
- Data Mining
- Big Data Techniques
- Machine Learning
    - Deep Learning
    - Neural Networks
        - Convolutional Neural Network(CNN)
        - Generative Adversarial Networks(GAN)[2]

Each of these subsets is involved in a particular field of application, representing many techniques developed in the AI scope. Inputs are not single, and, for this reason, various branches are born to provide an outperforming service ad-hoc. For what concerns visual inputs and how to elaborate them, Computer Vision is the subset regarding on. Through this, a machine can see an image, meaning the two processes of understanding what is inside and elaborating data derived. In this way, as for a human, now machines can process information perceived by their eyes, i.e., images recorded by the camera.

An example could be recognized still in autonomous vehicles since they have to auto-adjust their path through what is received by cameras. This fact means a high speed elaborating capacity, being applied to a moving car. The result is that thanks to Computer Vision, computers can recognize colors, shapes, sizes, and even more, attributing to machines a type of skill fundamental for their own growth to the following AI types.

Except for visual inputs, there are many others that machines need to process to provide a self-sufficient execution. One of these is language inputs and how computers can understand human speaking. What many experts are looking for is a complete comprehension from both sides. This AI branch is called Natural Language Processing (NLP) and supports machine activities in elaborating, interpreting, and analyzing people's language. The chatbot is the leading player in this area, but many others are existing and still in development. However, these two subsets are representing computers' sight

[2] Reynoso, R. (2019). *11 Applications of Artificial Intelligence in 2020*. In Learning Hub.

and hearings, allowing them to perform actions that only in recent years have reached the right level compared to a human one.

Another yield of application, going to traditional data input, corresponds to methods and techniques involved in processing a large amount of data in order to define recurring patterns and identifying a relationship between them. This result is what the Data Mining does, with the only purpose to elaborate data and extract information. Probably, it is the most common and well-known branch, since it is already entered in everyday life. In fact, every customized offer or ad is made through this, meaning a high impact on what concerns marketing and sales. This area can also be found in the Big Data subset, even if there is some dissimilarity from the previous one. While Data Mining's purpose is to go deeply inside data to extract the critical key from both a small and large dataset and Big Data techniques are referred just to analyzing a widely large amount of data. These are used to process such an enormous information quantity that standard data-processing software is not able to. An example could be TV companies that have to predict new movies or tv-series to produce, identifying trends coming from a worldwide audience, i.e., Netflix.

A step ahead is where is located Machine Learning, a discipline wider than previous ones. Here, machines do not have to process and access data under constriction and rules, but they should autonomously act in this way. To this corresponds the AI core, i.e., robots' useful capabilities in thinking and operating by themselves and in learning from experiences in the absence of a corresponding program. Even if this definition seems so far from our time, many examples in everyday life can be found regarding Machine Learning. Some of them are voice assistants on cell phones, targeted advertisements, and facial recognition software. In this panorama, many techniques have been developed into this branch, and one of the most famous is Deep Learning. Through this, machines have the opportunity to acquire the skills required to imitate human learning and storing information deriving from sounds, texts, images, and even more. Briefly, Deep Learning makes it possible for computers to learn by heart. As voice assistants hear hours and hours of human speaking to know how to participate in people's argumentation, autonomous vehicles learn how to drive from studying roads. Another Machine Learning techniques that are spread all over the world nowadays are Neural Networks. These are types of networks that recreate a human brain through artificial structures based on algorithms that identify recurring patterns. An example is object recognition, providing a significant number of items to investigate, and identifying what the objects are, absorbing information for the next run. Neural Networks can be subdivided again into two different main areas: Convolutional Neural Networks (CNN) and Generative Adversarial Networks (GAN). While the first one is developed only for analyzing, clustering, and classifying images, the other is involved in generating almost authentic photographs, taking data from different elements, and composing them into a mosaic that will represent the image.

Last but not least, there is the most famous and well-known AI application, Robotics one. When a person listens to the Artificial Intelligence term, it usually first thinks it is devolved to robots and futuristic forecasting of human-machine interactions. Even if such a target has not been totally reached, many signs of progress and projects have been developed, making our society nearer to a place where robots will become part of our life. One of these Robotics application is Connect-R, where two different robots will cooperate to produce a body movement as legs for one type and hands for the other. It will not have human appearance but will act like one of them, accessing and executing difficult tasks for a regular employee.

1.4 The AI economic impact

AI technologies have an enormous impact on the global ecosystem because they represent a continuous flow of innovation in many contexts. From an economic point of view, these technologies impact the economy in two main different ways:

- directly affecting the market for this type of solution
- indirectly impacting on goods, services, and labor connected

When a new AI technology is released, it has effects that could be positives and negatives for the production and labor aspects related to the sector where it will be implemented. For this reason, many analysts have been made trying to provide advice on how to quantify AI technologies' impact without any significant result. This reason is why to estimate these types of impacts, too many variables are included, involving complex previsions of difficult feasibility. The same situation can be located Connect-R since it will not have just a direct market impact but also will affect Nuclear and other industries where it will be adopted.

A recent survey on a worldwide level from the International Data Corporation (IDC) was stating in 2018 that advantages from AI will be had mostly by company organization. This survey, structured with multiple-choice possibility, has stated that the Internet Technologies sector, operation team, and product development will have a positive increase with a percentage of respondents of, respectively, of 58%, 49%, and 43%. Other minor benefits that would be received by the company organization could regard activities like labor productivity, revenue growth, and decisional processes improvement, as stated from the survey with a percentage of answers equals to 20%, 18%, and 17%.

Another opinion presented a few times ago was shown by work in collaboration between the MIT Sloan Management Review and the Boston Consulting Group (BCG). They published an article discussing a change in public opinion in recent years: even though a year and a half before it was not very confident about AI possibilities and implementations in the products and services offered with a small percentage of respondents equal to 14% when this survey was published public opinion became 63%[3].

Moving from surveys to complete studies, the McKinsey Global Institute (MGI) has presented a study called "*Modeling the Impact of AI on the World Economy*"[4]. Through this publication, it is claimed that Artificial Intelligence would cause a 1,2% Gross Domestic Product (GDP) annual growth until 2030, increasing the global economy by 13 $ trillions. In the past, just a few examples of such an enormous growth can be found as IT spreading in 2000 or the steam engine in 1800. For this reason, an increase like the one described by MGI can profoundly change the worldwide economy. However, it is reasonable to think that the growth path forecasted for AI will not be linear and constant. In fact, the first phases lay the foundation and are the steps that require more time. Only after these will it be possible to implement AI technologies at a higher speed. It is, then, possible to define AI growth as an S curve, where beginnings

[3] Fabbri, P. (2018). *Qual è oggi e in futuro l'impatto economico dell'intelligenza artificiale*?. In zerounoweb.
[4] Bughin, J. (2018). *Modeling the Impact of AI on the World Economy*. In McKinsey Global Institute.

are slower due to costs, researches, and investments, and taking a new inclination increasing more and more rapidly after a certain point. According to this, a survey by Hewlett Packard Enterprise (HPE) and Industry of Things World called "*The Present and Future of AI in the Industrial Sector*"[5] has shown the point of the S curve where AI state is located now. In fact, in this paper have been interviewed different companies to see the general commitment involved in this context until now. Results have claimed 61% of respondents that are currently working on AI projects, subdividing them in a 36% evaluating the investment, 14% convinced in implementing these technologies by one year and an 11% already using them. Moreover, all companies that already invested in AI have confirmed an incredible improvement in their working processes. From an average total of 1,95% from revenues that are typically invested in IT by companies, a value of 48% will be dedicated just for AI research and development.

However, this growth in companies' investments represents one of the indirect consequences of worrying about public opinion. Since Artificial Intelligence is innovating how it is conceived the practical way, many people are concerned that old jobs could become superfluous. Despite this could be true, in the same way, many other types of work will be needed, updating new skills requirements and causing a generational change in the workforce.

To sum up, the AI economic impact will be led by two main actors: companies and governments. While the first ones will decide how to implement these new technologies, i.e., looking for better internal efficiency or new innovative services, countries will have to understand if AI is going to bring a generally positive impact or not, supporting its development through regulations or inserting barriers to save the current situation. Moreover, to estimate how the impact will be, governments must evaluate new technologies from two different points of view: a direct one, analyzing the market positioning, and an indirect one, analyzing effects that will affect the regarding sector positively or negatively.

[5] Survey, (2018), *The Present and Future of AI in the Industrial Sector*. In Hewlett Packward Enterprise.

1.4.1 The AI direct effect: a growing market

A recent analysis from the International Data Corporation (IDC), a premier global provider of market intelligence and tech services, show an increasing trend in company expenditure related to AI services and applications. Previsions claim that the AI market value will become its triple, gaining a total equal to 77.6 $ billion in 2022 from a small figure of 24 $ billion in 2018[6].

Since Artificial Intelligence applies to every sector, it is a type of product that interests each market segment that could be automatized. For this reason, there are many investors all over the world, challenging themselves to develop something new before competitors. Major of them are located in the banking sector, manufacturing, and retail, which will surpass banking into this run by 2022, according to the latest researches. IDC also claimed that another sector that will implement many AI technologies is going to be the healthcare one.

It comes clear that companies see a great opportunity in investments regarding Artificial Intelligence, and this is shown by expenditures increase in its research and development of 43% in 2018 from the previous year.

In this scenario, Italy can be located in line with the European average with company total expenditure equal to 25 million in 2019, representing a 44% growth from 2018.

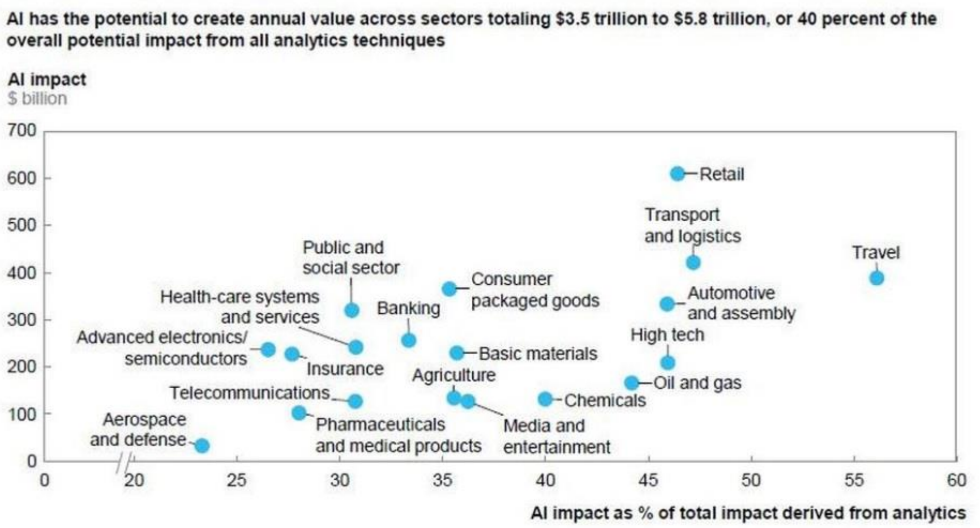
A discussion paper called "*Notes from the AI frontier: Insights From Hundreds Of Use Cases*"[7] was published by MGI. Results presented here have emerged through a connection between McKinsey's researches and firms' experience, relating a theoretic approach to a practical one. The study has been based on about 400 use cases regarding 19 different industries, structured in nine business functions. One of the more relevant insights was stating the possibility of generating an economic value among 3.5 and 5.8 $ trillions from an annual point of view for all these industries under analysis. This amount has been calculated as 40% of the total current analytical techniques, between $9.5 trillion to $15.4 trillion per year. Fig. 2 shows the AI impact grouped by the percentage of all analytical techniques implementation per sector[8].

[6] Fabbri, P. (2018). *Qual è oggi e in futuro l'impatto economico dell'intelligenza artificiale*?. In zerounoweb.

[7] Chui, M. (2018). *Notes from the AI frontier: Insights From Hundreds Of Use Cases*. In McKinsey Global Institute.

[8] Columbus, L. (2018). *Sizing The Market Value Of Artificial Intelligence*. In Forbes.

Figure 2



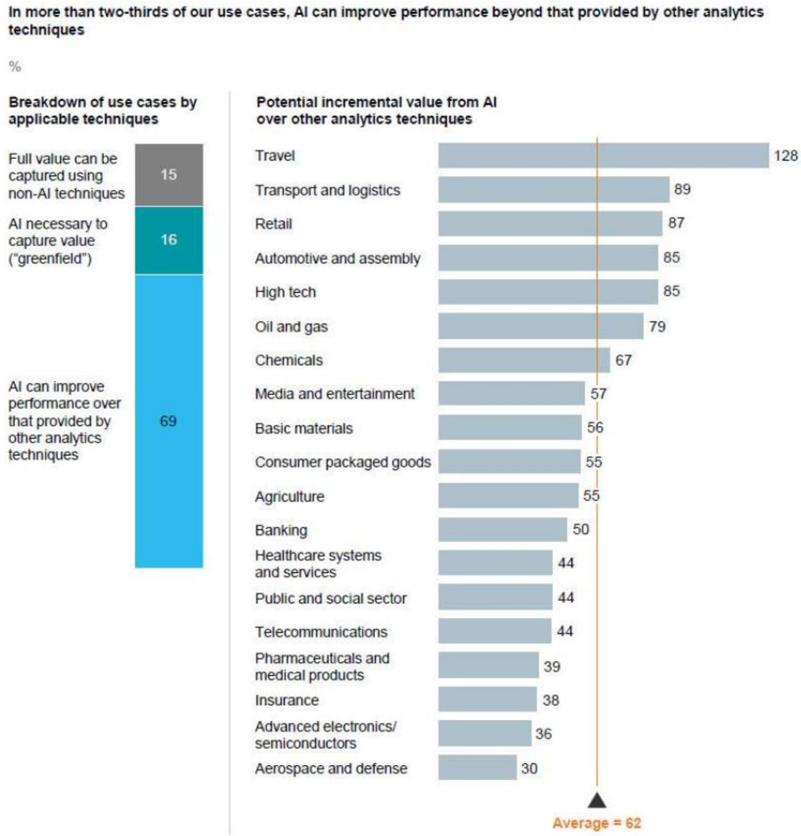
[Source: Columbus, L. (2018). *Sizing The Market Value Of Artificial Intelligence*. In Forbes.]

Nowadays, not all analytical techniques are structured through AI algorithms. Many of them are based on different ideas and, for these reasons, many are existing in the market. Its size is on a trillion scale, and it is still growing, mostly thanks to AI new implementations that are acquiring more and more customers. From the image, it is possible to see how the travel industry has adopted AI techniques for a value above 50%, substituting almost totally their previous analytics algorithms. Moreover, this sector has also achieved excellent outcomes due to AI impact. Only the Transport and Logistics and Retail industries are gaining higher revenues, positioning the Travel one as the third more profitable. The same nature of industries causes this since the first two can improve many of the characteristics just through AI opportunities. Even if they have a lower level of adoption activities and operation executed to have a high degree of iteration and could be easily switched to automation. It is possible to see, then how AI techniques are better performing on repetitive tasks and process industries. Other excellent performance can be found in the Consumer packaged goods and Public and social sector: their embracement level is still low, but they can extract significant value from their processes activities. The worst results have been identified in the Aerospace and Defense sector since military adoption is far from an excellent outperforming and probably not well accepted by public opinion. The Connect-R project will regard more than one industry, even if it has been started and developed in its first use for a Nuclear Power Plant decommissioning. It will affect sectors with already the right automation level, as Oil and Gas and Agriculture, but also other without a high AI previous adoption, as Aerospace, representing a milestone.

Another finding that emerged from the MGI study was how deep neural networks and AI had overpassed possible performances that can be offered by traditional analytical techniques. In almost 69% of all use cases involved in the study, efficiency and effectiveness have increased, reaching a level that was forbidden by previous algorithms limits. Compared to the previous insight, the current one is not regarding just the three main sectors where AI can have a better performance, i.e., Travel, Transport and Logistic, and Retail, but many others. In fact, higher results can also be found in the Automotive and Assembly, High Tech, Oil and Gas, and, lastly, Chemicals sectors. Fig. 3 will show scores attributed to the McKinsey analysis[9].

[9] Columbus, L. (2018). *Sizing The Market Value Of Artificial Intelligence*. In Forbes.

Figure 3

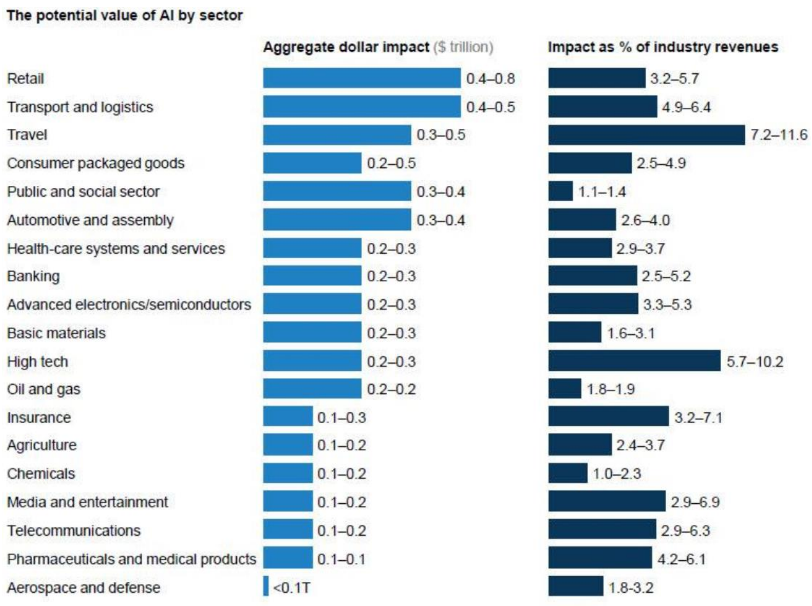


[Source: Columbus, L. (2018). *Sizing The Market Value Of Artificial Intelligence*. In Forbes.]

According to the AI adoption percentage impact, here is claimed how a greater embracement represents then more significant gains. The travel sector is the only one achieved such a big target, positioning above all other industries with an enormous gap. Transport and Logistics, Retail, Automotive, and High tech have been classified with a total score similar. Oil and Gas and Chemicals are the last ones with overperforming outcomes since other sectors have too low AI usage nowadays to see the same results. A breakdown of use cases by applicable techniques has been developed, showing how just a few parts were stating that full value can be captured by not AI techniques, as well as, that AI is only necessary to acquire the current value. This reason is why AI capabilities are not just used to reach the previous economic value but also for achieving new performance targets as never before. Old analytical techniques do not offer a quality level comparable to AI, and more this will be understood, all industries will see more improvements.

The study is also forecasting a revenue raise that will affect mostly those sectors having higher AI techniques embracement. Even if Retail was not the one with greater adoption, the cost abatement performed has signed a positive switch in accounts, thanks to AI and its opportunities. It has been forecasted it will have a raise in revenues equal to 11.6%. The same can be found for what concern the Transport and Logistics sectors, due to improvements that have reduced costs until reach a considerable increase in revenues. This one represents a more significant percentage of total industry gross than Retail, but the aggregate dollar impact is still lower. The results are presented in the fig. 4.

Figure 4



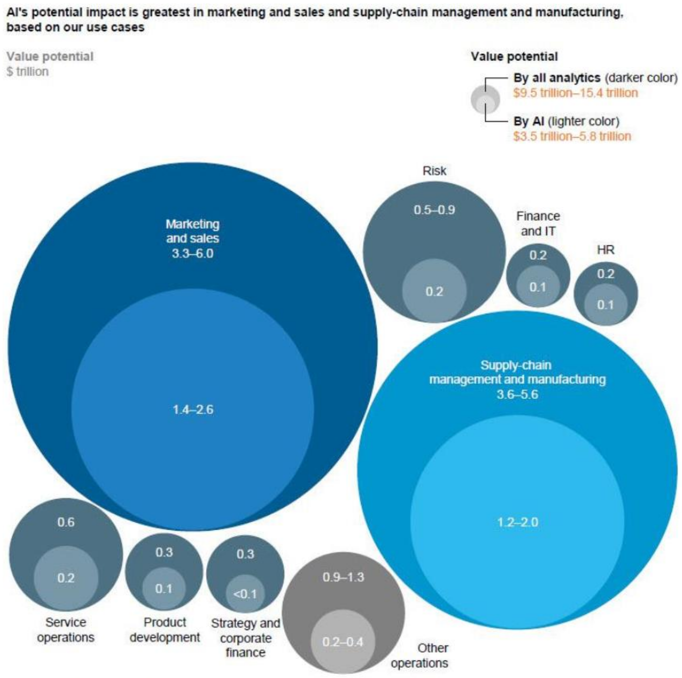
[Source: Columbus, L. (2018). *Sizing The Market Value Of Artificial Intelligence*. In Forbes.]

As predictable, Aerospace and Defense reached the worst result deriving from AI potential. Different is for chemicals since, from being one of the industries with an outcomes overpass, it has been positioned in the last ranks for revenues. In this case, it is how probably AI is improving productivity and efficiency, not affecting revenues directly. This result can also be explained by the fixed demand characterizing these types of products. On the other side, other well-performing sectors about revenues are the Consumer Packaged Goods and the Public and Social one. From this insight, it is, then, possible to affirm how investment in AI will have a direct impact on gains, even if much will depend on the nature of activities processed by each industry.

Regarding business sub-unit enterprise organization structures, the

McKinsey cited discussion paper sustains that Marketing and Sales and Supply Chain Management will be the ones creating more economic value. Related to Retail and High Tech sectors, these two business functions will create a raise in value equal to 2.6 $ trillions for the first one and two $ trillions for the second one. The reason behind this effect is the vast number of interactions among the customer side and the business one, allowing to create enormous datasets required for applying the AI analytical techniques. All the different types of data that will be collected are going to be used by algorithms to improve business unit efficiency and effectiveness. The following image shows results from the study.

Figure 5



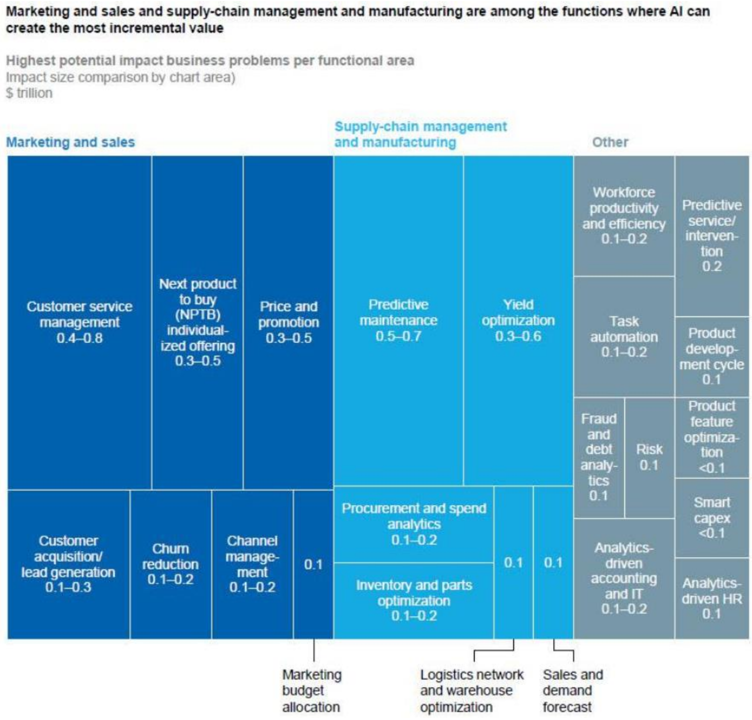
[Source: Columbus, L. (2018). *Sizing The Market Value Of Artificial Intelligence*. In Forbes.]

Findings derived from fig. 5, manifest how Marketing and Sales and Supply-chain Management and Manufacturing will be the industries where analytical techniques are going to have a higher economic impact. Moreover, these two will be the ones where AI techniques are going to have the most exceptional outcome, too: about from 3.5 to 5.8 $ trillions will be gained by them. Other business functions are all gaining a smaller amount of the value's possible growth, keeping a low standard. Risk and Service Operations are the only ones that could be cited for the potential increase.

More in detail, AI impact will affect mostly several functional areas inside business functions. The additional value will be generated in those areas where customers constitute a central role, due to the data amount created every second, and where an autonomous calculation is fundamental. Customer Service Management, Next Product to buy (NPTB) Individualized Offering, Price and Promotion, Lead Generation, Customer Acquisition, Channel Management, Churn Reduction, and Marketing Budget Allocation are, then, the more profitable areas for Market and Sales industry. On the other hand, Predictive Maintenance, Yield Optimization, Inventory, and Parts Optimization, and Procurement and Spend Analytics means the same for Supply-Chain Management and Manufacturing. While for the first sector, the result obtained is ad-hoc customization for each customer, trying to understand better and offer a different service individually, for the second one is a productivity improvement regarding procurement, operational activities, and maintenance. Below there are an info-graphic showing functional areas where AI can create more value[10].

[10] Columbus, L. (2018). *Sizing The Market Value Of Artificial Intelligence*. In Forbes.

Figure 6



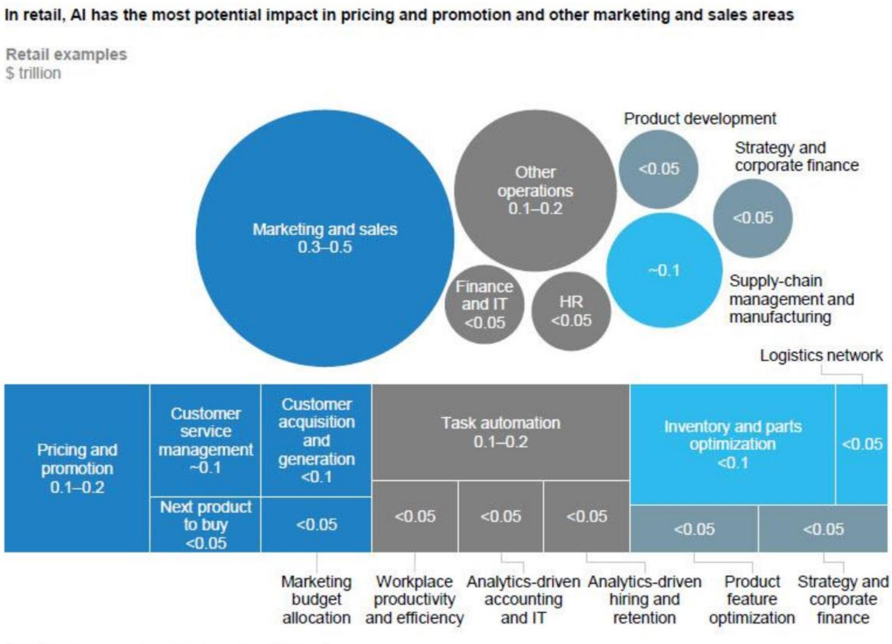
[Source: Columbus, L. (2018). *Sizing The Market Value Of Artificial Intelligence*. In Forbes.]

It is possible to see how several areas are enclosing the main parts of incremental economic value, identifying in which functional areas should be invested. In this image are treated the two principal business functions where AI has a more significant impact, helping, even more, to define which are the most prosperous areas of AI. For what concerns remaining business functions, they are only minimally analyzed, as the economic value generated has more stringent limits. In-Market and Sales, predicted areas with higher impact are constituted by Customer Service Management, NTPB, and Price and Promotion. Previsions claims a possible economic value growth between 0.4 and 0.8 $ trillions for the first one, confirming it as the most profitable area of all this analysis. The reason behind this is to connect to the Big Data concept since, even if AI techniques and algorithms are well-performing, datasets used to operate are needed to produce effective results. This period has been reached a level of data generation as never in the past, and only growth predictions have been proposed for data collection. In this panorama, it is clear that a functional area based on collected data amount, together with analyzing techniques offered to be AI, will be the one most successful, and this is why Customer Service Management is outperforming.

Regarding other areas, NPTB and Price and Promotion conquer the second and third place in money impact for the same explanation previously stated. In this function, the following positions are occupied by Lead Generation, Churn Reduction, and Channel Management. The last one, instead, is Marketing Budget Allocation because for how much can be improved, it still will not be allowed to earn significant gains. On the other hand, Supply-Chain Management and Manufacturing industry have less functional areas interested in AI impact, but in this, few are outperforming. Forecasting confirms a possible incremental value for the Predictive Maintenance in an interval from 0.5 to 0.7 $ trillions, classifying this area as the first more profitable in this function, and the second one in all the functions. Good results are also gained by Yield Optimization, overpassing NPTB and, Price and Promotion. The reason for this growth is still the amount of data generated from these operations and AI techniques required to analyze them. The only difference is that these types of data are not created by human-computer interaction, but from machines working autonomously. In this function, the following positions in scale are occupied by Procurement and Spend Analytics and Inventory and Parts Optimization, since iterative calculations can offer significant advantages for these areas. The last ones are Logistic Network and Warehouse Optimization and Sales and Demand Forecast. For what regards other business functions of less importance, the only areas where AI could have a significant impact on incremental value generation are Workforce Productivity and Efficiency, Predictive Service, Task Automation, and Analytics-Driven accounting and IT.

What has emerged from the McKinsey analysis corresponds to a success predominance of Retail and Supply-Chain Management in AI implementation, and, for this reason, MGI has decided to go deeper into the study of these sectors. Connecting results derived from business functions and functional areas, the next step is represented by a cross-analysis from these two points of view. While until here has been stated that Retail is an industry with enormous opportunities for AI techniques, let is go to study this sector by functional areas composing it. Even if it has been stated that both Marketing and Sales and Supply-Chain Management are the two areas with higher outcomes previsions in Retail, the second one is not having such an essential role as the first one. Marketing and Sales is the one bringing the highest money impact, compared to others that are not even reaching half of the possible economic value growth. Fig. 7 is presenting results found by MGI.

Figure 7



[Source: Columbus, L. (2018). *Sizing The Market Value Of Artificial Intelligence*. In Forbes.]

This info-graphic is showing in a cross way the money impact-related three different dimensions: industry, business functions, and functional areas. Even if the McKinsey study is claiming great success for the Supply-Chain, for what concerns this particular industry, that function is not so relevant. This business unit is going to have just an increase of about 0.1 $ trillions, being barely comparable to one-third of Marketing and Sales forecasts. This fact happens because Supply-Chain Management is not fundamental for the Retail sector, focusing its attention on customers' needs.

Other operations are including many different areas but all related by an equal prevision level of money impact, ranked between 0.1 and 0. $ trillions.

Only Human Resources and Finance and IT are positioned under this standard, reaching the smallest impact that has been calculated by MGI. This effect is because the same nature of these two functions, one focused on people's central role and the other not capable of earning significant gains. On the same level, there are two other units, Product Development, and Strategy and Corporate Finance. Thinking an AI application in these last two industries is not so easy for what is already existing, and this is why they have a limited effect led by AI. Maybe in the future new technologies will be possible to automatize also these units.

Last but not least is the Marketing and Sales business function, i.e., the area where Retail is gaining higher growth previsions. It has been forecasted a raise among 0.3 and 0.5 $ trillions just to this function, with a value that is bigger than all the other functions together. In detail, functional areas that will acquire more value will be the Pricing and Promotion first, followed by Customer Service Management, Customer Acquisition, and Generation, NPTB, and Marketing Budget Allocation. The first has a possible incremental value equal to an interval from 0.1 to 0.2 $ trillions, thanks to ad-hoc service customizations that will define a thicker line between different customers' profiles. Each person will receive a personally defined promotion that will enclose all results that emerged by collected data analyzed through AI techniques. For this reason, forecasts are claiming a rise in sales that will impact earnings in a broad way. These data will be useful also for Customer Service Management, and Lead generation is based on the same idea. Lower results in here will be obtained by NPTB and Marketing Budget Allocation since gains from these areas are very restricted. For what concerns other operations, the only functional area that should be taken into account is Task Automation, with a possible incremental impact among 0.1 and 0.2 $ trillions. This clear since AI's direct effect is to operate and execute activities and sequences of actions autonomously, positioning this area at the same impact level of Pricing and Promotion. If other areas would be comparable to Task Automation, maybe not only Marketing and Sales would be the outperforming one. In fact, other functional areas that can be identified are limited to an impact of fewer than 0.05 $ trillions related to Analytics-Driven Accounting and IT, Workplace Productivity Efficiency, and Analytics-Driven Hiring and Retention. The last one is Supply-Chain Management and Manufacturing, where the only functional area with good previsions is Inventory and Parts Optimization signing a score of 0.1 $ trillions. All the others do not overpass a threshold equal to 0.05 and correspond to Logistic Network, Product Feature Optimization, and Strategy and corporate finance.

To sum up, this study provided by MGI has been examined by future AI previsions from an economic point of view. Have been estimated enormous growth opportunities with a more and more higher degree of adoption for these techniques. In one industry, the Retail one, it has overpassed the half in its implementation and reducing other analytical techniques to about 40%. As here, many other sectors are moving, in the same way, embracing AI for at least its half. From these industries has also been deducted a potential incremental value linked to AI, generating more than what was possible before with older techniques. As a result of this incremental raise, an increase in revenues has been predicted for those sectors where AI is implemented more. In this scenario, Retail will earn 11.6% from the impact that these techniques are bringing and High-Tech 10.2%. After industries have been examined, the study is progressed in smaller details, starting to involve also business functions. It is emerged a predominance by two main functions, Marketing and Sales and Supply-Chain Management and Manufacturing. Here, possibilities coming from Big Data and AI together will sign their increasing relevance. The next step has been focusing on how business functions are structured, examining their functional areas. Even if the importance of them is depending on the industry where they are applied, some areas are always fundamental. These correspond to those with a significant role played by the customer and autonomous calculation, as Customer Service Management and Predictive Maintenance.

1.4.2 The AI indirect economic effect

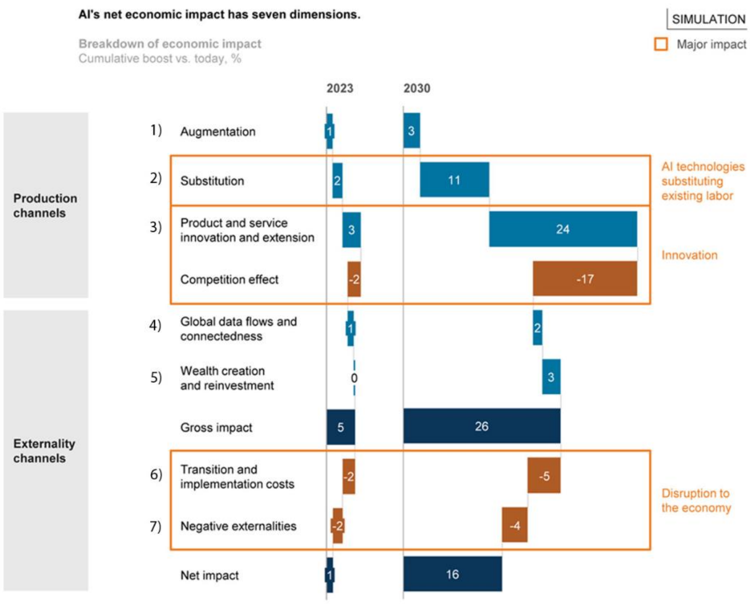
Although it has been released many different forecasting about AI technologies implementation, providing an exact measure of the structural update that will affect our worldwide economy remains very complicated, if not impossible. These technologies will not have just an impact on their own market, but also they will dramatically change all the environment-related. Many variables should be taken into account to express a discrete prevision, and, for this reason, MGI, with the study "Modeling the Impact of AI on the World Economy"[11], has defined seven dimensions that should be analyzed to have a complete view of the changing that is coming. Then, to have a better understanding of what is happening when an AI technology is released, the seven drivers interested are classified into two main categories:

- impact on productivity
- transversal impact

[11] Bughin, J. (2018). *Modeling the Impact of AI on the World Economy*. In McKinsey Global Institute.

In the fig. 9 it is represented an analysis by MGI that is trying to estimate in a numeric way the AI possible implementation scenario. As a result, it is emerging a net impact with a high positive trend. Below, each dimension will be described and evaluated until reaching an explanation for the net impact.

Figure 8



[Source: Bughin, J. (2018). *Modeling the Impact of AI on the World Economy*. In McKinsey Global Institute.]

Starting from the first one, i.e., how these technologies could improve production processes and efficiency, three main dimensions should be taken into consideration: augmentation in capital and labor, labor substitution, and product and service innovation and extension. For what concerns the first dimension, MGI has stated that AI investments are increased from 10% to 20% of IT company budgets in past years, and, for this reason, the same rate growth is forecasted for the future[12].

According to these previsions, a lot of new jobs will enter the market, defining new skills and capabilities that will be needed for the change that AI is bringing. Beyond experts and researchers already working on developing these technologies are going to be necessary maintenance and infrastructure management. New working figures will have to safeguard processes operation,

[12] Fabbri, P. (2018). *Qual è oggi e in futuro l'impatto economico dell'intelligenza artificiale*?. In zerounoweb.

controlling how machines are performing and, employees will have to provide a supporting infrastructure that will be able to fit together with AI technologies. The same will be for what concern Connect-R and its implementation, requiring people for execution supervising.

On the other hand, all these new capabilities required are missing on the current workforce, consequently meaning a generational change in company employees.

Since this could have negative externalities for the whole worldwide economy, companies have to be ready for what will come trying to cushion the impact. Then, AI implementation should be facilitated through investments. These will represent the main effect that AI will have, increasing two main investment categories. The first one is linked to infrastructure improvement, providing enough supporting technologies, and the second one is about a company training path, educating old workers on how to accept the future. In fact, more attention should be addressed to this last investment: MGI has claimed that 60% of current jobs can be automatized for a total of 30% of their operations. This result is particularly relevant because it means most of the routine jobs will disappear soon from the scenes, laying the foundations for a new type of working profile addressed to more complex activities.

The second dimension that has been analyzed corresponds to job substitution since it is the most crucial aspect concerning public opinion. Despite this, an excellent new technology performing is evaluated on how much satisfying and efficient its results are and on cost savings offered by the workforce need reduction. In this scenario, AI solutions seem to figure as jobs eaters, and many discontented people are deploying. For this reason, a contrast is emerging among concerned public opinion, worried about being substituted by machines, and companies, which desire to improve their efficiency and expenditures savings. It is challenging to forecast what will happen, since even if many old business models are going to end, many other ones new are going to become of frequent use, implying substitution in the workforce. MGI has called this dimension "*substitution*" even if there is going to be a substitution, and this will not abet machines instead of humans but only humans that will substitute other humans. Connect-R will have a role to play in this effect, too, since many operators will be substitute by this project. However, work types that Connect-R is regarding are hazardous, and maybe not a great public opinion will be against that. About this topic, MGI has also published a study affirming how 15% of current working time could be avoided by AI technologies implementation by 2030, confirming a probable old routine job abandonment in favor of a generational change and digital skills. The substitution can also be seen as a switch from labor to capital, investing in AI technologies, and progressively improving their outperforming.

The third dimension is characterized by the innovative products and services market affirmation, i.e., those types of investments extending company portfolios with products and services that are feasible only by AI employment. Together with new technologies introduction, new ideas and possibilities are going to be thought by companies, meaning new channels that will permeate the market. Due to its ductility, Connect-R will be one of these investments. New types of offers never seen before can easily create sufficiently high market demand, with an increase of the same market size. MGI has stated that companies will increase their portfolios until reaching a PIL raise of 6 $ trillions by 2030, showing high expectations in future previsions and AI market deployment. As never in the past, companies will drive our society in a progress path characterized by intelligent machines able to satisfy people's needs not created yet. This change, then, will be lead by the idea that a new good is defining a need, and not a need is defining a good.

After these three dimensions based on productivity AI indirect impact, now it will be under analysis transversals impact perceived through AI technologies employment. In this case, the affected drivers are four and can be subdivided into:

- global data flow and connectedness
- wealth creation and reinvestment
- transition and implementation costs
- negative externalities

The first one is global data flow and connectedness, which represents nowadays digital flows, i.e., all types of data and information that are leading players in the global market together with goods and services. Thanks to AI advent, digital flows will perceive an enormous increase due to new technologies, which are going to affect the digital world in two main ways: improving economic contexts more efficiently and impacting in non-economical one with many benefits.

AI technologies can impact digital flows from an economic point of view, and this can be seen in e-commerce since machine learning engines are fundamental, and for this reason, AI could impact e-commerce for 5-10%, as well as in increasing transparency to make transactions easier.

On the other hand, seeing AI from a non-economical point of view could be useful to understand that digital flows are related not only to commerce. There are many ways how AI could be used, and they can be listed in a translation engine improvement, ad-hoc customization for any service, medical dataset analysis, and many others. Almost 66% of global digital flows are based on these non-economical applications, and AI could impact them for a 10%-15%, with a PIL contribution equals to 1% by 2030. MGI has claimed that already in 2014, about 3% of PIL was due to digital flows, but according to new previsions, it is probable that in the future, its contribution will increase until 7% in ten years.

The second dimension is wealth creation and reinvestment due to economic expansion and its vicious circle. AI technologies market entry means a productivity increase, with a consequent general revenues raise. This effect could be translated into a salary increase, and, for this reason, consumption will increase too. In this way, it has been defined as a vicious circle with positive effects on global economic growth. An MGI numeric analysis has not supported this argumentation because they are mostly economic theories. Through retrieving from historical data, it is possible to affirm that situations similar to AI implementations can be classified as the first and second industrial revolution core. These two historical events have improved society in that period, providing positive effects to the economic market and its growth through vicious circles as now AI is doing. This reason is why there are positive expectations, even if current consumption is going bad due to nowadays economic crisis.

The third dimension is represented by transaction and implementation costs related to AI. This aspect is important because, during the period of change, many companies will need to update their infrastructures and organizations systems with costs depending on AI new technologies. Many expenditures will be required to make an adequate environment able to support AI, starting from firing costs of old jobs, continuing to training courses, and finishing with new working profiles hiring and research.

Finally, the last dimension includes all other aspects connected to AI and its indirect effect. Even if previous ones were just the main characteristics, many others are still existing and are not positives. Other negative externalities can be retrieved by the a-synchrony affirmation of good and bad effects that AI will have. In fact, although previsions are claiming them together, nothing can confirm that they will come simultaneously. MGI claimed that the worst scenario of AI implementation could actually have a 7 trillion loss on global PIL, attributable mostly to the last two dimensions above discussed.

In conclusion, MGI has forecasted a variable scenario for AI future employments since many aspects should be taken into account. From what emerges, as the best scenario, AI will have an enormous positive net impact, which is going to overtake negative aspects with a general wealth fare raise. Contrariwise, if poorly managed, AI spreading will affect many jobs reducing global PIL. For this reason, MGI claims the importance of leading a change in small steps, like the Connect-R project, not to upset the world balance and even improve it to levels never reached before.

1.5 Challenges

Even if AI is increasing all over the world, not every interested in this growth is rising at the same rate. While advanced countries and big companies are investing many resources with a consequent optimal result, other ones are receiving marginal improvements since they do not have the same investment possibility. Gaps between big and small companies will increase, generating an increasingly wider distance among who will have a complete AI integration in a few years and who is still moving slowly in its adoption. According to this, a study from MGI has stated that big companies will raise their revenues each year by 6% until 2030, representing a doubling of their current gains. On the other hand, which will apply for these innovations too late will have a slowdown in their revenues, with a loss, equals to 20% by the same year. It is clear, then, how investing in AI technologies will be the market key for the coming period, penalizing who will not be ready in time for the change that is arriving.

The same speech can be made for what regards countries' situations. As AI can raise the distance between companies, the same can happen for different nations. As predictable, an already advanced country will progress more rapidly than a developing one, and this is why the last one could have only a 5-15% growth far inferior compared to 20-25% for an advanced country.

Despite this, a negative aspect could also appear for this category: a lousy impact on the workforce could come from an implementation seen only as productivity increases and not as new solutions discover. For this reason, while developing countries will have a smaller growth due to necessary investments and improvements for their already existing productivity infrastructures, progressed countries will reduce jobs without offering new alternatives. So, in the absence of efficient and effective management of AI implementations, there will be negative impacts on the worldwide economy and not only in a few areas.

Workers represent the last ones interested in this near change. In fact, through AI technologies, the introduction, skills, and capabilities required to perform a job will become different from what current employees are owning. Instead of redundant tasks, what will be needed are competencies bonded to digital with various forms of applications. MGI has also claimed that old types of working profiles will be reduced by 10% in ten years, together with a salary decrease of 13%[13].

In conclusion, Artificial Intelligence will mark a breaking moment with the past, bringing so many changes as never before in history. This rupture is going to be of complex management since many aspects have to be taken into account yet. After many years of movies where were described as a dystopic future with machines acting autonomously, now it is arrived the time to perform their actual implementation into real society with consequent problems. From a generational change in jobs skills requirement, which could cause a loss of millions in workforce and all that entails, continuing to gaps increase among advanced and developing countries, which could raise the distance between rich and poor citizens, and concluding with a takeover by big companies against small ones, raising difference in market shares and making disappear slowly small players from the scenario. For avoiding these bad possibilities, it will be aimed at collaboration between governments and companies, establishing rules and regulations required to accommodate the change smoothly and progressively. Artificial Intelligence is something positive, and infrastructures must allow it to spread wisely, trying to limit impact's adverse externalities through adequate changing management. According to this, MGI has defined seven topics discussed before that will directly regard AI implementations and how it should be addressed for best results.

[13] Fabbri, P. (2018). *Qual è oggi e in futuro l'impatto economico dell'intelligenza artificiale*?. In zerounoweb.

1.6 AI prospects and current barriers

Despite the continued growth of the spread of AI technologies in the world market, their implementation in business areas and everyday life is only at the beginning. Even if there is a rapid adoption of these new technologies, companies can extract just a minimal economic value from them. Only big and conscientious investors that have already understood possibilities that AI can offer perceived an enormous increase in revenues due to higher value extraction. This result is the reason why they implemented AI technologies in a wider and deeper way, involving their entire organization and not applying them just too few processes. A recent online survey about AI's current implementation and its future prospects was released by MGI in 2018, analyzing only nine selected business contexts compared to the total size[14]. These problems that are nowadays solved by AI for companies correspond to: natural-language generation, computer vision, physical robotics, natural-language speech-understanding, machine learning, autonomous vehicles, natural-language text understanding, and robotic process automation. Results emerged by this survey are showing how companies embrace Artificial Intelligence only by a circumstantial level since the most common behavior is to take on these technologies just in one single process, with a percentage equals to 49%. The greater part of last respondents affirmed that they are still testing AI to learn which benefits can earn, due to a degree of conviction not sufficiently high. They represent a percentage of 30%, showing many doubts still concerning opinions. Only the remaining 21% has manifested trust in these technologies, embracing them in more than one process, obtaining results as never expected before. The protagonists of this adoption's success are just three of the nine business problems that have been investigated, i.e., machine learning, robotic process automation, and computer vision. What emerges from this survey is, then, companies' dearth in knowledge AI application, meaning a not yet mature degree of diffusion of AI real possibilities. There is much reason behind this behavior, but the most common one, all over the world, corresponds to the difficulty in switching from traditional and old ways in executing business processes to a digitization era involving main organization areas. Many Countries are affected by this problematic, depending on the

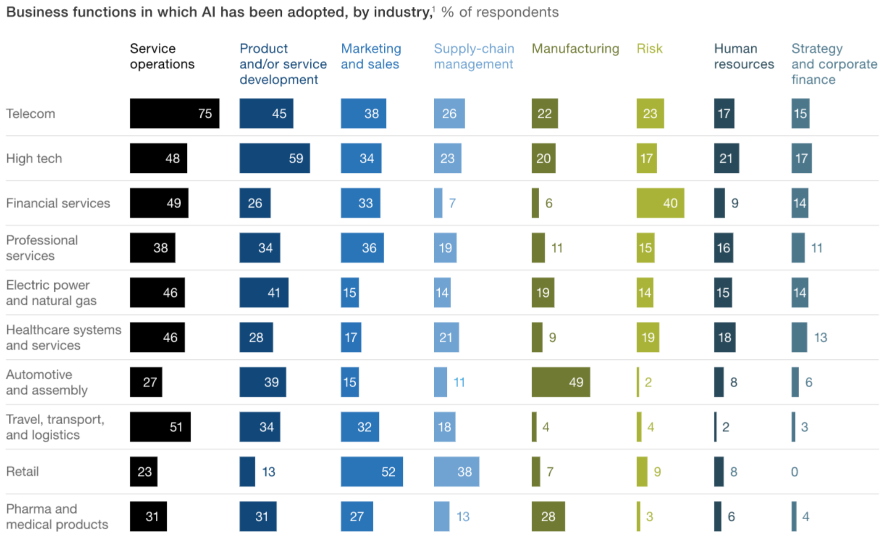
[14] Chui, M. (2018). *AI adoption advances, but foundational barriers remain*. In McKinsey Global Institute.

digitization level owned by governments. IT low-progressed international players as Italy will have a long path to walk, with the target of reaching a wider AI diffusion in every small, medium, and big companies operating in their territory. Differently, who already has achieved good targets in digitization is manifesting a greater desire to invest in this field, since they already know benefits and the economic value that these new technologies can provide.

However, this is not the only cause of clogging up AI deployment. Another barrier currently obstructing AI implementation is represented by the lack of skills and capabilities that employees have, is an entirely different field from what they are used to. Depending on the degree of digitization owned by companies, various solutions and methods have been involved in training employees, but the problem still remains. In the worst case, a generational change in the workforce will be needed to perform a proper usage of opportunities offered by AI, i.e., job loss. This fear is also fed by the substitution phenomenon that will move out labor in favor of autonomous systems. Although these technologies will have a severe initial impact, after a learning and training period, benefits will starts to come.

Currently, AI adoption is universal in all the sectors and is progressively improved in how it should be used. Even if not all the sectors have equally embraced new technologies at the same level and this means a different diffusion across areas. The company does not need something that could automatize their processes without an effective improvement in their costs and productivity, finding useful just those technologies capable of generating economic value. Since each sector is structured differently, this value can be found only in those areas where Artificial Intelligence can make the difference. Below there is the fig. 10, realized by MGI, representing AI spreading.

Figure 9

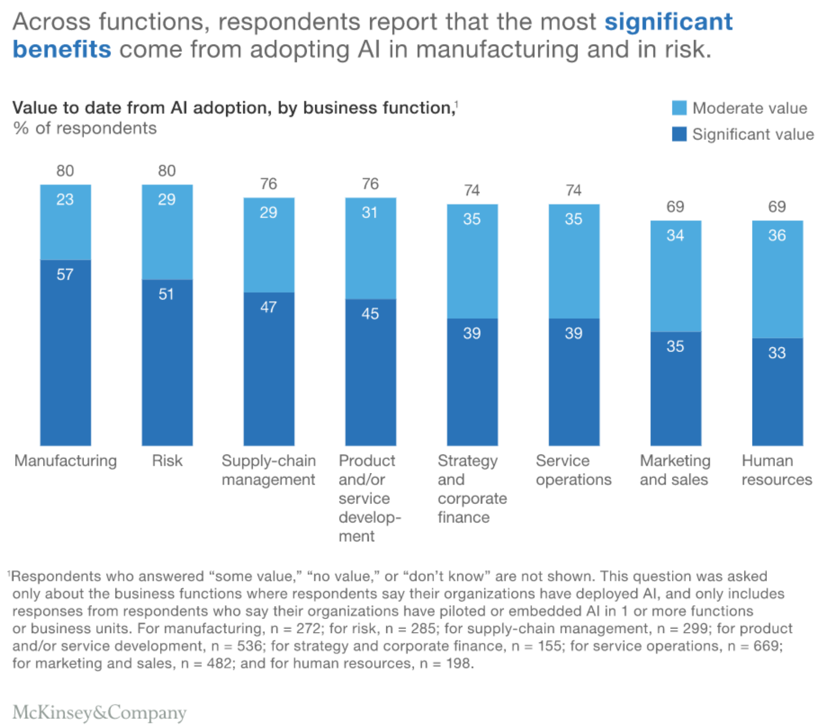


[Source: Survey, (2018), *The Present and Future of AI in the Industrial Sector*. In Hewlett Packard Enterprise.]

From here is emerging an increasing trend for what concerns telecom, high-tech, and financial services, investing more and more in all their business functions. The telecom sector is leading the in-service operation, with a second position occupied by the travel, transport and logistic one. These two especially require activities that can be easily substituted by automation, even if this business unit is one of the most AI updated for all the sectors. In the product and service development, instead, the primary industry is high-tech, followed by telecom also here. This business function, together with the previous one and marketing sales, corresponds to principal ones where AI is embraced. Here, through machine learning and robotic process automation, many operations are already improved, and there are still possibilities of growth. In each case, for each industry, there is a business function where AI technologies have been adopted more since the economic value that can be extracted is stored in different places of the value chain depending on the sector. Starting from supply-chain management where retail is leading, manufacturing is led by the automotive and assembly, risk by financial services, human resources by high-tech and, strategy and corporation finance still by high-tech. These two lasts business units are almost equal for all the industries since they are fundamental for enterprise management.

However, more AI technologies are embedded more significant rewards are gained. Every company with an enough high implementation level has stated how many advantages come from AI usage. MGI, from its survey, has also demonstrated that not even one enterprise from those who do not have any effects or harmful modifications in economic value. It is, then, possible to affirm that opportunities offered by AI generate a surplus if they are well managed. Despite this, not all the business functions can be extracted the same value, and someone is more indicated to automatize since there are too many activities that can be realized independently and without continuous human supervision. Fig. 11 manifests how much AI has been involved in each business unit, according to MGI survey results.

Figure 10



[Source: Chui, M. (2018). *Notes from the AI frontier: Insights From Hundreds Of Use Cases*. In McKinsey Global Institute.]

The outcome of this study manifests how AI is spreading mainly in just two different business functions, defining manufacturing and risk management how its strengths. These last two gained a significant value percentage higher than all the others, limiting their moderate economic value to 25% of the total. This effect is a direct consequence of the activities nature linked to these business units: both manufacturing and risk are composed of redundant actions and complicated calculations that are complexes for a human. In this way, results gained by employees until now have been surpassed, since machines better execute these types of actions. This effect is translated into higher economic value extraction, substituting the old workforce with systems.

On the other hand, on the opposite side of this business function estimation, there are human resources and marketing and sales. Here, the significant value percentage calculated is equal to about 50% of its total amount, meaning another half dedicated to moderate value earning. The reason behind this should be defined as the central role played by human operators in these types of activities. In fact, skills strictly connected to ethical marketing and sales performance correspond mostly in knowing how to establish a trustful relationship with the customer. In human resources, instead, people management is needed, and this cannot be done by a machine, as smart it may be.

Conclusions

What emerged from this discussion corresponds to a three hundred and sixty-degree view of AI. From a first definition of the various technologies currently in use, a division was made between "weak artificial intelligence" and "strong artificial intelligence". While the former is what we know today as exact implementations of autonomous technologies, the others remain for now a purely theoretical concept. In addition, the direct and indirect effects that an AI technology would have in the market segment in which it was released were analyzed, resulting in overall positive even if with possible complications. The sectors most affected are some such as retail, transport and logistics, and high-tech. The prospects for the future are exciting and are linked to future technological applications that will be implemented. Connect-R is one of these and has already set in motion a process that will lead to a significant change.

Chapter 2: Connect-R

After defining the context in which this experimental project takes place, in this chapter, it will be discussed what Connect-R proposes. From the foundation of the idea and the team that collaborates in its realization, the purpose of this machine and its technical functioning will be exposed. These will be precisely the factors determining the potential for innovation. It will be analyzed its possible application fields and the purpose for which the prototype is being built. It will be compared through a benchmark with competing products, and, in the end, its likely future impact in the industrial sector will be estimated.

2.1 The project foundation

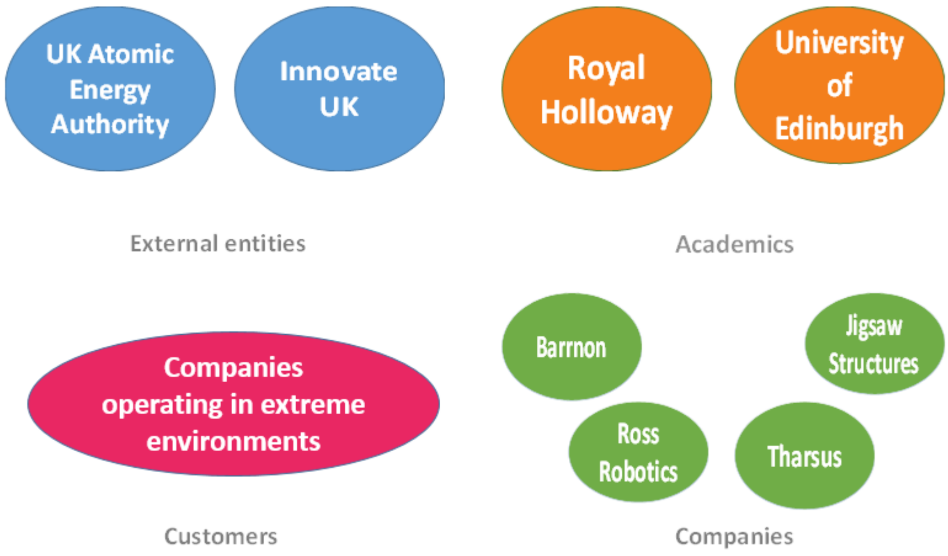
In one of the moments of technology's greatest prosperity and, in particular, of the Artificial Intelligence branch, new ideas capable of profoundly changing the way we live are conceived every day. From private to professional life, every aspect can be affected by this wind of change, without knowing whether it will arrive shortly or not. Nowadays, in many industries, there are already implementations of what AI can offer, and, in each of them, the size and effects of these technologies are different, as previously described. The cause of this phenomenon can be correlated with two aspects dialectic strictly linked one to the other: the value of the idea and the related nature of the sector where it is applied. To quantity project impact, although innovative and revolutionary, it is necessary to establish if it will produce significant improvement in the sector where it is addressed. It will have the effect to influence its efficiency and effectiveness positively. Only respecting this dualism, new technological solutions can bring a real change that will last in time.

However, what will happen if a solution capable of being adopted in many industries would be developed? This is the case of Connect-R, a project with the purpose of building structures in unstructured environments. Its definition is pretty extensive, and it is explained by the number of possible actions executable and situations where it can be implemented. From construction, maintenance, and dismantling, all manufacturing operations may be performed by Connect-R. For this reason, it will be applicable in every industry where these types of activities are required. This fact means many implementation fields and an impact on everyday life as only a few times before in history. It is not just an AI doctrine product but combines with its sophisticated robotics engineering methods, meaning the creation of autonomous robots.

This project is born by the collaboration of famous academics and companies at the forefront of technological research. They worked together to achieve a frequent target and looking forward to the future to bring it to us. Participants are the Royal Holloway University of London and the University of Edinburgh from a side, while Barrnon, Ross Robotics, Tharsus, Jigsaw Structures, and UK Atomic Energy Authority from the other. Barrnon is a provider of solutions in nuclear decommissioning, Ross Robotics is an expert in offering modular robotic creations, Jigsaw Structures construct lightweight engineering structures, and Tarsus is an advanced manufacturer of machines. It is a new project funded in 2019 by Innovate UK, a public body operating separately from the government as a protagonist of research, development, and innovation in the United Kingdom[15]. Its aim is to soliciting technological growth and spreading, doing this by investing and financing on many projects every year. In fig. 12, there is a representation of project stakeholders.

[15] http://www.cs.rhul.ac.uk/home/sara/projects.html

Figure 11



[Source: personal elaboration]

What stakeholders are looking for is something able to shake today's economic balance and, at the same time, ready to allow a jump in the future. From the idea of combining two different doctrines like Artificial Intelligence and robotic engineering, in the UK is born a new project to become a pioneer in technological progress.

All these features have been detected in Connect-R, an idea that will affect how manufacturing is thought across many industries. The project duration planned for this first application on nuclear is for two years, from the 01/01/2019 to 31/12/2020. Even if possible future implementations will be in high quantity, for the early adoption, this is the application field where this robot must be applied. Currently, the prototype is being developed for nuclear power plants, i.e., building and decommissioning their structures. In this way, not only working performance will be improved, but another vital aspect too, job safety. Being able to operate autonomously, Connect-R will intervene in those types of works that are risky for human operators. The result will be of eliminating dangerous activities in hazardous environments for workers. It is clear, then, how nuclear building construction and dismantling is the perfect example of all the advantages that this robotic solution can have. In fact, it is a common and well-known public opinion about the risk that those types of energy plants can mean.

On the other hand, based on the idea of creating an effective and general "auto-manufacturing" solution, application fields seem infinite as well as the business market demand for this product. It is so much versatile that it may be implemented in every industry, meaning an improvement in terms of efficiency, effectiveness, and job safety. In every case, the idea of this project is started with a primary target, nuclear power plants. They represent Connect-R first application, and they will be an excellent canvas for expressing its advantages. The result is that many other ideas for possible alternative implementations are coming quickly. Since other industries will progressively reach all these benefits only in the upcoming years, the prototype for the nuclear will show outperforming results. It is how Connect-R and its "extreme auto-manufacturing will conquer this particular nuclear market segment."

2.2 Connect-R purpose: auto-manufacturing in extreme environments

Many industries require today different nature works, which appear to be very specialized and parceled. For this reason, the labor market is very competitive in each of these job categories, from those one requiring simple operations to others based on complex and even risky tasks for a human operator. Many work contexts currently need the execution of activities in hazardous environments, with a high probability of work accidents. Examples can be described as the deployment of tools and the building of structures in hostile situations since these could be valued dangerous for manual worker health and safety. This is the scenario where Connect-R is located, a robotic and autonomous solution developed to intervene in those practical realities capable of injuring man, but that is necessary for the current society. Related primary industries are nuclear power plants, oil, and gas, mining, and space, and they will be discussed in another paragraph.

Through the adoption of this new technology, it will be possible to perform tasks in a more effective, efficient, and safe way. At the same time, it is representing future infinite positive prospects. It is important to note that Connect-R is a concept addressed to those types of sectors where significant timescales for completion and high cost of deployment are. In fact, the purpose of this project can be explained by providing structures in unstructured extreme environments in industrial realities of enormous size.

Before this idea, for many years, the man had to face up the execution of risky but necessary tasks, pending a solution capable of substituting them. The complexity was consisting of the replacement of these critical activities since complete removal of human operators was resulting in difficult feasibility.

No solutions able to offer a proper and efficient alternative were found until Connect-R arrived. It is an entirely autonomous and robotic operator capable of performing a wide range of actions reaching every position or point in the intervention context. From executing operations on the ground to arriving at the ceiling, every activity shows excellent elasticity and a wide variety, but at the same time, it is meticulous and specialized. Since its application fields are enormous, its possible actions are almost infinite too. In order to define what opportunities this project offer, a general tasks description is the following:

- Hazardous working environments requiring protective equipment and limited time temporal windows for operation
- Limited access through which to deploy the systems
- Unstable structures present that prevent the occupation
- Lifting of heavy objects (~50kg) that require mechanical assistance
- Processing of large volumes of liquids (1000s liters)[16]

What emerges from this description is a robotic solution capable of performing every action related to construction, maintenance, and dismantling of structures that are risky or complex for humans. As for hostile environments needing particular precautions, as for situations where tools deployment is limited or just where there are unstable structures to work on, Connect-R will be implementable in many contexts and will replace those kinds of jobs not so much safe. To build structures autonomously, it will need to transport heavy objects in high quantity. It means a need for exceptional durability and endurance, and, moreover, capacities in moving not only solid materials but liquid too.

To provide a proper definition of what Connect-R represents must be introduced to the concept of "auto-manufacturing." This term manifests

[16] http://www.cs.rhul.ac.uk/home/sara/projects.html

machines' abilities in executing independently a series of activities finalized to construct or produce something. In fact, through this project, a completely autonomous system will be able to build structures and deploy necessary tools by itself. For this reason, Connect-R purpose is offering an industrial-scale system structured with a self-building modular robotic solution, capable of providing access to work-sites in extreme areas. In the total absence of human operators, it will intervene in those environments that are hazardous, with the effect of reducing labor risks and positively influencing job safety and efficiency. This has been possible just thanks to two doctrines synergy, Artificial Intelligence, and robotics engineering.

2.3 First application: Nuclear decommissioning

The prototype of the project that will be developed by the end of 2020 will be applied to a particular case of nuclear decommissioning. Given the volatility of public opinion in this sector, a considerable number of plants are opened and closed every year. Unfortunately, construction and dismantling of these structures require a series of hazardous and harmful operations for a person. For this reason, a high probability of accidents is linked to the construction of these systems, and, currently, no effective solution has been found that could replace the manual operator. Moreover, history has shown several times how human errors in these areas are the cause of enormous tragedies. Due to the possibility of making mistakes will always be linked to the human being, it cannot be canceled unless thanks to the introduction of a free alternative. Through this, the error possibility will be canceled, and no other adverse event could be repeated in treating nuclear plants as in the past. Connect-R will eliminate any possible damage related to working with radioactive materials and chemicals, no longer exposing people to these risks. Furthermore, thanks to the dualism that ties the two parts of Connect-R, it will be possible to create easy access to narrow or narrow areas. Here, with the support of the necessary path where to move, multi-tasking robots can also transport materials such as water, gas, or energy.

Although it is true how building nuclear-related plants are hazardous, this is not the only industry where dangerous activities are required. In fact, after the future first implementation of Connect-R in nuclear, the project already foresees additional areas of adoption. This reason is why it is a very flexible product capable of being applied everywhere. Other possible applications will be discussed in the next paragraphs.

Among other things, many other robotic solutions have been invented so far to intervene in nuclear-decommissioning problems. Being a particularly risky sector where toxic waste or irradiated materials need to be removed, robots are already on the market capable of helping in the dismantling of these plants. In some of them, even radiation levels are emitted, which is a few minutes that could exceed the maximum threshold allowed for a worker. It is, therefore, clear why the robotic operator has been the key to these tasks for a while. However, the existing solutions do not have many of the critical characteristics that Connect-R demonstrates.

For this reason, the introduction of these vital aspects not yet present on the market could almost be called a "blue ocean" strategy. The comparison between our project and the current competitors on the nuclear decommissioning market will be subsequently discussed. In conclusion, despite being a project of vast nature, Connect-R was born for a well-defined purpose of intervention in nuclear plants. This result is demonstrated by the collaboration of the UK Atomic Energy Agency, one of the external stakeholders that finances and places high hopes on this project, given the cost and risk that decommissioning a plant represents.

2.4 Technical framework: self-building modular dualistic robots

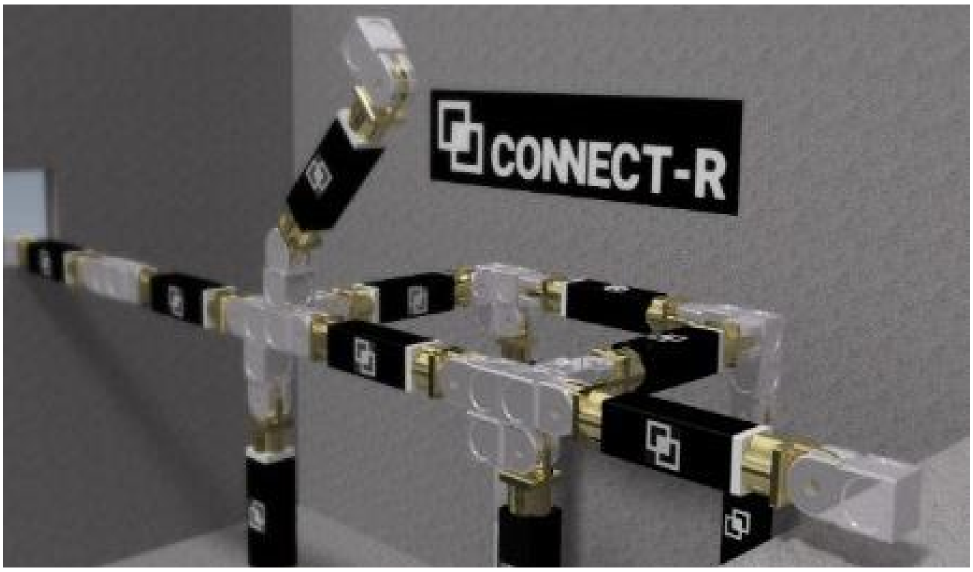
As explained, the Connect-R goal is represented by providing a solution to all kinds of problems that could occur performing manual tasks in hazardous and extreme environments. In these conditions, many actions of different nature must be executed in particular points, consequently requiring the ability to traverse and orientate across obstructing areas and locations. To make this possible, performing technical support is necessary. The hardware structure must allow the execution of various manufacturing and building activities on the one hand but must also offer the possibility to perform these actions in different points and therefore move from one area to another. Being challenging to provide two tasks of such a distant nature with a single robotic structure, Connect-R overcomes the limits defined by this mental circumscription. This fact is possible through a solution allowing not only a meticulous execution of every possible action but to move smoothly along the affected area too. The innovation that this project proposes is characterized by a dualism between two different and separate entities:

- Multi-task Bot (MTB), the performer of what concerns construction, maintenance and dismantling activities
- Struts, the robots optimally forming the path on which MTBs will move

The collaboration between these two different entities unleashes the potential that this project hides. From the synergy between the MTB and the Struts, it will emerge flexibility in the execution of more varied tasks in equally innumerable places. While one will take care of providing the optimal path to reach all the points concerned, the other instead will be able to concentrate entirely on carrying out a massive amount of different activities concerning manufacturing in general, i.e., and it is called Multi-task Bot.

Thanks to these tasks division, both categories of necessary actions will be performed most efficiently. Robots will communicate with each other during the activity and, consequently, continuously improve the result. Just as automatic controllers would do, in case of error feedback is perceived in one state, an action aimed at reducing that error will be performed at the next one. Besides, being two separate entities, the feedback control will be performed twice, and a Strut will exploit the information obtained from an MTB and vice versa. In the following image is represented as a modeling version of what the first Connect-R application will be. Only Struts simulation is manifested since the project is still in an experimental phase and not complete yet, is more focused on moving robots.

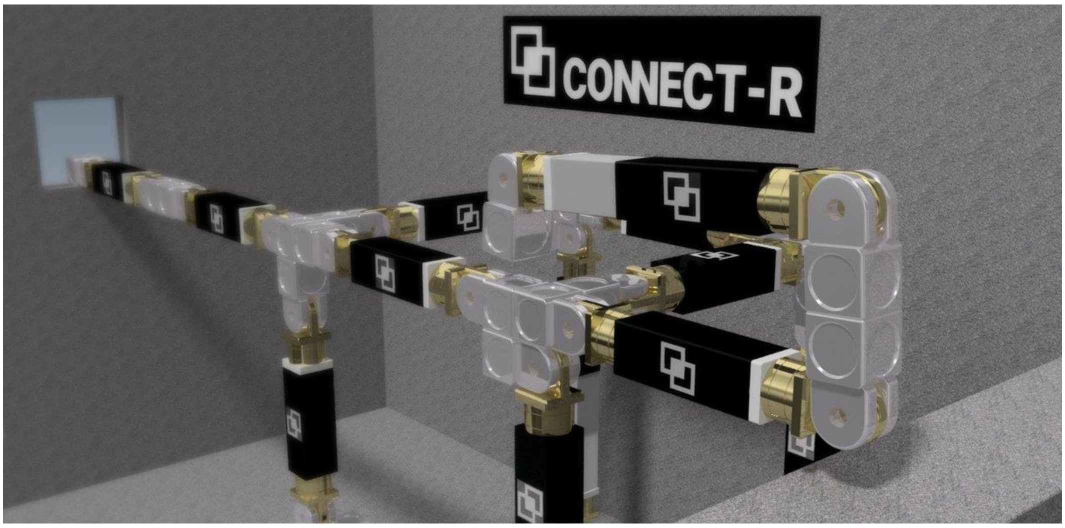
Figure 12



[Source: twitter @Connect_R_robot]

As it is possible seeing from fig. 13, various Struts will arrange themselves in such a way as to create an easy path for MTBs. It is aimed at crossing and reaching every possible point of interest. Through their autonomous and optimal choices, Struts will define the way, and the MTB will have to walk on it and perform subsequent actions. It is important to note that how Struts work in groups, MTBs could execute their activities in more than just one per time. This will sign a time cut for every construction, maintenance, and dismantling need, making it possible to accelerate production only by adding another robot. What emerges from this is the definition of a “self-building” modular robot, capable of constructing itself autonomously across locations needing to be accessed. All hardware parts movements will be allowed through conjunction with electronic and hydraulic systems. To check if the position where robots will locate will be the correct one, methodic and sophisticated Artificial Intelligence techniques will be used to understand signals from the surrounding environment. In fig. 14 it is shown the Struts model going some state forward.

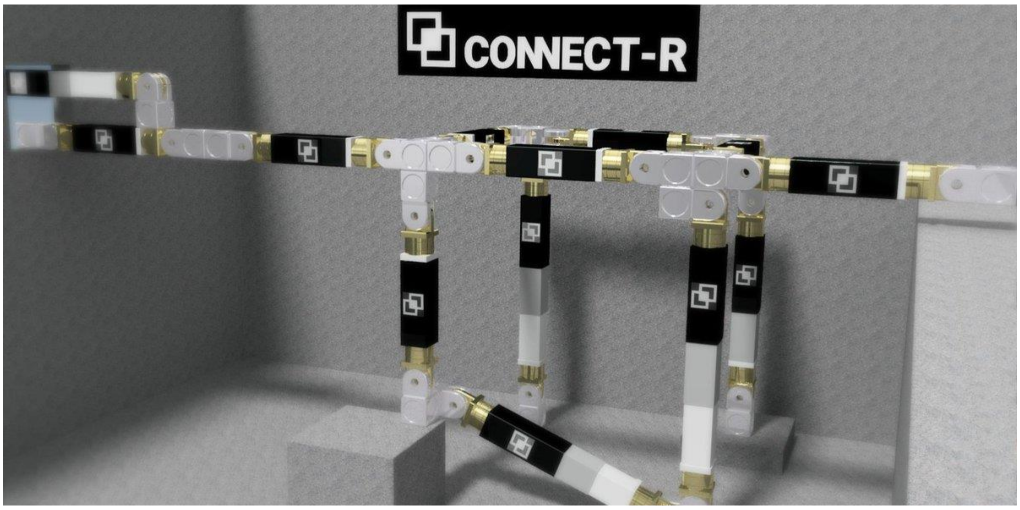
Figure 13



[Source: twitter @Connect_R_robot]

Furthermore, another positive aspect derives from the fact that when MTBs cross the Struts path. In fact, in this way, they are also able to carry out mappings and samplings of the surrounding area, thus generating a map of what is around it. Once this is defined, this is transmitted to Struts, having the effect of updating their path or their arrangement along the area. The result that comes is a continuous improvement of the perception possessed about the external environment and, consequently, better planning of the actions to be performed, due to a feedback mutual exchange process. Through this continuous loop, the artificial intelligence techniques applied to Connect-R are expressed, while the hardware part is under construction thanks to robotic engineering principles. Unfortunately, given the participation in the project of various academic and business realities, technical details regarding the production of this idea cannot be treated due to non-disclosure agreements. This fact is also understandable given the experimental nature of Connect-R, being still in an initial state. Fig. 15 shows how this robotic solution is effective in reaching and acting on every different possible location, thanks to Struts ductility.

Figure 14



[Source: twitter @Connect_R_robot]

To sum up, there are two fundamental concepts behind the Connect-R technical realization, and two keywords can define them in turn:

- Dualism
- Self-building modularity[17]

The innovation that this project brings is based on these two critical characteristics that until now had never been achieved in the industrial sector as it is intended to do here. The dualism represented by MTB and Struts can almost be seen as the same dualism that characterizes a human body. That to normally live needs arms and legs capable of performing different actions. However, being a robotic solution, while man is limited to the conjunction of arms and legs, Connect-R will be able to separate the two parts composing physically. Despite this, it is still remaining connected from a functional point of view. In the future, this will also allow the possibility of exceeding current human skills in construction beyond the currently known level, thanks to this possibility of the disjunction permitted by this project.

On the other hand, beyond dualism, what makes Connect-R unique is the ability to be a self-building system, structured modularly through the use of different units. This effect will imply the absence of implementation costs too

[17] https://www.edinburgh-robotics.org/project/connect-r-industrial-scale-self-building-modular-robotics

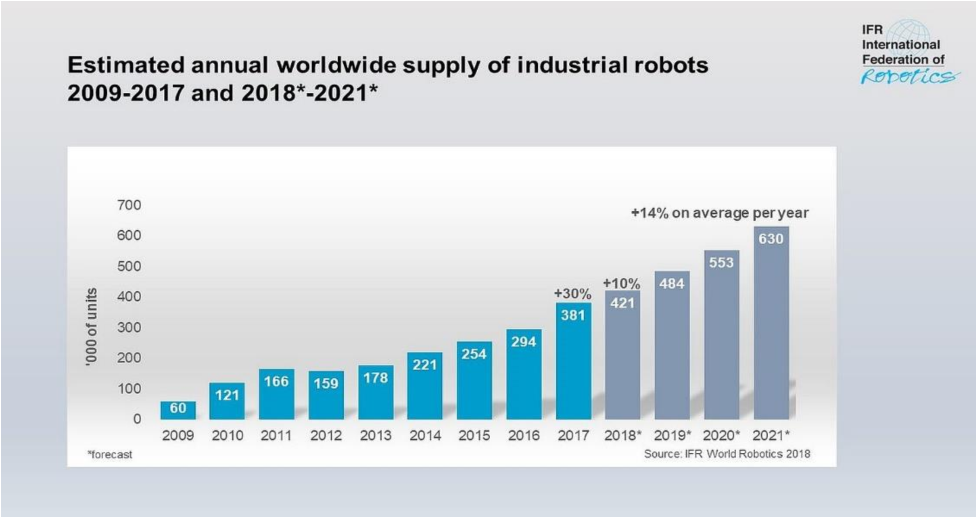
since once activated, and it will generate and build by itself whatever it needs in order to complete the task assigned. Therefore, thanks to these two strengths, Connect-R encompasses the potential to become an unprecedented success capable of opening up a new way of conceiving automation from aside, and in how to join the two doctrines of artificial intelligence and that of robotic engineering from the other.

2.5 Benchmark

Since 1961, when the American inventor George Devol created the first industrial robot, manufacturing and robotics started a collaboration lasting still today. Benefits deriving from autonomous manufacturing implementation could be listed in improved work efficiency, competitive advantage in the market, and job safety. Many industries are already using these machines, especially like food, pharmaceutical, automotive, and electronic ones.

The more time passes, the more the required number of these technological solutions increases, with continuous growth that has never stopped since its inception. Never like in recent years, the growth rate has exponentially augmented, meaning several robots impossible to suppose before. In the following image, it is possible to see the progress of this raise, which has allowed the total or partial automation of many industrial productions in the last years.

Figure 15



[Source: Heer, C. (2018). Global industrial robot sales doubled over the past five years. In International Federation of Robotics.]

As it is possible seeing from fig. 16, the actual start of the mass implementation of these technologies has been between 2009 and 2010 through a doubling of the demand for these robots. In the following years, this growing trend remained constant, except for a few years where the growth has been incrementally greater. Although it has no longer received a 50% increase, another large raise can be found in the years 2016-2017, where production reached 30% more. From what is predicted by the International Federation of Robotics (IFR), growth will be even faster in the coming years with its climax in 2021, where the required quantity will be ten times 2009 one. What we deduce is a raise average of 10% over about ten years. In addition, the slope of the curve has been accentuated recently, and this means that this growth rate will increase more soon.

In this panorama, Connect-R is presented, in the automation of industrial sectors through artificial intelligence techniques and robotic engineering. Differently from others, this project manifests characteristics such as the possibility of operating in environments that are difficult to reach or very dangerous. Furthermore, thanks to the variety of actions that can be performed by MTB, the field of application is infinite. For this reason, a real Connect-R competitor among these traditional industrial robots is not present.

However, it is a different speech for what regards automation in nuclear decommissioning. Many strategies were developed to reduce workers' exposure to dangerous radiations and to allow faster demolitions. In fact, in this kind of context, radioactive materials are hazardous to be managed by human operators, and technological solutions were needed since time. This reason is why many different projects were created with the common purpose of intervening in those extreme environments that can affect human health and safety. The leading role of robotics in these application fields is to limit radioactive exposure levels for workers and to store those kinds of materials with high-radiations and long-life, i.e., high-risk nuclear waste. When a person works in direct contact with these materials, the human body perceives a certain level of radiation. If the threshold is reached, normative regulations forbid this particular worker to continue that work.

For this reason, the definite advantages of robotics adoption could be the reduction of workers' numbers, savings deriving from the cost cut for safety prevention, and less administration. The problem is that until now, not even a single technological solution has offered the possibility of complete removal of human operators and stakeholders remain doubtful about their usage. This effect is the explanation because Connect-R has the potential to become the solution to all questions that until now were not answered.

Currently, various robotic solutions dedicated to nuclear decommissioning have been released on the market, even though they always need a controller to perform a correct functioning. Given the variety of existing problems, solutions proposed so far had different aims and horizons. While some were designed to solve a single issue, others showed greater adaptability. It is important to note, that even if autonomous systems are not yet existing, the category is inserted since the future presence of Connect-R. The classification of these projects can be formulated into:

- Customized solutions for specific problems
- General-purpose plant
- Systems fabricated from off-the-shelf components
- Autonomous systems[18]

The first category is characterized by a "single-run" proposal, specially developed for a specific problem. These situations could happen if facing up with an unexpected or particularly complex issue, which requires an ad-hoc

[18] Seward, D. (2005). *The Use of Robotics and Automation in Nuclear Decommissioning.*

solution to obtain the optimal result. An example of this type of application can be identified in the idea adopted to dismantle the Windscale Advanced Gas Cooled Reactor (WAGR). The triggering cause was the need to remove the reactor from this plant, which emitted some radiations too high to allow human intervention. It was estimated that the maximum permissible level of radiation absorption would be reached in about 20 minutes. Thus, DECON was proposed, a project created and implemented individually for this plant, in which a robotic and automated machine capable of transporting hazardous materials outside was inserted inside the structure.

Furthermore, due to the need for a remote controller, necessary protections were also added to protect workers from the emission of radiation, in addition to the lift truck created. With this robotic support, it was thus possible to complete the plant decommissioning having optimal results in terms of efficiency, less in costs, since the total value of this project was £ 80m. These types of projects do not present a business model, as they are developed for a single situation. Missing commercial applications, it still remains a pioneer of robotic technology applied to nuclear power.

In the following categories, there will be a progressive capabilities expansion of the proposed robotic solutions. While the previous one was adapted to a single case, the next three types will be implementable in different situations. This fact is the case of general-purpose plants, which is of robotic solutions controlled by remote control. Through them, the operator can position himself in a safe area far enough away not to be hit by radiation. An example of these technologies is the Brokk, famous both from a commercial and technical point of view, capable of performing various tasks all dedicated to demolition. It is electrically powered and can act in tight or difficult to access places. Below there is a representation in fig. 17.

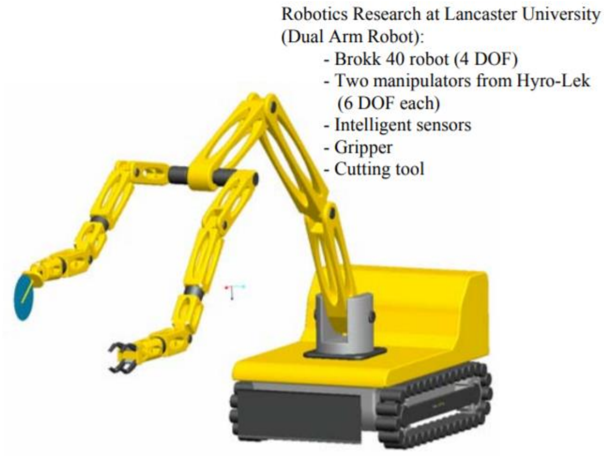
Figure 16

[Source: Seward, D. (2005). *The Use of Robotics and Automation in Nuclear Decommissioning.*]

As it is possible to see, Brokk is a structured robotic solution directed to demolition. Its hardware structure is based on one single harm with a limited range of actions performable.

The last category is one of the systems fabricated from off-the-shelf components, where machines perform a more comprehensive range of activities but always in remote control conducted by a person. With this typology, it is almost approached what Connect-R offers, although the key details still remain very far. Here, robots must have greater mobility than a hypothetical Brokk and must have a physical structure that allows this type of operation. A well-known and applied example is the Dual Arm Work Module (DAWM). This robot aligns very much with the concept of dualism offered by Connect-R, thanks to the two arms of which it is provided. However, while DAWM is limited to a mandatory duality of arms, our project relates it to arms and legs. This result means that Connect-R will not only have the same capabilities as DAWM, but moreover, it will be able to make much more forceful movements. The other big difference lies in the lack of autonomous operation. It is precisely here that Connect-R supremacy is manifested, i.e., supporting the total elimination of the human operator. No more remote activity, often the cause of errors. The DAWN is shown below.

Figure 17



[Source: Seward, D. (2005). *The Use of Robotics and Automation in Nuclear Decommissioning.*]

The dualistic arms concept shows the similarity with Connect-R dualism. Even if DAWN does not achieve versatility offered by our project, it still remains a significant milestone in robotics. Its ductility in executing actions like dismantling reactors and, moreover.

The last subdivisions are the ones regarding autonomous systems and, therefore, Connect-R. It is not still in the market since no efficient products were offered before our project. For now, Connect-R is the only player inside this category, and it will be until new projects come out.

All these example solutions have been limited to performing direct telemetric tasks. This effect is because a machine to perform this type of behavior must take into account two aspects: the accessibility of the area and the variability of the situation. In fact, before Connect-R, the only possible way to perform these tasks in extreme environments was remote. This result was due first since exceptional milestones have not yet been reached in terms of automatic operation, and secondly, since supervised systems were not possible in these extreme environments. The common belief was that if the variability is high, an autonomous machine is not sufficient to make all decisions alone, while if the variability is low independent system is performing well.

However, with the advent of Connect-R, this problem will no longer be a limit, being able to perform actions in a hazardous context in a completely independent way. In this way, a new path is opened to walk for these types of robotics solutions and how they are implemented. To provide a suitable representation of findings that are emerged from this benchmark, the following table is showing the main differences from alternatives already existing and what Connect-R will offer.

Figure 18

	Functioning	Versatility	Structure	Accessibility	Cost	Self-building modularity
Connect-R	Autonomous	Really high	Dualistic	Really high	Medium	Yes
DAWM	Remote	Medium	Single	Medium	Medium	No
Brokk	Remote	Low	Single	Medium	Low	No
DECON	Supervised	Single	Customized	Customized	High	No

[Source: personal elaboration]

Here it is shown why Connect-R is a break with the past, meaning innovative characteristics never seen before. Before this project, no other technological solutions were developed to work autonomously since the required versatility in these environments was too high. Through its idea, new horizons will be reached, and new perspectives will be thought. Previous better results were possible to be found in DAWM, that even if it is limited to an arms dualism, it was the one with greater versatility.

In conclusion, no past technology made in these areas will be able to compare the potential offered by Connect-R. It has two abilities: accessibility to every area, to reach any point in any hazardous context; versatility in operations, performing a wide range of actions. It can go from treating materials meticulously to food.

2.6 SWOT Analysis

In order to estimate the potential and prospects adequately that Connect-R offers, a SWOT analysis model was applied to the case under consideration. Here, four key features of the project are compared, providing a wide-ranging view. These four key aspects are: the strengths of the project and its weaknesses, from an internal point of view to the current situation, the opportunities and threats deriving from the external context. The SWOT created on Connect-R is shown below.

Figure 19

INTERNAL	**STRENGTHS** • **Tasks variability** • **Accessability in extreme areas** • **Autonomous functioning** • **Self-building modularity** • **Dualism**	**WEAKNESSES** • **Experimental** • **Long-term horizons for a complete implementation** • **Dualism**
EXTERNAL	OPPORTUNITIES • Human operator removal • Efficiency improvement • Safety improvement • Low implementation costs	THREATS • New competitors entry in the market • Companies distrust in autonomous current capabilities

[Source: personal elaboration]

What emerged from the analysis is a presence of great positive potential, of both strengths and opportunities, capable of giving excellent prospects to this project. On the other hand, since it is in the development phase yet, it is difficult to predict what will happen when it is released commercially. As for the Strengths side, they can be summarized in Connect-R's ability to adapt to any environment, specialized in extreme conditions. Both from the accessibility and variability points of view, nothing similar had ever been produced for industrial purposes. Moreover, thanks to its autonomous operation and its self-building capacity, it offers a type of service yet to be discovered but which hides enormous potential. The last strong point corresponds to the dualistic logic with which it was made, allowing for an overwhelming variability and accessibility. The direct consequences of these strengths are being transformed into the opportunities, which it will have in the future. As an effect of autonomous operation and self-building modularity, a human operator will no longer be necessary.

Furthermore, it marks an improvement in efficiency and safety, eliminating human error that could trigger accidents. Among other things, thanks to the ability to build by itself to reach every area, companies will not have to face high costs of implementing the robot in their working situations. About the negative sides, it is necessary to affirm that the project, although of excellent prospects, is still experimental and under development. As long as it is put on the market in various sectors, as has been foreseen, a long time will have to pass, considering that only for the prototype dedicated to nuclear decommissioning will it still require at least a year.

This fact implies that, given the nature of artificial intelligence and robotics to be in continuous progress, other solutions could be presented on the market during this period, which is why this represents a threat. Until now, a completely autonomous system capable of completely removing the human operator has never been proposed. For this reason, there is a possibility which companies' confidence in entrusting all these risky tasks to robotic entities is not is very high. A transition period will, therefore, probably be necessary to test these technologies, and only subsequently, approve and adopt them on a large scale. The result is an even more significant increase in the time horizon, within which Connect-R will be of common knowledge. Finally, the study also showed a double-faced aspect of the dualism proposed by this project. On the one hand, if this feature allows its excellent skills of variability and accessibility; on the other, it also means that a malfunction could also affect the other robot functioning. This would duplicate the probability of technical failures and, therefore, necessary continuous maintenance.

In conclusion, Connect-R is a project with enormous potential, capable of upsetting the way many works or sectors are seen nowadays. It intends to introduce something still missing in the industrial market, that is, a completely autonomous operation. However, the times are still immature, and before it is possible to evaluate what will happen when the project is ready to be marketed in multiple areas, years will have to pass.

2.7 Business model

Figure 20

<table>
<tr>
<td>Problems

• Hazardous working environments
• Difficult accessibilty areas
• Human supervision need
• High costs</td>
<td>Solutions

• Autonomous robots performing operations
• Dualisitc system to reach every area
• Self-building modularity</td>
<td>Unique Value Proposition

Robotics engineering and Artificial intelligence as support to substitute human operator in manufacturing extreme environments</td>
<td>Unfair Advantage

Born with a single finality but implementable in many others</td>
<td>Customer Segments

Companies operating in extreme and hazardous environments</td>
</tr>
<tr>
<td>Existing Alternatives

Robotics technologies limited to remote or supervised control functioning</td>
<td>Key Metrics

• Number of accidents on work
• Robot completion time/human completion time
• Cost reduction</td>
<td>High Level Concept

"Connect-R: providing structures in unstructured extreme environments"</td>
<td>Channels

Distribution channels related to the government, universities and companies involved in project development</td>
<td>Early Adopters

Companies operating in nuclear decommissioning</td>
</tr>
<tr>
<td colspan="2">Cost Structure

Robotic parts construction
Task planning
Simulations
Testing</td>
<td colspan="3">Revenue Streams

Connect-R sales

Subsequent maintenance and updates</td>
</tr>
</table>

[Source: personal elaboration]

Through a canvas business model, it has been tried to define critical points of the marketing model with which Connect-R is to enter the market. Since there are different external entities, universities, and companies collaborating, it would have been wasteful to apply a business model relating to each of them, and for this reason, it was decided to generate one for the project. As can be seen from fig. 21, the problems on which it intervenes are dangerous areas of work or difficult access, where even through the use of a robot, the human operator is always required, and this entails very high costs. For this reason, Connect-R proposes to intervene with a totally autonomous solution thanks to its self-building modularity and thanks to the dualism offered by the two robots from which it is made. Precisely this is the unique value proposition that Connect-R entails, which is to offer a unique solution that combines artificial intelligence and robotic engineering in order to remove the worker from those environments. This effect is described more generally by the high-level concept, i.e., the purpose of providing structures in unstructured extreme environments. At the moment, there are no alternatives that offer the same opportunities on the market and especially not on that of nuclear decommissioning, where only supervised or remote-controlled solutions are used.

Distribution channels will be offered by more than a single entity, bringing together what the British government, universities, and businesses can do. Among the various definable customers are all those companies that operate in working conditions where hazards are encountered under challenging environments very often, however, the first to adopt it and to benefit from Connect-R will be those operating in nuclear decommissioning. This event is precisely the unfair advantage that characterizes this project, being developed for a purpose but being applicable to many different ones. With a single effort, it is possible to collect as much as possible. The value of the efficiency improvement can be assessed through specific metrics such as the number of accidents at work or the percentage of time saved that would be used for the execution of tasks by human operators. It is essential to evaluate also when the investment is repaid and the overall savings in monetary terms. The cost structure necessary for the realization of Connect-R is a structure in the different phases of the realization of a project. In any case, different entities take part in it, and for this reason, the costs are amortized. Unfortunately, the same also happens for revenues, deriving from the sale of the service offered and planned ad-hoc for the case in question, but also from the subsequent maintenance and updates that will be applied.

2.8 Connect-R market effects

As defined in the previous chapter, artificial intelligence technologies have a double result when they are released on the market: a direct effect, i.e., direct marketing concerning the product, but also an indirect effect, i.e., all the

consequences that that type of solution and its adoption bring to the sector. In this paragraph, it will, therefore, try to perform an adequate analysis of Connect-R concerning these two effects. Unfortunately, being still experimental and under development projects, sensitive marketing data cannot be shown due to copyright. However, it will instead be possible to analyze perspectives that Connect-R hides indirect effects. Starting from the Augmentation, i.e., the increase in capital and labor investments, it will be characterized because of the success that this project will have. If results perform optimally by entering a new market area not yet occupied, then other companies will also want to invest in it. It is the case of automation in robotic systems for nuclear decommissioning. This result will imply a Substitution phenomenon, leading to a generational change in the workforce.

Moreover, thanks to the prospects for implementation in many different sectors, the longevity potential of this product is also optimal, resulting in continuous innovations and extensions. These correspond to all the effects directly related to the product applicable to various sectors. It should be noted that Connect-R, applying to several different industries, implies all these effects for each relative industry. Once the impact related to the single product is treated, there are external ones. Examples from the global data flow and connectedness are the number of users and devices connected worldwide.

Here Connect-R would hardly have much impact, unlike wealth creation and reinvestment. It represents the possibility of making new investments deriving from the earnings from the savings due to Connect-R. The cost cuts would be very high, due to the elimination of the human operator and Implementation and Transition costs would also be zero due to its self-building modularity. Finally, Negative Externalities could derive from different times of reception of the positive effects previously discussed, from negative ones such as expensive investments and staff cuts. In conclusion, Augmentation and Substitution results could represent Connect-R economic impact mostly. In addition, it will demonstrate how it is possible to provide long life to a project, making it applicable to many sectors. The results related to the Global data flows will be less significant, without stimulating general connectivity.

In any case, thanks to positive balance sheet results, new investments can also be made, with minimal implementation costs. Only the Negative externalities remain a question mark, not being able to predict the chronological order of how these effects will occur.

2.9 Possible other implementations

Due to the wide range of executable tasks that Connect-R can accomplish, many areas of application have been foreseen. Being defined – as stated - like a project with the aim of providing structures in extremely unstructured environments, all various industries where this type of activity is necessary could benefit from the advantages offered by this product. Many different sectors can be listed in this definition, and those currently evaluated correspond to:

- Oil and gas
- Mining
- Agriculture
- Space

As previously stated, it is essential to highlight that the Connect-R idea was born with the finality of interaction in nuclear power plants.

However, many success previsions are forecasted for other adoptions. The second most feasible sector, according to experts, corresponds to Oil and Gas, which has always been renowned for the riskiness of the extreme environments in which it operates. Regarding both Onshore and Offshore plants, all the various processing phases correspond to very high risks. The extraction, production, transmission, and processing of oil and gas represent precisely those areas of difficult access and of dangerous contexts, for which Connect-R was designed. Examples are, respectively, a pre-oil plant and the maintenance of those machines. The benefits that could be obtained from the adoption in the Oil and Gas sector are therefore evident, being already the field of various existing alternative automation solutions for those plants. Many solutions have already been found to automate this industry. However, opportunities offered by Connect-R, of a system capable of intervening in any extreme condition in any place of difficult access, had never been reached before. Many other benefits could also come in terms of efficiency and cost savings, from the elimination of the risk for the human operator and of the unquantifiable cost that human life would have. Some examples could be the production and drainage optimization in Onshore as well as a cut in operative costs and an improvement in fixed or floating structures in Offshore.

A further area of application can be identified in the Mining industry. This result is easily deduced due to the same activities nature, i.e., risky operations in underground areas of precarious stability. For this reason, always going to work in the mine has been seen as a very hazardous activity, because of structural failures and gas leaks. If this happens, human operators would have a practical difficulty in reaching the exit of the underground area in those short moments, allowed before a collapse inside a mine. However, although many technological solutions have been adopted in tunnels over the years, no one like Connect-R has the potential to provide a significant change. In fact, through the total absence of the need for the presence of a manual operator, the risk of a cost in terms of human lives is instantly canceled. Here too, through the dualism between MTB and Struts, every possible action performed by man could be performed in the same way by a robotic entity. Furthermore, there would be no human errors, and the whole surrounding area would be mapped and analyzed in order not to allow any landslide or subsidence.

A different discussion can be made regarding the agricultural sector. Although it is not extremely risky like the previous ones, here too, a series of complex and maintenance activities could be easily automated. From the irrigation of large fields to the pruning of very tall trees, Connect-R's ability to perform any action in extreme environments or difficult to access is also easily shown here. Benefits deriving from this implementation would correspond to better and more stable growth of agricultural products. This result can be done through the sensors of the robots, mapping the areas where intervention is needed, would regularly analyze them. Connect-R would automate harvesting, sowing, soil fertilization, and all other phases of the agricultural process with positive results. Obviously, in order to compare the costs with the benefits, in this context, it would make sense using this solution only for vast agricultural land or for particular situations such as the spatial one, described in the following paragraph. Here, this ductility is a strength compared to competitors, proving to be able to perform activities of a completely different nature, from the production of food to that of objects.

2.9.1 In-Space Manufacturing

Another one of the essential perspectives related to this project corresponds to the potential applications that Connect-R could have in the Space industry too. For a long time, the concept of In-space Manufacturing (ISM) has been spoken about the possibility of creating and building structures and tools directly in space. The aim was being useful for the operation of space stations. NASA has been working on this type of project over time, as it is a horizon of new possibilities like never before. The reasons behind this are to connect to long-duration in space missions, where manufacturing activities are fundamental for mission completion. Possible examples of these needs could be space station logistics and maintenance, repairing structures, recycling materials, on-demand fabrication, and moreover.

By providing the opportunity to solve autonomously and independently any problem that may arise, an incredible cost-cut will result from a cost-benefit analysis. This effect is due to side effects that would be avoided in case something was needed in space, but that is not there. These are those costs related to the launch of a new vector to provide necessities or structures. Moreover, it is also important to note the technologies developed on earth may not have the same direct effect in extraterrestrial space, and therefore, further research and changes should be made to allow Connect-R to provide an In-Space Manufacturing service too.

In any case, in this area, Connect-R is not the only actor but competes with the product under construction that NASA is also developing. Such is the magnitude of the idea of this project that the impact it could have would be able to upset the way the space industry is viewed. Until now, only in science fiction films like Star Trek had there been talked of similar technology. It is the principle to allow a life of long horizons exclusively in space. Through this invention, it will be possible to stay for long periods in spatial structures but, at the same time, expand their construction. It is making them increasingly larger and efficient directly in space. The strength that Connect-R has compared to the ISM of NASA is defined by the variety of tasks it performs, not only in the space sector. Due to the possibilities to perform tasks related to agriculture, Connect-R will not only be able to provide structural maintenance of space stations but the production of food too. In this perspective, it is clear how the combination of a massive amount of possible different actions, Connect-R advantages compared to a product that is made only for one area. Just the flexibility of this robotic solution is, therefore, the strong point that one day could make its protagonist also of the innovation concerning space and everything that surrounds it.

2.10 Connect-R and job safety

Nowadays, many practical realities present the need to perform tasks that involve risks for the health and safety of the worker. Unfortunately, the nature of these unfortunate accidents at work is varied and cannot be attributed to a single cause. From environments full of radiation to areas contaminated with viruses, those involved in these activities are subject to constant hazards. This result represents a real problem for companies, as life does not have a cost, and severely damaging one would have a very negative impact on the company in question.

Since costs involved in a case like this could be too high, robotic solutions capable of performing the same people tasks have been used. The limitation was constituted by the fact that these robots can operate only in a supervised way or via remote control. In this way, a human operator would still have been at risk, albeit to a lesser extent. However, thanks to the invention of Connect-R, a new solution will solve the typical problems of these industries. The benefits deriving from a completely autonomous operation of a robot capable of self-building will limit the risks on the job found so far. These hazards are different, and it will be defined which of these, our project will fight. They can be divided into following categories:

- Biological, i.e., those areas of work where organisms harmful to human health are always present, such as bacteria, viruses, insects, animals, and much more. Here, a robotic operator would be able to intervene effectively for any purpose, without reaching any obstacles. An example of a Connect-R application in dealing with this type of hazard can be the agricultural implementation area. Here, viruses or substances harmful to humans could be present, and a human operator would be forced to inhale them.

- Chemicals, where chemicals substances are dangerous to a human body, are produced or released. These can result in mild problems, such as skin irritations, or even more severe effects, such as blindness. Here too, Connect-R will be able to intervene as efficiently as possible, having been created to operate in the presence of chemical agents within companies or plants.
- Physical, if environmental factors can injure a worker physically. This fact is the case of narrow or steep to access areas, where a minimal lack of attention corresponds to a considerable risk. Here too, our robotic solution aims to solve these problems, being able to act in extreme environments where not even a person can move adequately.
- Safety, if unsafe working conditions are present. Examples may be damaged stairs inside an office or malfunctioning electrical outlets. In the contexts, Connect-R does not find application, being problems of a voluntary nature and easily solvable, not like the previous ones.
- Ergonomic, typical of muscle pain, due to incorrect postures or heavy physical exertion. Our robotic solution will be able to partially solve this type of problem, i.e., which related to the transport of heavy materials if it is required in extreme environments. However, he will not be able to resolve pains resulting from incorrect postures.
- Psychosocial, as certain working conditions can affect a person's mental health. If this person feels in constant danger during his work, the accumulated stress is equally harmful. Connect-R will intervene indirectly in this area, given the possibility of subjecting no longer people to such a dangerous situation.

To summarize, there are several types of hazards to work. Being Connect-R a project that aims to provide a more efficient and safer service, it has been tried to analyze which hazards types this project can afford. The results emerged to demonstrate how Connect-R can intervene in all the main varieties, obviously not being able to deal with problems related to damaged stairs or the like. Although it mainly affects Chemical, Physical, and Biological risks, it may also have an impact on Ergonomic and Psychosocial, albeit to a much lesser extent. It will be a project capable of solving the problem of workplace safety in an almost definitive way.

2.11 Further project future forecasts

In the future, nothing denies the possibility of deploying it also in structures building manufacturing applied to standard cases and making Connect-R commonly used. This fact will depend on a comparison between benefits and costs, being the latter very high for people's health cases. If something wrong happens during work to an operator, companies will need to face up high expenses related to the injury gravity. Therefore, by adopting Connect-R benefits will be purely positive, not being able to compare a human life at a cost. On the other hand, Connect-R implementation costs will not be presumably low, representing a different matter for investments in non-extreme manufacturing. If it is thinkable that today the construction technique is now oriented to the construction of 3D printed building structures, the advantage that derives from a synergy between this technology and Connect-R. It could have the task of assembling quickly, and in a way, it is evident as diverse as precise, the various construction components. It is a vast application field that ranges from single homes to large structures, like skyscrapers and bridges. Here complexity degree and danger of operations are evident. The benefit could be cost reduction and better production times, as well as a better quality result.

An investment is made only in the case that the revenues deriving from it are optimal not only in terms of efficiency but also in cost. For this reason, although in non-extreme environments, Connect-R still represents an improvement in productivity, talking about safeguarding the profit margin is more complicated. The payback time of the loan must be calculated on the incremental difference that derives from the replacement of human operators with robotic ones. Although it is short-term, it is clear that the creation of Connect-R still has a long way to go. Like any other invention, even if the prototype is functional, it will take time before forms are found to optimize its production in an increasingly productive and economical way. Only then will it be possible to talk about a possible implementation of Connect-R in non-hazardous working areas.

For this reason, the premises that Connect-R shows us are nothing but positive, and, over time, they will always be more positive. From the autonomous construction of structures in extreme environments, there will be great opportunities in conventional building, giving this project the potential to become a milestone. In a not so near horizon, Connect-R will be already adopted in extreme environments, and the costs will drop. This result will be possible thanks to scaling or learning economies by the Connect-R implementation, even in the most common manufacturing contexts.

What emerges from these premises is another aspect to keep in mind for the future, i.e., the job replacement phenomenon that this project will bring. Even if, as far as the extreme work is concerned, replacing the human worker with a robotic one will not be very problematic from an economic point of view, the impact

would be very different if Connect-R were also adopted in non-hazardous environments. What would happen can be described in a progressive replacement of human resources with technological ones, making them less expensive. The effect would influence global economic equilibrium, eliminating millions of jobs in favor of automated robotic solutions. This result is one of the most common reasons why public opinion is frightened by the effect that AI and robotics could have on our society. Many job places in the construction sector will be eliminated, leaving at home an innumerable quantity of people. Even if they always worked only in that area and who would hardly be able to find alternatives. This aspect is a critical one, given that the building sector is a particular type of industry. It is concerned and at the base of all the other industries and therefore including several workers which is very high all over the world. Despite this, a machine to operate will always need someone to supervise it and, thus, new jobs will be created. The output will not be an overall reduction in employment, but a generational change in favor of training and skills increasingly oriented towards technology. As it has been in all times when humanity has made great technological leaps: it is what is called progress.

It is difficult to say what the result of this transition could be since it is not possible to evaluate from now the impact that the two parallel phenomena would trigger. If, on the one hand, the elimination of thousands of old jobs would mean a hole in the world economy, on the other, the introduction of these new job figures will progressively close the gap created. The question is whether these new jobs will be enough to bridge the difference or whether the digitization brought by Connect-R will damage the global balance. On the other hand, this is a general aspect that affects the whole field of AI, which is considered by experts to be a more important invention than the wheel or the fire.

There is no answer at the moment to this question, and however, it is tried to predict what will happen, an estimate can never be entirely correct. Too much data, variables, and externalities should be taken into consideration to evaluate the economic impact of such a technological solution. In fact, unlike other innovative ideas, Connect-R is a concept applicable not to a single sector being a self-building construction project.

In any case, digital change is coming, and it is better to be ready since science does not progress linearly and steadily but in massive single leaps. One of these leaps forward will be Connect-R, which after its realization and a first test period, it could become an icon of the future waiting for us.

Conclusions

The results show that Connect-R has all the potential to become one of the maximum progress expressions that AI wants to bring. It is born from the collaboration of government bodies, universities, and companies. It aims to completely replace the human operator by providing structures in unstructured extreme environments, i.e., those areas that are difficult to access and require great versatility of tasks. These characteristics offer adoption opportunities in many different sectors, also meaning a decidedly favorable future market. This effect is possible due to its technical key characteristics: the dualism of robots and self-building modularity. In fact, completely autonomous solutions such as this have rarely been adopted in industrial areas. Precisely for this reason, Connect-R will become the first completely independent solution in the implementation for which the project was born: nuclear decommissioning. It will be covered in the next chapter.

Chapter 3: The civil Nuclear

In this chapter, the context where the first adoption of Connect-R will take place will be studied. Nuclear power today is located at the center of a competition aimed at identifying the successor of fossil-fuels. Renewables also participate, and therefore a comparison will be made between the two types of energy sources, trying to understand what the energy of the future will be. Later, the results that nuclear power has on the market at the moment will be analyzed, paying attention to the UK and Italy results. Finally, the positive and negative effects that nuclear will bring, and how new technologies can limit the last ones will be discussed. One of these is nuclear decommissioning, the reason behind Connect-R.

3.1 The energy problem: a "green" need

In the current society, the word energy corresponds to a much-debated concept. Everyone needs electricity for almost everything in every life aspect, starting from the basic everyday life needs and arriving until complex tasks. However, where is energy coming? There are different answers to this question: fossil fuels, natural gas, coal, nuclear, wind, solar, hydro, biomass, and still others. Each of this source, with an adequate process, it is turned into energy. Unfortunately, many studies have shown that traditional sources will not have a long life due to their exploitation that is depleting stocks. Together with this phenomenon, which is causing supplies nationalization and cost growth, environmental pollution, and climate change are the other two concerns that are rising fast. Traditional energy sources usage, with consequent carbon dioxide emissions released in the atmosphere, is irreparably harming world ecosystems. Even if in the past, this aspect was considered not relevant, due to nowadays society's climate awareness, now times are ready for a change. It seems clear that old energy sources should be overpassed and substituted with something new. There are many feasible, achievable, and sustainable alternatives that are gaining share in the market.

In this panorama, one of the most critical issues of these times is identifying what the energy sources of the future may be. Three main key-aspects, regarding this topic, could be identified into:

- energy source sustainability
- indirect production emissions
- low costs need

The first characteristic represents the raw materials life span, which is the duration until the depletion of the material stock available in nature. First references are renewables, i.e., those sources that for nature are not exhaustible. Despite this, thanks to technological progress, the fuel quantity required to produce a small amount of electricity with other different sources, which are not renewables, will become less and less high, looking like infinite inferior on a human times scale.

The second topic that has attracted all global attention is indirect production emissions. These problems have been discussed for a long time, trying to ignoring them for many years to not upset the world economic order. However, nowadays, ONU is soliciting all the Nations to gradually switching their electricity sources from traditional to something greener. After many policies, ONU's purpose seems determined and unambiguous: it is forbidden to procrastinate, CO2 emissions have to stop for saving the planet. The best path offered to the target achievement is the one offered by renewables, which –state of the art - seems to be the best solution. Then, why the renewables shift has not happened yet? Because these sources have two significant problems: they are expensive and, mostly, not highly efficient. For example, realizing a system powered by a solar panel is costly, and it does not guarantee a safe and continuous energy supply. Keeping low energy production costs will remain the most laborious necessity and challenge, renewables do not yet win that. For all these reasons, a type of energy that answers to these three main questions could be identified into Nuclear. Its advantages could be described in green electricity produced without emissions, longer-term sustainability then fossil fuels, that will also be higher through new scientific discoveries and a lower cost per unit, despite investment costs, remains currently remarkable.

Many studies like the "World Energy Outlook" by the International Energy Agency claim that the minimum supply of oil, natural gas, and coal will end soon, taking down the economic order with them. More in detail, with the current production rates and the future previsions, the oil will run out in 53 years, natural gas in 54 years, and coal in 110 years[19], consequently progressively increasing costs[20].

According to the World Meteorological Association data, in 2018, the average global concentration of carbon dioxide in the atmosphere has reached 407.8 parts per million (ppm)[21], from the 405.5 ppm of 2017. Experts also claim that the overheating effect on the climate, or the total radiative forcing, has grown to 43% due to the persistence of greenhouse gases in the atmosphere, with a CO2 contribution of 80%.

"*There is no sign of a slowdown, not to mention a decline, in the concentration of greenhouse gases in the atmosphere, despite all the commitments made with the Paris climate agreement*", commented the WMO secretary-general Petteri Taalas[22].

Until now, climate change was not enough considered due to difficulties that could mean a switch from a fossil fuel-based economy to another one. The final target is to move into an economy that should be supported only through renewables energies in a low cost and sustainable way, but the problem lies right here. At the moment, even if they have been achieved many signs of progress about renewable energies, they can only guarantee an intermittent supply, without considering costs that for a renewable plant are expensive yet. Depending on the territory, solar and wind will change a lot their effectiveness in producing energy, and, for this reason, they are not still convincing enough investors. In fact, in a society structured as its own is, without investors, trust a new product will never take hold in the market.
To sum up, shortly two counter-current problems will have to be tackled: the reduction of carbon dioxide emissions and the increase in global energy consumption. However, if producing energy means producing carbon dioxide at the same time, how is it possible to find a solution that satisfies both problems? The vicious circle created by fossil fuels based economy needs to be broken, surpassing any previous constraint through new social awareness.

[19] https://www.arcadia.com/energy-101/environmental-impact/the-long-term-effects-that-stem-from-fossil-fuels/
[20] Sing, S. (2015). *How long will fossil fuels last?.* In Business-Standard.
[21] Nullis, C. (2019). *Greenhouse gas concentrations in atmosphere reach yet another high*. World Meteorological Organization.
[22] Nullis, C. (2019). *Greenhouse gas concentrations in atmosphere reach yet another high*. World Meteorological Organization.

3.2 A historical point of view: a bad reputation

Nuclear energy history begins at the end of the eighteenth century through Uranium discover by Martin Klaproth, giving to it the planet name. The next step came only one-hundred years after when Wilhelm Rontgen found out the ionizing radiation by moving electricity into a glass tube and generating X-rays. Only in 1896, Henri Becquerel was experimentally demonstrating the existence of beta and alpha radiations thanks to the pitchblende that darkened a photographic plate. Instead, another scientist called Villard discovered gamma radiation. In the same year, Pierre and Marie Curie were calling these phenomena radioactivity for the first time. After this event, many people were interested in the discoveries, and a few times, they found out a medical treatment with Radium or that radiation destroy bacteria in food.

In this scenario, atoms studies played a lead role. The leading exponents were Ernest Rutherford that began a full understanding of the atoms, and Niels Bohr, that claimed the path of the electrons around the nucleus. Therefore, in sequent years many scientists continued and deepened the study on this new research area, with the alternation of various names like Chadwick, which was discovered the neutron in 1932. It had to wait until 1939 for understanding that despite fission already release much energy: in the process, additional neutrons are set free, causing fission in other Uranium nuclei, starting an automatic chain reaction that could bring to an enormous release of energy. During this period, all the Countries were interested in this new research area, and each one started studies about it. Even if it was already possible to think about a military application, nobody was interested in it. This way of thinking continued until 7 December 1941, when the Japanese attacked Pearl Harbor convincing Americans to develop atomic bombs.

Therefore, the United States officially opened the "Manhattan project" with England and Canada's support. The intent of this project was the creation of a nuclear weapon, also trying to steal information from Germans. Initially, Americans wanted to keep it secret, but soviet spies managed to found out what they were doing.

Only in December 1942, Enrico Fermi created the first experimental reactor. Therefore, even if nuclear was thoughts for many possible implementations, unfortunately, the first one chosen was a war-one with the tragic conclusion in the second great world war, Hiroshima and Nagasaki destruction. Some years after, Russians developed the Zar bomb, able to reach the three times power of American ones. Only in 1954, the USA president Eisenhower officially approved the "Atom for Peace" project, to help the introduction of nuclear energy into civil applications. The result was the creation of the first nuclear power plant in 1955 in Idaho.

Despite officially military applications were ended, in 1986, a nuclear power plant caused the Chernobyl disaster, classified as the worst nuclear accident in history. During a safety test, the nuclear core reactor was overheating with the result of killing many people and infecting through radiation many others.

Again, in 2011 there was the Fukushima Daiichi nuclear disaster in Japan, which has been devastating for the local ecosystem, although it was of minor impact.

In conclusion, nowadays-nuclear usage has increased thanks to the new commercial uses and implementations. However, due to its troubled past, there still are concerns about its riskiness, and many people currently go against it.

3.3 The global market's Nuclear affirmation

As previously stated, Nuclear energy worldwide usage for electricity production is born in 1950, with a subsequent slowdown between the 80s and 90s and a new growth since the 2000s. During this slowdown, many Countries publicly declared dismantling and abandonment policies to deactivate their Nuclear power plant capacity. The first was Sweden in 1980 through a popular referendum, followed by Italy in 1987, Switzerland in 1990, the Netherlands in 1994, Germany in 2002, Belgium in 2003, and Spain in 2008[23]. Reasons that led to this choice were mostly: the electricity market liberalization, which was increasing the dangers of financial investments in the nuclear sector; the fall in price of fossil fuels, which has introduced a more competitive substitute product; the Three Mile Island and Chernobyl accidents, which have fueled people's fear. Therefore, about two-thirds of the utilization forecasts that were

[23] https://it.wikipedia.org/wiki/Energia_nucleare_nel_mondo

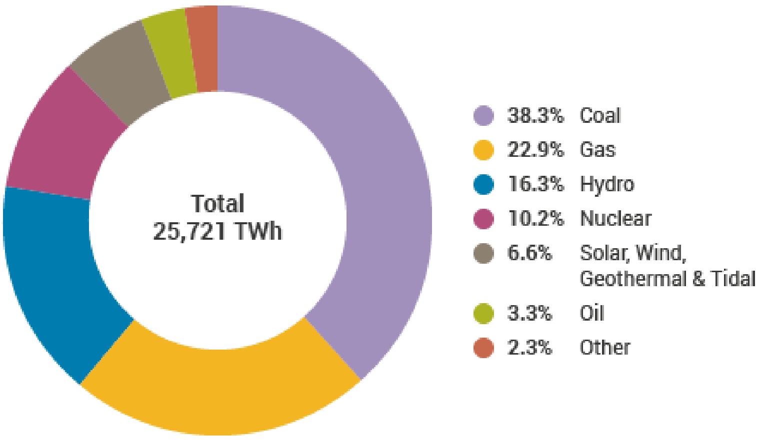
appearing in the years between 1970 and 1990 were cancelled. In this panorama, also other Nations decided to suspend or end their Nuclear projects, like Austria and Philippine which were not using their recently completed plants for own will, Cuba that closed its plant in 1995 due to financial difficulties and North Korea that suspended its program because of international political pressures. We will have to wait until 2000 when Switzerland chooses not to renew the ten years production suspense act to see the first signs of nuclear new growth. After that, the Finnish parliament decided to build a fifth nuclear reactor in Olkiluoto. This action represented the changing trend that was beginning, in fact, not a decision like that was taken for much time.

Consequently, the trend was started, and many governments were nullifying their nuclear energy production dismiss deliberation, like Sweden, Netherlands, Philippine, and Spain. In a short space of time, 43 different Countries were planning to build new reactors from zero or put back into operations the old ones. However, a new slowdown was deploying due to the new Fukushima Dai-ichi accident in 2011 discussed before. First, there was Japan that was abandoning 14 new reactors already in development and arresting the already existing ones, for verifying their security. This consequence has lasted until 2015 when the Sendai plant has restarted to work. Secondly, Italy that cancelled the new law disposals to take nuclear power plants on its territory, renouncing to the international agreement. Switzerland approved the gradual disuse, and even Germany that recently had changed its mind into continuing the production decided the completed closure by 2022. Despite all, a different way of thinking comes from Belgium, which stated that until it is found new renewable resources, it will extend its nuclear plants' life.

However, in current days all the wealthiest nations in the world have nuclear reactors in function, producing electricity. For this reason, Connect-R has been mainly thoughts and first implemented. Due to Nuclear worldwide spread in building and decommissioning, opportunities for applications were already high and are increasing day by day. The only exception of those Countries is Italy, which is only importing it in a significant amount. Nuclear power plants are producing about 10.2% of the worldwide electricity, and it is classifiable as the second source for energy in the European Union with a 27,8% of the market, together with many new reactors still in construction. Other sources with a higher implementation value are coal and gas, which produce more energy in the world, having a percentage of 38.3% for the first one and

22.9% for the second one. Besides, hydro is gaining a significant share in the market[24].

Figure 21



[Source: IEA, (2019). *Electricity Information*.]

Future forecasts show that in all the possible scenarios that will come, Nuclear energy will play a significant role. AIEA analyzed this topic, stating that could be two possible scenarios, one of minimum impact and one of maximum impact, with more restrictive laws about carbonic dioxide emissions. In the first one, usage will continue to increase from the current use of 453 Gigawatt in 2020 to 546 GW into 2030 and to 550 GW into 2050. In the second one, there will be 803 GW into 2030 and 1415 GW into 2050[25]. According to Nuclear Energy Technology Roadmap[26] estimates, published by the International Energy Agency and from Agency for Nuclear Energy, more the CO2 emissions will reduce the Nuclear energy implementation will increase. If emissions become half by 2050, the total nuclear energy supply could become about 24% of the total market with a total capacity all over the world of 1200 GW.

The nuclear energy production process could be described in several phases: conversion, enrichment, fuel fabrication, reprocessing, and waste treatment. However, since construction costs are high, not all the Nations internalize every phase with the consequent processes externalization.

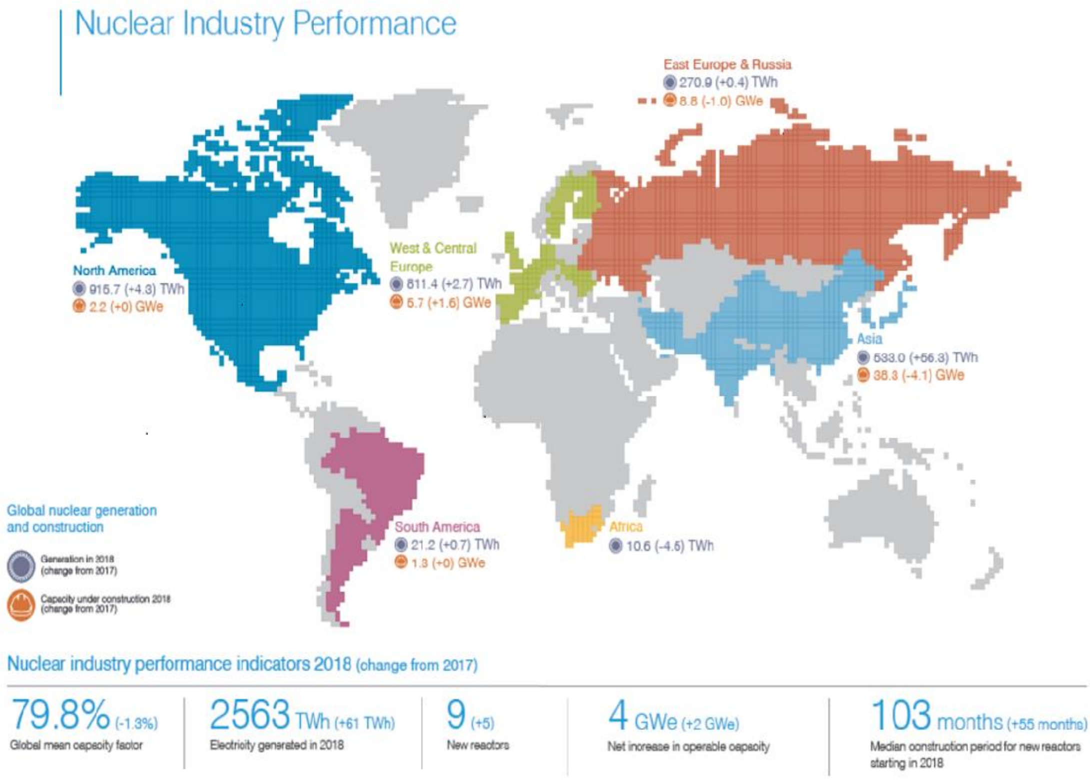
[24] World Nuclear Association, (2019). *Performance Report.*

[25] IEA, (2019). *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050.*

[26] IEA, NEA, (2019). *Nuclear Energy Technology Roadmap.*

In 2017, performance indicators were stating that the total amount of electro-nuclear energy generated was equals to 2563TWh, with a global mean average capacity factor near to 79.8%. Even if there were few reductions in electricity generation and capacity under construction, the net calculation was increasing both values. Generation capacity net increase was 4Gwe and electricity generation increase was 58.9TWh, mainly thanks to the Asian, where Nuclear energy generation is almost fifty times the ones from other nations, except for North America. Moreover, the other nine new plants have been built during this year[27]. Even if the capacity is growing, it is still not growing sufficiently enough to overpass the old nuclear reactors decommissioning or political decisions about shutdowns.

Figure 22



[Source: World Nuclear Association, (2019). *Performance Report.*]

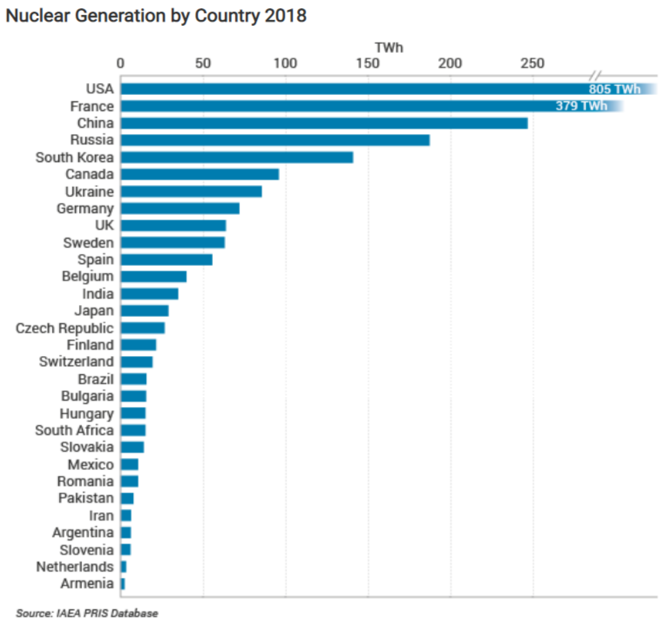
New plants construction is begun in 2018 for the UK and Turkey, confirming the trend that more and more nations are choosing Nuclear as an answer for their reliable, predictable, and clean electricity needs. In a high

[27] World Nuclear Association, (2019). *Performance Report.*

growth market like India and China, the new challenge to find a new energy source that not pollute the air have investments in nuclear as a result. On the other side, despite nuclear importance to reach sustainable targets, many governments are still decommissioning reactors, forcing retirement a lot of production capacity. In this way, while many plants are being built, many others are being closed, representing no variations in their total number. In China, in 2019, the first months, there were 46 operable nuclear reactors, equals 11% of the world's nuclear capacity. Besides, to satisfy the climate obligations will be necessary for an enormous expansion in capacity, as stated by China's National Development and Reform Commission's Energy Research Institute. In Japan, the will of Prime Minister Shinzo Abe is to provide at least 20% of its total country electricity need only through nuclear by 2030. South Korea, instead, is already generating about 25% of its electricity only with nuclear power. In India, there is a nuclear mania explosion with the construction of seven new reactors. Another place is Russia, where it is possible to claim that its strength in the nuclear industry is connected to the export market for new reactors. They have taken many agreements with different nations to build new plants. Coming to Europe, France had plans to reduce nuclear power from 75% to 50% but decided to postpone them because the priority is to produce clean energy. The same is happening in Germany, where their plans to reduce CO2 emissions will be missed, and this is why it has been chosen to postpone nuclear phase-out. Instead, the UK has started the new plant construction in Hinckley Point C. In addition, Turkey put in construction its first nuclear reactor in April 2018. Lastly, in the USA, at the start of the year, 98 plants have become 97 because of Oyster Creek closure. Despite this, the American government remains a nuclear supporter, and it is soliciting nuclear spreading in the world thanks to new policies and for reducing carbon dioxide emissions. Argentina and Brazil also produce electro-nuclear energy.

However, the difference in production between the United States and Europe remains evident. In the USA, nuclear plants produce about 20 percent of the country's electricity. France is the only European exception, where nuclear energy serves as a guarantee for more than 80 percent of the total country energy. In the EXTRA-EU countries, on the other hand, there is a robust affirmation of the nuclear market, especially in Russia and China.

Figure 23



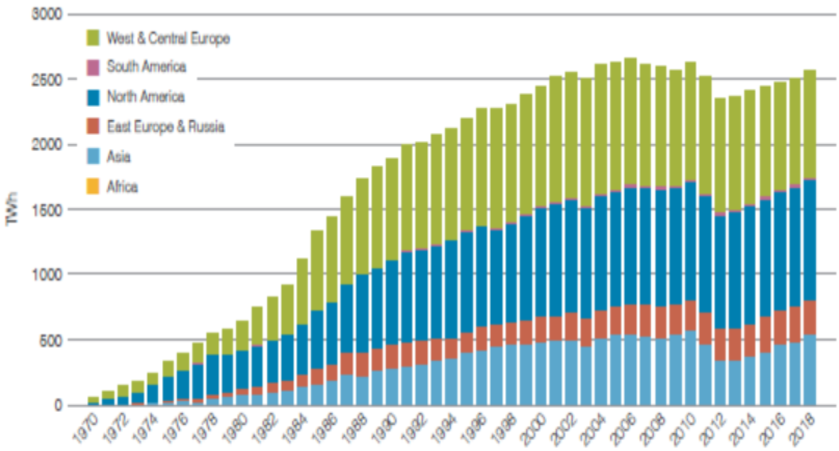
[Source: World Nuclear Association, (2019). *Performance Report*.]

Most of International Players have understood that Nuclear will have a high impact on the future, and this is why more and more countries are investing in it. The electricity generated need has grown recently and will continue to increase, as it has happened for the past six years consecutively. Nuclear reactors produced a number of 2563TWh of electricity in 2018, rising from 2502TWh in 2017[28].

The peak had during this year was equal to 402GWe of total net capacity, up from 394GWe in 2017. In every case, the total net capacity has been reduced until the end of the year to 397GWe, which was more than 2017 with 393GWe. In the fig. 25 there is nuclear electricity production by years.

[28] World Nuclear Association, (2019). *Performance Report.*

Figure 24



[Source: World Nuclear Association, (2019). *Performance Report*.]

Since the 70s, nuclear production has continued to rise, having a faster step each day firmly. The only slowdown could be recognized in the year 2011 when there was the Fukushima Daiichi nuclear disaster in Japan. It is possible to see that the quantity contraction in that year was mainly attributable to the Asian market. In a demonstration of this, the sequent table shows that from 2011 four Japanese reactors do not produce electricity. Only at the start of 2018, these reactors have been restarted arriving until the number of nine for Japan. Overall, there were 449 operable reactors this year, from 448 in 2017. However, even if there are new reactors opening and under construction, every year, many of them are decommissioned due to political pressures or because they are too old. Fig. 26 synthesizes the 2018 openings and closures.

Figure 25

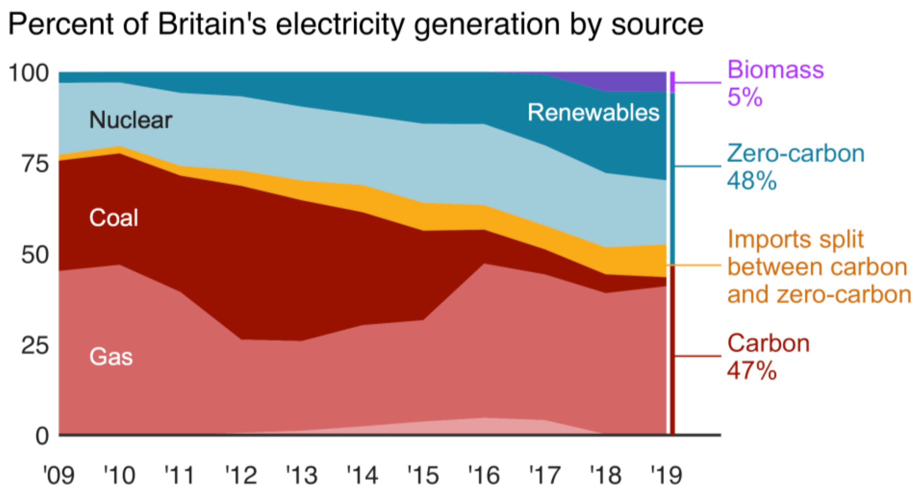
	Africa	Asia	East Europe & Russia	North America	South America	West & Central Europe	Total
BWR		26 (-2)		35 (-1)		11	72 (-3)
FNR		0 (-1)	2				2 (-1)
GCR						14	14
LWGR			14 (-1)				14 (-1)
PHWR		25		19	3	2	49
PWR	2	90 (+4)	35 (+2)	65	2	104	298 (+6)
Total	2	141 (+1)	51 (+1)	119 (-1)	5	131	449

[Source: World Nuclear Association, (2019). *Performance Report.]*

3.3.1 The Nuclear market in the UK

Currently, in the United Kingdom, 21% of its electricity is produced by 15 working reactors, with a capacity equals to 9.5GWe. In 2017, data from the Department for Business, Energy and Industrial Strategy was estimating a total energy annual production about to 78.3GWe, subdividing 16.7GWe from traditional steam, 31.8GWe from combined cycle gas turbines (CCGT), 16.2GWe from wind, 11.9GWe from solar, 4.3GWe from hydro and 5.7GWe from bioenergy[29]. The market share is subdivided as below.

Figure 26



[Source: BBC, (2019). Nation GRID of Data for the first five months of the year.]

These results show UK policies' effectiveness in reducing fossil fuel usage under half of the total electricity demand. Government policies pay great attention to reduce CO2 emissions and carbon employment since 2008 when it was published the Energy Act. In fact, from 2015, coal exploitation has been avoided up to reduce its need by half, thanks to doubling of the carbon price floor. Moreover, even if renewables generation capacity has been increased, it did not have the expected outcome: not favorable weather conditions harmed wind and solar production. It is claimed that these two sources are intermittent,

[29] https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx

according to the UK territory climate. For this reason, from August 2015, renewables no longer receive exemption certificates as a climate change levy. Considering all these complications, the only energy source that seemed to convince the UK government was Nuclear[30].

In the same year, new policy priorities about energy were enacted. Their purpose was providing greater confidence in Nuclear power and undue reliance on coal. These policies were not the first sign of the British interest in this area since they were producing Nuclear for many years. As stated by the UK energy secretary: "*Opponents of nuclear misread the science. It is safe and reliable. The challenge, as with other low carbon technologies, is to deliver nuclear power, which is low cost as well. Green energy must be cheap energy.*

We are dealing with a legacy of under-investment, and with Hinckley Point C planning to start generating in the mid-2020s, this is already changing. It is imperative we do not make the mistakes of the past and build one nuclear power station. There are plans for a new fleet of nuclear power stations, including at Wylfa and Moorside. It also means exploring new opportunities like small modular reactors, which hold the promise of low cost, low carbon energy.[31]"

As claimed by the energy secretary, recent forecasts claim that energy peak demand will increase to 85GWe by 2050, and Nuclear power production plants should be ready for satisfying every need with efficiency and effectiveness. There are already plans to sustain nuclear growth to expand and build new plants. Existing reactors are all privatized and under government regulations. A French company, the EDF Energy, is the one that owns and operates all the UK plants. Below there is a list.

Figure 27

Power reactors operating in the UK

Plant	Type	Present capacity (MWe net)	First power	Expected shutdown
Dungeness B 1&2	AGR	2 x 520	1983 & 1985	2028
Hartlepool 1&2	AGR	595, 585	1983 & 1984	2024
Heysham I 1&2	AGR	580, 575	1983 & 1984	2024
Heysham II 1&2	AGR	2 x 610	1988	2030
Hinkley Point B 1&2	AGR	475, 470	1976	2023
Hunterston B 1&2	AGR	475, 485	1976 & 1977	2023
Torness 1&2	AGR	590, 595	1988 & 1989	2030
Sizewell B	PWR	1198	1995	2035
Total: 15 units		**8883 MWe**		

(Source: https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx)

[30] https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx

[31] https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx

UK reactors are subdivided into two types: AGR, which is an Advanced Gas-Cooled Reactor, and PWR, which is a Pressurized Water Reactor. Moreover, most of AGR plants are running under their maximum capacity. Even if has been already decided a shutdown date, due to reactor ten years life decided by the Office for Nuclear Regulation, EDF Energy want to extend their durability for averaging eight years. Here is where Connect-R ideas are born, and it is easy to understand why. Britain sustains and trusts in Nuclear is evident, and it is possible to see it in all projects trying to improve the industry, as Connect-R purpose is doing.

First signs of the United Kingdom Nuclear support began in the 90s and was suspended until 2006 when the government's opposition to building new capacity was reversed. Since this is a private sector, many policies were enacted to facilitate new reactors built. Although the government is changed into 2010 and 2015, Nuclear power support continued as a high priority. After, due to the Brexit referendum into 2016, the Department of energy and Climate Change (DECC) was abolished in favor of the Department for Business, Energy, and Industrial Strategy (BEIS) that was insisting on Nuclear importance.

Moreover, the UK left the European Union as well as to leave the European Atom Energy Community (Euratom). Even if Euratom is a separate entity from the EU, it is closely connected to the institutions. It must establish and manage a common market for nuclear goods, people, capital, and services and protect the Nuclear Non-Proliferation Treaty. Therefore, in order to maintain equilibrium in the world market and safeguard its position and shares in Nuclear energy commerce, it seems clear that the UK will be open to the negotiations of new agreements, having to manage already an awkward exit from the European Union. In fact, without new arrangements when the UK will leave the EU and the Euratom, NIA alerted that will be a rupture. Moreover, the UK will no longer have to submit to EU energy rules thanks to Brexit.

Meanwhile, an international agreement is under negotiations, EDF Energy plans to go on and extend its nuclear plants. Two new reactors will be built in Hinckley Point in Somerset, thanks to investments coming from China. They will be operational for 2025 with a new reactor type called Evolutionary Power Reactor (EPR), which is going to be a step forward in reactor history.

Because of demand growth forecasting and UK government support, EDF Energy is planning to build new plants. There are already some proposals, but EDF Energy has proposed not all of these. There are many new companies and competitors interested in invest in UK Nuclear since all the possibilities offered and to new technological discoveries that will continue to create new systems and new reactors types. The new ones proposed are the Advanced Boiling Water Reactor (ABWR) and the Hualong One, which is a Chinese water pressurized reactor. They could be listed as in fig. 29.

Figure 28

Power reactors planned and proposed

Proponent	Reactor/site	Locality	Type	Capacity (MWe gross)	Construction start	Start-up
EDF Energy	Hinkley Point C2	Somerset	EPR	1720	2020	2027
EDF Energy	Sizewell C1	Suffolk	EPR	1670?		?
	Sizewell C2	Suffolk	EPR	1670?		?
Total planned	**3 units**			**5060 MWe**		
China General Nuclear	Bradwell B1	Essex	Hualong One	1150		
China General Nuclear	Bradwell B2	Essex	Hualong One	1150		
Horizon	Wylfa Newydd 1&2	Wales	ABWR	2760		
Horizon	Oldbury B1&B2	Gloucestershire	ABWR	2760		
Total proposed	**6 units**			**7820 MWe**		

(Source: https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx)

A problem that the UK must face is nuclear wastes management. Several low and intermediate level wastes were moved into the ocean deepness until when the government decided to forbid this behavior, starting from military programs in 1982. In this period, low-level wastes are stored into the Low-Level Waste Repository at Drigg in Cumbria, meanwhile intermediate and high-level wastes are disposed of mostly at Sellafield. The government provides these safety disposals through the Nuclear Installations Act 1965, which rules nuclear plants safe operation and construction.

As it is possible to see, the UK is a great supporter of Nuclear power, and its public opinion has expressed itself as favorable. According to this, nowadays, the government is investing in nuclear development as the £2 billion loan guarantee for the Hinckley Point C project. A nuclear research center called "Joint Research and Innovation Centre" will be co-fund by UK and China, as a recent announcement was claiming.

The National Nuclear Laboratory has expressed itself on the topic: "*The work of the center will help to optimize the nuclear power generations systems we have operating today, as well as working to develop the reactors and fuel cycles which we will deploy in future and better ways of dealing safely with nuclear waste*"[32].

[32] https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx

3.3.2 The Nuclear market in Italy

In the current scenario, where all central Countries are investing more and more into Nuclear, Italy is the only one that is bucking. No one nuclear plant is working and operative since 1987 in Italy. This year there was a referendum with the result of public opinion not in favor of reactors usage and with high costs for the whole economy. Since that date, Italy continued to reject every nuclear plan until 2008, when a new program of generating 25% of the country's electricity was approved[33]. Despite this, in the 2011 referendum, this plan was abolished again, and nothing extraordinary happened until now. However, to sustain electricity demand, Italy needs to import an enormous amount from other Nations. In 2018, net imports were 56TWh from Switzerland and France, corresponding to about 20% of its demand and classifying this country as the second world's largest net importer of electricity. For this reason, electricity prices in Italy are well higher than the EU average.

Even if Italy was a pioneer of nuclear technology development, today is the only G8 country without its production. Also, in its territory are present four different reactors have been shut down for many years. There is a list below.

Figure 29

Italy's former nuclear power reactors

Reactor	Model	Net MWe	First power	Shutdown
Latina	GCR	153[h]	05/1963	12/1987
Garigliano	BWR	150	01/1964	03/1982
Enrico Fermi (Trino Vercellese)	PWR	260	10/1964	07/1990
Caorso	BWR	860	05/1978	07/1990
Montalto di Castro (Alto Lazio) 1&2	BWR	982 each	Cancelled	-
Total operated (4)		**1423 MWe**		

(Source: https://www.world-nuclear.org/information-library/country-profiles/countries-g-n/italy.aspx)

[33] https://www.world-nuclear.org/information-library/country-profiles/countries-g-n/italy.aspx

How it is possible to see, all plants' first power dates are back to the 60s, when Nuclear was just discovered. After that, Italians opinion decided not to trust this technology anymore since all the many accidents that are happened in history. The last one of Fukushima Daiichi in 2011 marked the end of every new possible nuclear revival, or at least in the next few years. Currently, Italians are importing Nuclear energy from abroad for 8% of the total electricity consumption, causing usage costs to raise that goes to burden even more on expenses. However, thanks to new lowering-carbon targets achieved by other countries at low costs, there is the possibility that in the future also the Italian government and citizens will see the nuclear opportunity without any concern behind.

3.4 Nuclear advantages and negative sides

Nuclear market success is due to different aspects that make it a competitive product on several fronts, allowing it to be one of the energy significant factors. From a business point of view, even if the investment costs needed for a nuclear power plant construction are not so cheap, nuclear energy continues to be defined low-cost energy because it is cost-competitive, or rather, electricity is produced with fewer costs than other competitor sources such as coal, gas, oil, and renewable ones.

Another aspect that deserves attention is new material usage discover, as Thorium. Only after many years, it was found its employment as fuel for nuclear reactors. Nowadays, this material has captured the interest of many Countries thanks to its properties, which is about three times the Uranium worldwide quantity and a less environmentally damaging fuel source. A Thorium reactor cannot release radiation and meltdown without high temperatures, making it a safer choice. Shortly, nuclear will may leave its competitors behind like it is already started in China, Russia, and India, where they are building Thorium reactors almost ready to work.

Moreover, in this period, eco-sustainable thinking is spreading all over the world because of global warming, and most claimed electricity types are renewable ones. Even if these are the greenest solutions, their implementation is still cost expensive without a significant gain of electricity. So, how to reduce CO2 emission as soon as possible? Nuclear power plants provide a stable baseload of energy. This effect means that it could work synergistic with renewable energies, increasing the reactors' generation when wind and solar sources are missing and reducing reactors when renewables are available.

A futuristic possible scenario is that nuclear energy could become a "renewable" one in the future. Despite there is a limited amount of reactors fuel between Uranium and Thorium, if it could become possible to control atomic fusion could also become possible to produce unlimited energy. Therefore, with breeder and fusion reactors technology progress, nuclear could begin to be classified as sustainable. Besides, it is possible to claim that the energy density resulted from fossil fuel combustion is really lower than the one resulting from the nuclear fission reaction. In fact, the electricity released from the same fuel quantity is about ten million less in an old type power plant compared to a nuclear one.

For all these reasons, it appears clear why nuclear energy is continuing to increase in its employment and its market share. Even if there are many possible complications through the usage of this source, it is not easy to renounce to the advantages that it takes. Consequently, thanks to careful management and to the technological progress that are come, and that will come, nuclear could lead us to a new era where energy consumption concept and sustainability will be completely different.

Even if nuclear energy carries many advantages as the lack of fossil fuel burning and, consequently, the lack of the air release of combustion products like sulfur dioxide and carbon dioxide, also negative aspects come from its use. Despite job security, it is already a very relevant topic in itself that is concerning many people in the nowadays society, wastes arising from the use of nuclear plants are even worse. These are subdivided into two categories: low-level and high-level material, based on the radioactivity emitted. Typically, the first ones are stored in the nuclear power plants or some special storage, mostly burying them under the ground. The second one represents the main problem because they have to be kept safe and isolated for almost 10000 years. Due to this reason, for a short period, they are stored into the site of production and, after, sealed in glass and other limiting containers. As the last step, they are moved to some underground storage. To get rid of wastes, many countries throw them into the depths of the sea, which is a way of behavior not encouraged by some nations.

It appears bright that long-term wastes management needs an innovative remedy.

However, the purposes that have been chosen during the war and, after, the accidents happened for a not enough safe working disposition, has caused a common fear that could be reconnected to the sound of the word nuclear. Even if military implementations are forbidden by the Non-Proliferation international agreement, in history, it is possible to count a certain amount of tragedies that happened because of this energy.

After many years, people's minds finally started to change, and when there were first signs of a new point of view for nuclear, in 2011 happened an accident at Fukushima Daiichi again. This event signed a significant slowdown of nuclear affirmation since many nations abandoned their relative plans. For example, Italy, due to its scared public opinion, never began a nuclear project again.

Another negative aspect of nuclear power corresponds to the high costs to be incurred for the operation of its energy plant. Only the planning of the construction appears very long and complicated, lasting about ten years. Besides, plant maintenance is often necessary, which can be expensive and dangerous. This fact results in a final cost of energy, which at times may not yet be competitive in free-market conditions. Costs must be incurred regarding financing, provisions for nuclear decommissioning, for possible accidents, fuel costs, and a hypothetical early closure of the plant whose average duration is 50-60 years. Therefore, nuclear negative sides can be classified in:

- Waste management
- Job security and general safety
- High plant costs

From the premises, one question is emerging to the public opinion, considering a continuous nuclear growth for how long will available sites be available? If new plants are build and new plants are decommissioned, always more areas will be used as storage for nuclear wastes with the consequent decrease of possible sites, which have a limited amount of availability. In this scenario, will wastes disposal causes nuclear energy to end? This question could find an answer only in the future and that, to have a negative result, appear bright that technology will need to progress and to find new solutions capable of deleting completely Nuclear waste.

3.4.1 Nuclear decommissioning

Due to the reputation that nuclear power has in public opinion, many plants are closed every year. This event mainly happens for older systems, having been built with past technologies and safety measures. Not being able to guarantee a sufficient guarantee, and implying the enormous investments necessary to update these plants, one way that is often chosen is that of the complete deactivation of the nuclear plants. In technical terms, it is called nuclear decommissioning, that is, those series of activities aimed at deactivating and safely removing the remains and toxic waste that come from these plants. Due to the complex and risky being of these activities, the costs for a single decommissioning are exorbitant and can be estimated at hundreds of millions of euros. They are divided into various parts, from those devoted to the precautionary measures for the intervention of the human operator, up to those of using robotic solutions for those areas that are difficult to access and radioactive. However, despite the very high costs, the results obtained by these technologies are limited to supervised or remote-controlled operations, therefore always requiring a human operator. All this results in an even more significant increase in costs, having to resort to both workforce and expensive and cutting-edge robotic solutions. Only soon, thanks to the invention of Connect-R will these current limits be overcome. Precisely thanks to its main features, such as autonomous operation due to self-building modularity, the ability to access in any extreme environment, and its versatility of actions that can be performed, it will have the effect of removing human operators and using less expensive robotic solutions. All this will translate into a considerable reduction in the expenses necessary to decommission a nuclear power plant, also improving its dismantling times and the risk of accidents. Precisely for this reason, the first Connect-R implementation was made for this area.

3.5 How long will Nuclear energy last?

To sustain world energy demand, each year, nuclear power plants require at least 70000 metric tons of uranium at the present day. This quantity could be translated into 2.8 trillion kilowatt-hours of electricity, generated from light-water reactors through low-enriched uranium. If it is considered that for producing a metric ton of this type of uranium are required about ten metric tons of natural uranium, it seems necessary to ask the question, "how long will the natural stocks will last?".

At the current usage rate, it has been estimated from the Nuclear Energy Agency (NEA) – as stated from an article by Scientific Americans - that nuclear power plants could run for almost 200 years yet. This assumption has been made thanks to the quantifying of the total uranium resources discovered until now, which is near 5.5 million metric tons, and that still remains to discover approximately an amount of 10.5 million metric tons[34].

However, forecasts provided by NEA could mislead in case of progress in uranium exploitation. This heeling could come in two main ways: work improvement and technology improvement. The first one could be translated into a more efficient uranium usage, through a reduction of light-water reactors need with work enrichment and, through implementing plutonium and uranium from spent low-enriched uranium, to make fresh fuel. On the other side, two technological solutions could increase uranium supply directly: uranium extraction from seawater, that could make available about 4.5 billion metric tons more; starting to use fuel-recycling fast-breeder reactors, able to produce the same energy quantity with 1 percent of the uranium required for a light-water reactor. Thanks to these breeder reactors could be possible to have nuclear energy providing for more than 30000 years instead of the current 200.

According to these discoveries, it seems clear that Nuclear will have a long life, characterized by new signs of progress that will improve its employment and its durability. Even if it cannot be classified as a renewable source, technologies could make its fuel life cycle so long that there will be enough time also to continue researches on other sources like solar and wind.

[34] Fetter, S. (2009), *How long will the world's uranium supplies last?.* In Scientific American.

3.6 Technology innovation into Nuclear industry and Connect-R positioning

To sustain nuclear energy economic growth and its competitiveness in world markets, a critical factor that should be taken into consideration is the technological innovation connected to it. In a fast-progress society, as the current one, tech innovation defines product future possibilities and implementation as well as market success and competitiveness position. In fact, in the challenge for fossil fuel inheritance, aspects that are leading nuclear to the head are new technologies still in progress. Discoveries are not just confirming its current predominance on renewables, but they are laying the groundwork to progress in the future in the same way. Even if many governments are beginning to reduce their contribution to R&D to solar and wind, the situation changes when it is spoken of nuclear.

For this reason, today, this energy type has a high rank in requirements like safety and reliability, eco-sustainability, society expectation, and market competitiveness. For confirming this, OECD/NEA member countries have promoted the development of nuclear innovation, stating goals and roadmaps. In this way, also nations that had abandoned it like Italy will need to continue R&D on the argument, at least for getting rid of wastes and decommissioning. Moreover, at the current time, many innovative ideas are not still been implemented on an industrial scale, although they have been proposed. In addition, nuclear represents a possibility to satisfy the increasing global future energy demand in a sustainable way and with an optimum out-performing result. In this context, technological innovation will play a major role in letting disappear public concerns about its large-scale deployment. The possible areas that could be improved by research are many and different:

- Resource preservation, since Uranium is not an endless material and this is why nuclear is not classified as renewable
- Wastes reduction, trying to build more efficient plants, which are capable of producing energy with a minor radioactive quantity produced
- Job security and accidents prevention, with the elimination of every catastrophic event possibility

- Market competitiveness, as a result of all the previously described technology improvement
- Investment risk reduction, thanks to its concreteness achieved by confirming the market positioning
- Nuclear decommissioning, in order to remove toxic and radioactive materials in dismantling in a safer way[35]

To claim electro-nuclear as tomorrow's energy, other aspects that should be realized are a safer nuclear building, a higher efficiency, a power raise implementation, and a costs decrease, regarding fuel and operational ones. According to these progress requirements, many projects are still work in progress regarding every area cited above. Nuclear patterns development for every nation could be described as a self-dependent project definition followed by a technology transfer from abroad and autonomous development. Therefore, it is clear that a standard agreement between international entities and governments is an essential step for nuclear progress. On the other side, not all the projects that have been developed for this scope had success consequently. Products or ideas that failed to meet market requirements did not find a market acceptance, and projects programmed without the Industry help are difficult to apply. On this topic, it is vital to claim public opinion importance in sustaining or not new technologies, a complicated issue caused by social nuclear old awareness.

For this reason, in order to create the right ecosystem where nuclear progress can proliferate, some characteristics should be met. First, a project should start with an agreement between different players like government, R&D structures, safety regulators, industry suppliers, and energy providers. Only from the synergy of these actors can derive the necessary scope needed to let the innovation change happening. Therefore, these players could be identified as change drivers and could be classified into, technical drivers, market drivers and political drivers.

The first one represents the collaboration between R&D and the Industry to develop new solutions, the second one means the competitiveness that the project will have in the market and its positioning from a business point of view

[35] OECD, (2007). *Innovation in Nuclear Energy Technology*.

and, the last one, states a government framework characterized by country dependent measures.

Some possible areas examples of nuclear technological innovation could be classified into three main categories: new classes for advanced reactors, developing new types of them characterized by an unprecedented versatility that can be much less expensive, guarantee a higher safety and burning wastes as fuel[36]. This new reactor is called a NuScale Power advanced small modular reactor (SMR), and it is now in developing in the USA, with a market release planned to 2026; advanced manufacturing, which will dramatically change the way how these structures are built by 3D printing introduction into the development of different nuclear components. Through this new idea will be possible to realize a complex building that will be tested and prototyped fast, reducing money and time needed; advanced fuels, i.e., new kind of sources that will perform better at higher temperatures. The material used for this research is TRISO-X, an extremely resistant fuel to high degrees. However, this is not the only one, since more than one source can be used as fuel for reactors. In fact, currently, Global Nuclear Fuel (GNF), Framatome, and Westinghouse are testing many different possible fuels that will be inserted in the market in the next ten years.

In this scenario of possible nuclear technological innovation defined by many projects that are working in progress, Connect-R and its purpose could be positioned as a new technology that will solve several nuclear challenges, and that will represent a futuristic approach in managing these types of complexities. Connect-R is a project with an intent to reduce until disappearing human factors in risky situations derived from everyday life in nuclear power plants. From most uncomplicated actions, like goods handling, arriving until dangerous and complex ones, as the required closure of Uranium losses, Connect-R will be classified as a project that will try to improve job safety in a nuclear scope, and that will decrease the possibility of catastrophic accidents, helping to avoid in the future disgraces happened during the history. Connect-R prototype has been thought for a nuclear decommissioning case, but nothing excludes plant construction adoptions, too, for the future. Also, this project will not only be a better guarantee of employing nuclear power plants but will also represent an improvement inefficiency. Thanks to the automation of many working processes, lead-time and continuous production will be the other two

[36] McGinnis, E. (2018). *3 Innovations Transforming the Nuclear Industry*. In Energy.gov.

advantages that Connect-R brings. However, this project is not the first robotic application on nuclear, since many implementations have been made to integrate energy production and plant dismantling until now.

Despite this, Connect-R represents an enormous step forward from traditional ways of working, and it will mark nuclear history forever, completely changing dynamics between human factors, automation, and nuclear power plants.

In the last chapter will be analyzed, from a technical point of view, Connect-R purpose of being implemented into a nuclear decommissioning case and how tasks performed at the Royal Holloway University of London during the past six months have affected its realization.

Conclusions

In this chapter, the world nuclear market, the actual first user of Connect-R, has been analyzed. Currently, due to CO2 emissions, a new energy source is being sought, based on three concepts: being "green", being sustainable and not having high costs. From what has emerged, nuclear power presents more "reliable" results than renewables. This result is due to the opportunity to immediately offer an effective and non-variable solution. Many governments are veering in this direction, limiting renewable energy policies in favor of nuclear power. An example is the UK, where about 21% of the energy used is nuclear and where this project was born. The Italian point of view is the opposite, refusing to produce but importing 8% of this energy from abroad. This fact depends on the bad reputation that nuclear power has, in public opinion, is considered very risky and dangerous. Even only in the dismantling and deactivation of the plants that are no longer in use, in fact, there are huge hazards due to radioactive materials and toxic waste, but also to the relative costs of thousands of millions of euros. It is thus in nuclear decommissioning that Connect-R was born to eliminate the risk for the human operator and, at the same time, reducing the relative costs. However, it is still a project under development, and before it can be applied to the case under consideration, many steps must be taken. For assisting in its development, several tasks have been performed by the student and will be described in the next chapter.

Chapter 4: Tasks to support Connect-R development

In this last chapter, the student's tasks to support the Connect-R project development during the six months at the Royal Holloway University of London will be discussed.

These tasks fall into two different categories: one for Struts graphical simulation and one for comparing the tasks planning system used by researchers for development and one explicitly developed by the student using alternative tools. While the first type contributes to the planning of the action plan that will be executed by the Struts, the second tries to investigate whether the system used is the most efficient, in order to guarantee optimal results for Connect-R.

4.1 Tasks subdivisions

Connect-R is a highly complex project and is composed of many different parts contributing to reaching a frequent target. Since robotics requires many fields of knowledge, subjects of different nature are involved. Many experts from Universities and companies are implied in working for this solution, and each one is specialized in a particular area. During the collaboration carried out in the last six months at the Royal Holloway University of London, an extensive list of tasks has been realized to support project development. From graphical simulation to planning systems creation, many Connect-R aspects have been studied and analyzed.

Two main categories can be defined for the types of the task executed:

- Graphical Simulation
- Planning-Problem

In order to go more in detail, a general Connect-R process description is needed. The functioning of this robotic solution is related to two different robots: Struts and MTB. As previously stated, these two act as, respectively, legs and hands of a human employee. In fact, Connect-R is a path auto-building solution, able to generate the path autonomously where to move on. In the same way, when the location is reached, it acts in an independent way for the various activities that can be executed, as building, repairing, and dismantling objects. This fact is the reason why Connect-R is a project capable of being applied in many industries and problematics, since the variety of possible actions. Even if it is born for a Nuclear application, in the future there will be high hopes to see it adopted Space, Agricultural, Mining, and other sectors. Connect-R will offer a way out to problems that are still without a solution and to those where it will offer a more competitive alternative than existing ones. The two robots are performing dissimilar types of tasks: while Struts compose the path to walk, MTB is moving on Struts to reach the location and start to operate. In this way, it is possible to perform an infinite number of activities, from small fixes to intricate constructions. What Connect-R can purpose is described by the synergy of these two actors, cooperating to satisfy every target. However, these robots are not developed from the same institution, since each one requires ad-hoc characteristics due to their own nature. While MTB is in production by private companies, Struts programming has been taken in charge by the Royal Holloway University of London. Hardware parts, instead, are in development by the University of Edinburgh and many other enterprises.

In each case, this project is still a work-in-progress and, for now, has moved just into firsts steps. For this reason, Struts path calculation has not been completed yet, and graphical simulation of what Struts should do was necessary in order to support plan planning. Many Struts are needed to create a road to walk to perform their tasks of an auto-building path.

By their conjunction, what emerged is a structured path made by robots where MTB will walk on. However, Connect-R is born from a Nuclear application, and its first implementation is studied for that particular usage. Maybe in the future, when Connect-R will also be implemented in other situations like space or agriculture, other studies will be required to forecast and program how Struts will need to move to solve a particular problem. For defining the path in this case, room dimensions and sizes have been analyzed to find the optimal path that Struts should perform. In the future, probably

Connect-R will also walk other ways that are not related just with Nuclear building and decommissioning when it will be programmed to operate in different environments.

Regarding its first application, Connect-R will have to move inside a room defined by two walls, identifying a path useful to reach positions where MTB will need to execute actions. To sum up, Connect-R is a high complexity project, and many actors are working on that, joining efforts from Universities, Companies, and Government. In fact, while the first two are occupied in developing different project parts, both software and hardware, through a great synergy, also the Government is seeing enormous opportunities in what this project could offer, financing, and investing in Connect-R in a reasonable quantity. Despite this, many people are involved in this idea, and the leading role is occupied by the Royal Holloway, University of London. In fact, during six months passed there, many tasks regarding Connect-R have been developed, contributing to the final result of the project. These tasks are different and will be discussed in the following paragraphs, from the robots graphical simulation until the planning-problem argument.

4.2 Struts graphical simulation

In order to perform optimal programming able to find a solution to the real problem case used for this first application, a graphical simulation is needed to offer different points of view and the possibility to check with eyes what is happening. For realizing this, it is needed to enter Computer Graphics discipline, i.e., the subject that creates and manipulates images, videos, and graphical applications. Many vital arguments can be found in virtual reality, ray tracing, vector graphics, user-interface design, and, last but not least, 3D modeling. All these techniques and software are allowing these activities are using concepts from physics, geometry, and optics. However, before starting a 3D modeling for Struts movement simulation, it has been developed an early attempt to support robots domain-problem programming. This result is why the first step to realize the simulator was coding a 2D simulation program, providing just a first help for planning. After this fast task, defined as a preview of the real simulator, the target was to produce an efficient 3D modeling of the

Struts path inside the room. It is important to note that Connect-R is a work-in-progress project, and, for this reason, the path planned obtained as a result of researcher efforts is in development too. Initially, the first sequence of action or plan, find out by experts, was made for a 2+1 dimensions representation and characterized by just four angles. This effect means that the height that was reachable by Struts in this first plan was not possible to overpass the second level, not regarding vertical positions. Moreover, only the 0°, 90°, 180°, and 270° angles were under exam when this first version was planned. On the other hand, after this step has been realized, another plan with a full 3D representation and based on six angles, comprehending 450° and 540° too. The difference is this second graphical simulation regards vertical movements too, going ahead of the second level of height. Each Strut can perform different actions, based on the plan depending on the domain and the problem for this particular situation. However, since vertical operations are not possible in the first simulation version, there are fewer commands. There is a list of 2+1 simulation commands:

- insert
- walk_forward
- rad2
- radx
- walk_backwards
- Swing

Initially, there are some Struts in an initial position. After this, the Insert command corresponds to the Struts entry inside the room, since each unit of Struts has to do it. After that, the first Struts has arrived in the sequent position, each of those actions can be executed depending on the plan derived. The walk_forward consists of a movement a step ahead performed by the robot, while walk_backwards is the same but in a reverse direction. Rad2 and Radx, instead, correspond to a Struts direction change, meaning a switch in the angle. Only Swing is remaining and shows an extension of a Struts length with another, which from being above, goes down and continues the previous Struts. For what concerns the full 3D version, there are two more commands due to the possibility of going up and down vertically speaking. The other two commands are:

- Rad1
- Radwn

These two actions are the ones that move up Struts in a vertical way, and the one that brings down to a horizontal position. All these inputs are those allowing to these robots to move and auto-building their own path.

For developing a proper graphical simulation, three different ones have been realized with parallel progress of Connect-R until that moment:

- 2D struts graphical simulator
- 2+1D struts graphical simulator
- 3D struts graphical simulator

4.3 2D Plan graphical simulation

To provide an immediate reference and to start first approaches of simulation, the first attempt was recognized into a graphical representation made just in two dimensions. In order to develop this program, it has been chosen to use Java as a programming language, owing to an easy-to-access programmable graphic interface. In succession, there are pictures taken from the application to show the first result obtained. For developing this GUI with Java, it has been used the Java Swing library, i.e., a framework part of Java Foundation Classes (JFC) used for graphical interfaces. Many Swing classes are composed of widgets and tools useful for a GUI. This tool is the official library in Java for graphical interfaces, and it is easy-to-use. The compiler used was Eclipse.

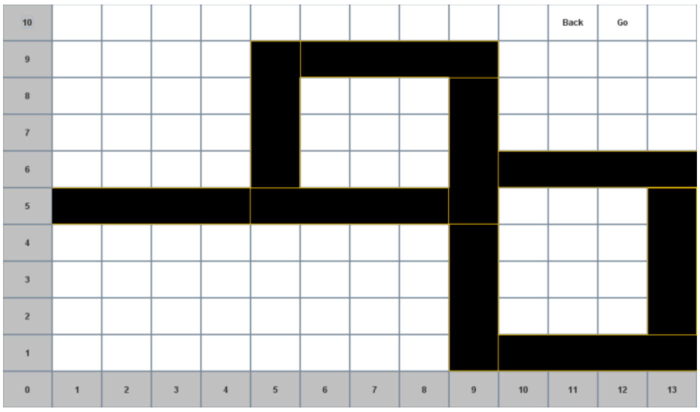
More in detail, the program is composed by a rectilinear coordinate grid where inside is evidenced the first desired Struts path. Going ahead with the relative button means going to the next state, after a movement of single Struts. When a robot is moved, the position occupied by the new action become blue if it is the first Strut and yellow if it is an overlap, until reaching the complete disposition of all the struts in the path. Moreover, it is present the possibility to making a reverse action for each step by clicking on back. The system behind its functioning is a state structure, when for each step there is a different state. The main logic was a state structure where for each state number was connected a relative action executed by a single Strut. Main functions developed here are regarding the movement state structure and the same for the text switching. At that moment, the plan resulting from PDDL planning executed by other experts was:

(insert 0c 5c 3c 0ang 8 7)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(rad2 4c 5c 8c 5c 8c 0ang 90ang)
(insert 0c 5c 3c 0ang 7 6)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(radx 4c 5c 8c 6c 9c 0ang 90ang)
(insert 0c 5c 3c 0ang 6 5)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(swing 8c 5c 8c 4c 1c 90ang 270ang)
(radx 4c 5c 8c 6c 9c 0ang 90ang)
(insert 0c 5c 3c 0ang 5 4)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(radx 4c 5c 8c 4c 1c 0ang 270ang)
(insert 0c 5c 3c 0ang 4 3)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(rad2 8c 4c 8c 0c 11c 270ang 0ang)
(radx 4c 5c 8c 4c 1c 0ang 270ang)
(insert 0c 5c 3c 0ang 3 2)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(radx 8c 4c 9c 0c 12c 270ang 0ang)
(rad2 8c 5c 8c 9c 5c 90ang 180ang)
(radx 4c 5c 8c 6c 9c 0ang 90ang)
(rad2 8c 0c 12c 0c 3c 0ang 90ang)
(rad2 8c 9c 4c 9c 6c 180ang 270ang)
(insert 0c 5c 3c 0ang 2 1)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(radx 8c 5c 7c 9c 4c 90ang 180ang)
(radx 4c 5c 8c 4c 1c 0ang 270ang
(rad2 8c 9c 4c 9c 6c 180ang 270ang)

(insert 0c 5c 3c 0ang 1 0)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(radx 4c 5c 8c 4c 1c 0ang 270ang)
(radx 8c 4c 9c 0c 12c 270ang 0ang)
(radx 8c 0c 12c 1c 4c 0ang 90ang)
(rad2 12c 0c 12c 4c 9c 90ang 180ang)

The total cost of this plan is equal to 35, reputed as the number of steps needed to reach the final state. In a particular state, Struts are disposed of in a way that will change in the following state through a single robot movement per time. However, the graphic result obtained is subsequent:

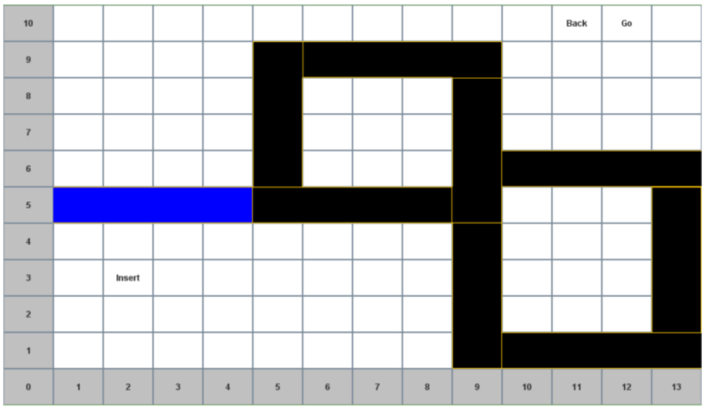
Figure 30



[Source: personal elaboration]

In the fig. 34, there is the initial phase, where only the possible path is shown. With the black is evidenced path guidelines where Struts will walk. In this way, it is possible to offer a better idea of the Struts movement, being limited to a 2D visualization. In the next images, there will be the first command of Inserting a Strut inside the room and how to continue with the walk forward.

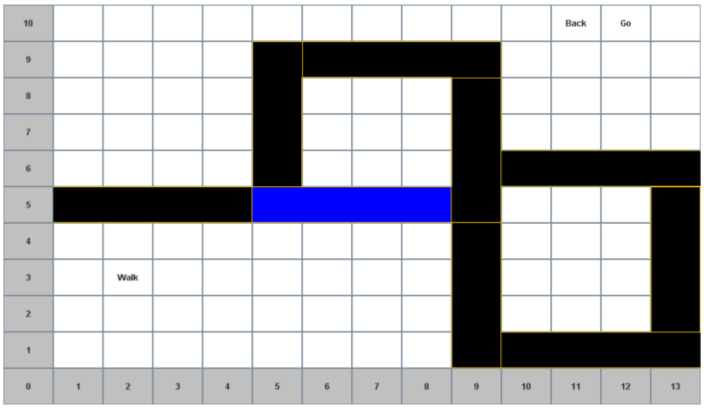
Figure 31



[Source: personal elaboration]

As it is possible to see, after the first Strut entrance inside the room with the insert command, the robot is continuing its path going ahead through a walk_forward command. Since many steps are present to arrive at the end of this program, not everyone will be shown.

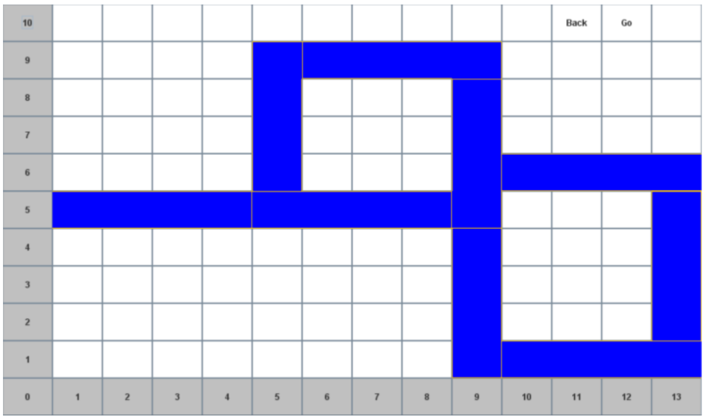
Figure 32



[Source: personal elaboration]

After the rest of the movements, the final state is described by a complete disposition of all the Struts on the pre-established path. In this way, the entire path becomes blue because all robots found their position. A better view of robot movement inside the room will be offered by 3D graphic modeling, where will be shown all possible actions. However, the next image is, then, the last state of this graphical simulation program.

Figure 33



[Source: personal elaboration]

The source code of this program has been published on GitHub and can be retrieved at the following link:

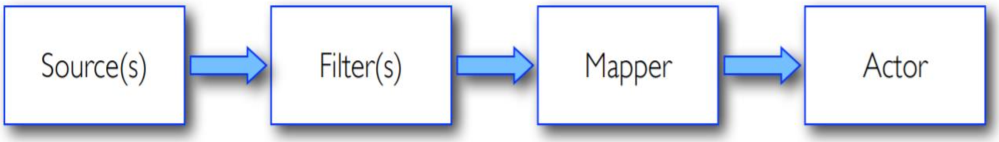
https://github.com/MikeRendine/2D-plan-graphical-simulation

4.4 VTK

In order to develop a 3D graphical simulation, among all the opportunities, it has been chosen to use the Visualization Tool-Kit(VTK) as software. VTK is an open-source solution used to display and manipulate data. It offers the possibility to provide tools and widgets for 3D rendering and interaction with 2D implementations. VTK has been written in C++ by Kitware, and it is of everyday use in many areas, as R&D and business. Through this software can be done, Mesh and Imaging process, Scientific Visualization and Computer Graphics, and supports languages like Java, Python, C++, and Tcl/Tk. It has an object-oriented design based on cells with a high level of abstraction. Some examples of VTK adoption can be isosurface extraction, image analysis, mesh, and polygon processes and developing visualization of volume data or scalars and vectors. Although it is not preferable for rendering large 3D scenes with lots of dynamic contents, this software has excellent rendering performance, and it is a competitive solution for rapid prototyping of 3D tools.

For what concerns VTK functioning, visualization pipeline is subdivided into four main steps to process an object: Source, Filter, Mapper, and Actor.

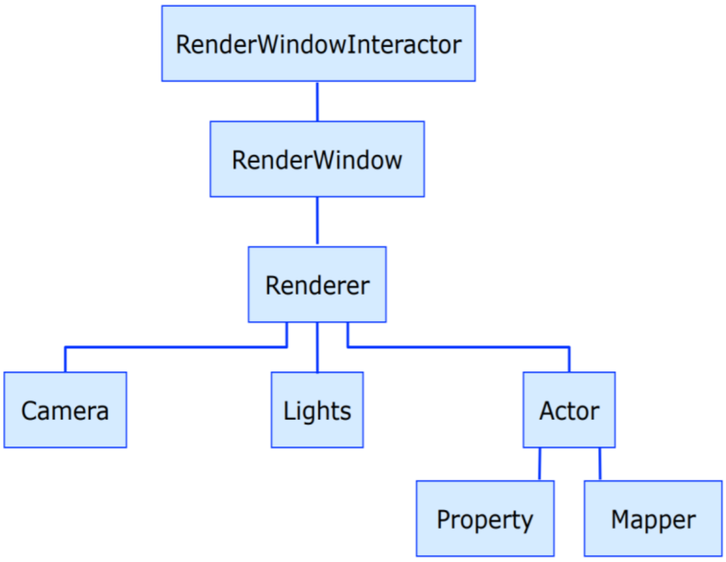
Figure 34



[Source: https://www.cs.purdue.edu/homes/xmt/classes/slides/CS530/VTK.pdf]

The Source corresponds to input data and can come from setting up the data structure, generating data from parameters, and reading data from a file. Many source classes have been provided to construct simple objects as geometric ones, as vtkSphereSource, vtkConeSource, and vtkCube. Otherwise, it is possible to read data from file to work on something already existing. The following step is the Filter applied to the source, which can be defined as visualization processing. In fact, it creates representation, transforms, and computes data. Its process can be defined as taking data, modifying them, and returning the result. Some applications are creating geometric objects from data, processing images or polygon meshes, and selecting data of the same characteristics. After this, there is the Mapper, a tool able to generate output data and writing data to files, interfacing with more than one software, and creating graphical primitives. These are points, lines, and triangles that can be displayed by the renderer. The last is the Actor, i.e., the result generated that will be subsequently added on the rendering scene. However, VTK rendering is structured in different phases too. Rendering is processed able to create images from a 2D or 3D model through computer software. As fig. 36 shows, the Renderer is what connects Camera, Lights, and the Actor.

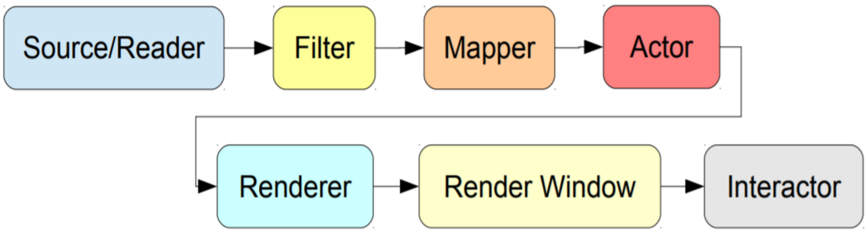
Figure 35



[Source: https://www.cs.purdue.edu/homes/xmt/classes/slides/CS530/VTK.pdf]

After that, the Renderer has been established, it is connected to the window where it is shown, called the RendererWindow. The last thing allowing performing a 3D optimal graphical representation is the interaction with simulations, provided by the RendererWindowInteractor. For performing these operations, mouse and keyboard can be included allowing to zooming and rotating the camera or moving actors and time events. In this way, VTK is capable of offering a satisfying service and an easy to understand dexterity, due to all different languages that can be used to program with this software. The fig. 37 provides a general and comprehensive representation of the VTK process to work.

Figure 36



[Source: http://www.cb.uu.se/~aht/Vis2014/lecture2.pdf]

To sum up, VTK is an open-source software offering many different capabilities regarding Computer Graphics. Its application area is vast, and for this reason, it is used in many contexts. For showing an effective graphic model, it is always required the same process from the data source until the interactor. To be run has been adopted CMake and Microsoft Visual Studio.

4.5 "2+1D" Plan graphical simulation

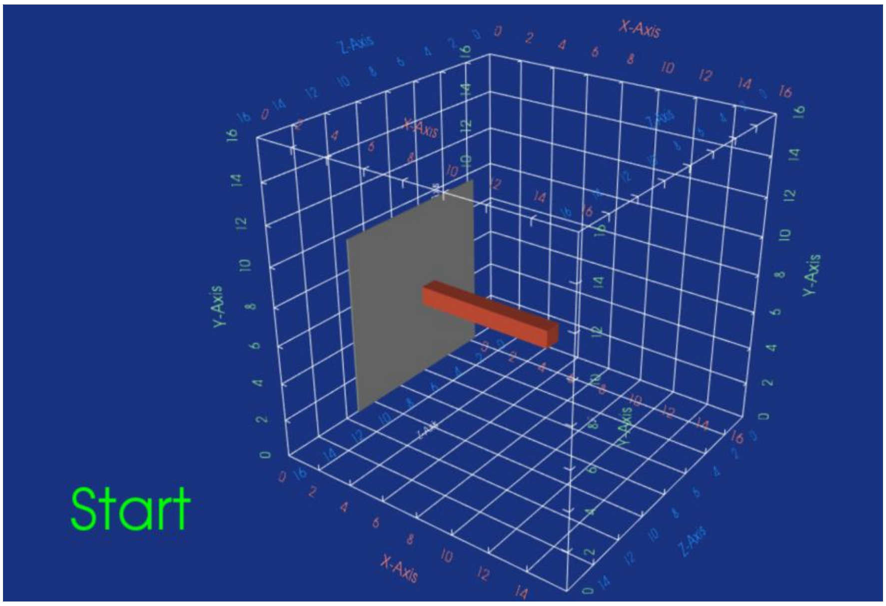
The first path simulation, realized with VTK, has been developed starting from a work-in-progress path. This has been realized without vertical movements and the possibility to overpass the second level of highness. Moreover, this path prototype has been created just with a four-angle camera, including 0°, 90°, 180°, and 270°. For all these reasons, this version has been called a 2+1 dimensions, meaning a still not complete 3D. The path determined for this simulation was the following:

(insert 0c 5c 3c 0ang 6 5)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(rad2 4c 5c 8c 5c 8c 0ang 90ang)
(insert 0c 5c 3c 0ang 5 4)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(radx 4c 5c 8c 6c 9c 0ang 90ang)
(insert 0c 5c 3c 0ang 4 3)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(walk_backwards 8c 6c 8c 5c 5c 90ang)
(swing 8c 5c 8c 4c 1c 90ang 270ang)
(radx 4c 5c 8c 6c 9c 0ang 90ang)
(insert 0c 5c 3c 0ang 3 2)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(radx 4c 5c 8c 4c 1c 0ang 270ang)
(insert 0c 5c 3c 0ang 2 1)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(rad2 8c 4c 8c 0c 11c 270ang 0ang)

(radx 4c 5c 8c 4c 1c 0ang 270ang)
(insert 0c 5c 3c 0ang 1 0)
(walk_forward 0c 5c 4c 5c 4c 7c 0ang)
(radx 8c 4c 9c 0c 12c 270ang 0ang)
(walk_backwards 9c 0c 8c 0c 8c 0ang)
(walk_backwards 8c 6c 8c 5c 5c 90ang)
(rad2 8c 5c 8c 9c 5c 90ang 180ang)
(radx 4c 5c 8c 6c 9c 0ang 90ang)
(walk_backwards 8c 6c 8c 5c 5c 90ang)
(radx 8c 5c 7c 9c 4c 90ang 180ang)
(rad2 8c 0c 12c 0c 3c 0ang 90ang)
(walk_backwards 7c 9c 8c 9c 8c 180ang)
(rad2 8c 9c 4c 9c 6c 180ang 270ang)
insert 0c 5c 3c 0ang 7 6 (1)
walk_forward 0c 5c 4c 5c 4c 7c 0ang
radx 4c 5c 8c 4c 1c 0ang 270ang
radx 8c 4c 9c 0c 12c 270ang 0ang
walk_backwards 9c 0c 8c 0c 8c 0ang
radx 8c 0c 12c 1c 4c 0ang 90ang
walk_backwards 12c 1c 12c 0c 0c 90ang
rad2 12c 0c 12c 4c 9c 90ang 180ang

The cost of this path is 38, as the number of steps that are needed to reach the final state. In this first version, only eight Struts are involved since it is not a complete solution yet. Each command is expressing coordinates of each movement for every Strut, providing orientation through angles. This simulation offers the possibility of going ahead and coming back for every single action, linking the name of the command. The textbox is movable and can be increased or decreased. Even if the path has been developed only with four angles, this simulation offers a 360° visualization of the sequence of actions. The result obtained is the following interactive program, showing a graphical representation of this path calculated through PDDL.

Figure 37

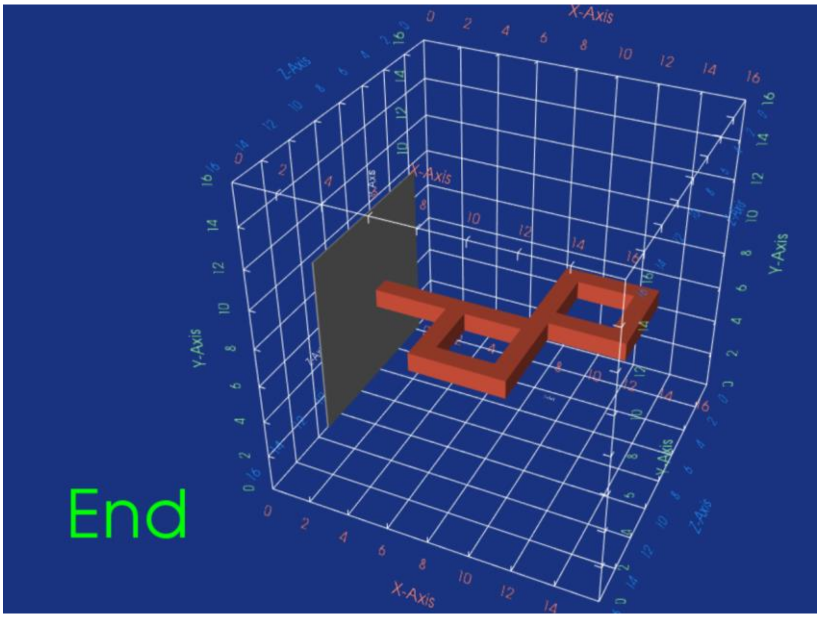


[Source: personal elaboration]

From the initial position of one Strut inside the room in fig. 38, connected to the wall, the simulation will go ahead until the completion of the path elaborated for all Struts. In this prototype, eight Struts are working to realize the desired path. It has been developed into a 3D cube grid, providing a measure of X, Y, and Z axes. In this way, it is possible to evaluate robot positions and movements, observing results needed to improve this WIP with the new version. Thanks to this graphical 3D simulation are, then, possible to have a better understanding of what is thought during its planning. Each Strut has been estimated with a size of four coordinates unit with an orange color. Inside the cube, it is also present a thin grey cube that is the wall from where these robots are inserted inside the room. From a coding point of view, this program has been realized through C++ and with the adoption of VTK geometric objects sources. The only shape used is the cube, as Struts and as a wall. To do this has been declared a *vtkSmartPointer<vtkCubeSource>* for each robot, as well as has been done for Mappers and Actors.

The final position reached with this prototype is in fig. 39:

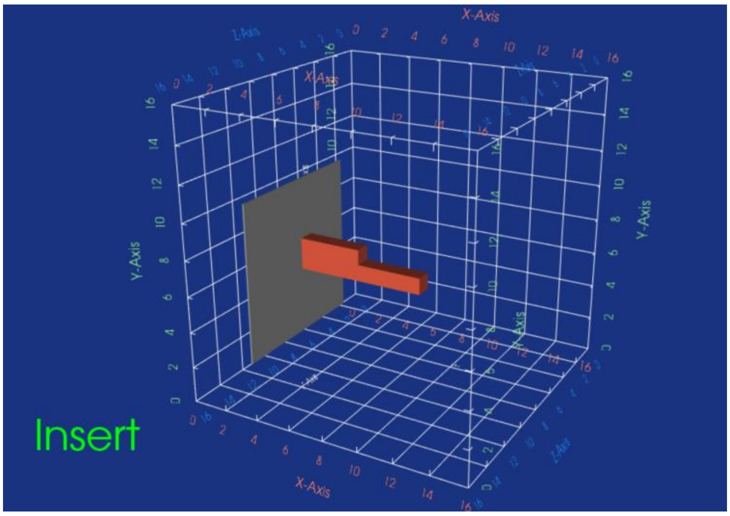
Figure 38



[Source: personal elaboration]

This result corresponds to an asymmetric square composed of seven Struts, creating the path where MTB will walk on. In this representation, movements over the second level of overlapping are not calculated and, for this reason, have this aspect. For showing a visualized definition of commands claimed previously, the other images will show one by one. All the possible steps are not shown since their number is too high. The first is the insert, i.e., the first step starting this simulation. To manage text has been declared the *vtkSmartPointer<vtkTextWidget>*, a suitable solution needing a *vtkSmartPointer<vtkTextRepresentation>* to operate properly. A text Actor, too, will be required to define what to insert inside the textbox. However, the key of this software is the state structure allowing to perform each movement of every single Strut in all the simulation accurately, as this will be explained below.

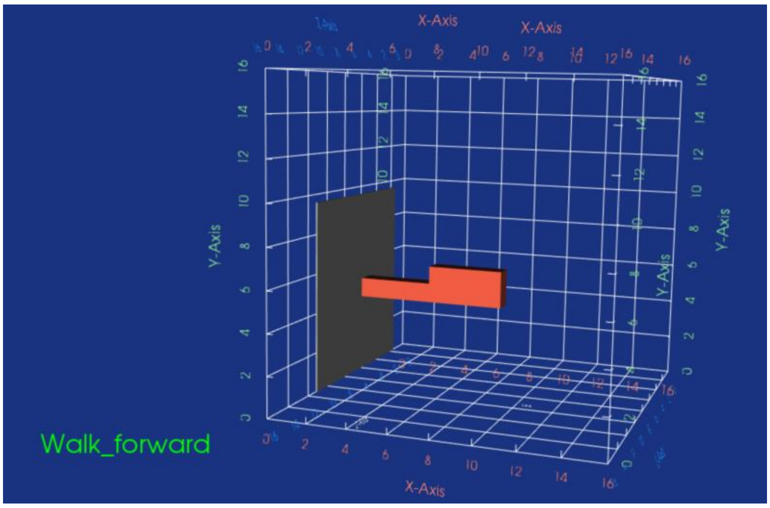
Figure 39



[Source: personal elaboration]

After the insertion of the first Struts, the second movement executed is walking forwards, moving the Struts ahead. It is important to note that this program is made with a full 360° camera, offering the opportunity to see from different angles each movement related to the plan. In the same way, this prototype plan has been developed just with four angles thinking, and, for this reason, is lacking a complete awareness regarding the practical room and robots. In order to be visualized, this program has been rendered with a *vtkSmartPointer* <*vtkRenderer*>, where has been added to all different actors. After this, the *vtkSmartPointer*<*vtkRenderWindow*> was necessary to define the window.

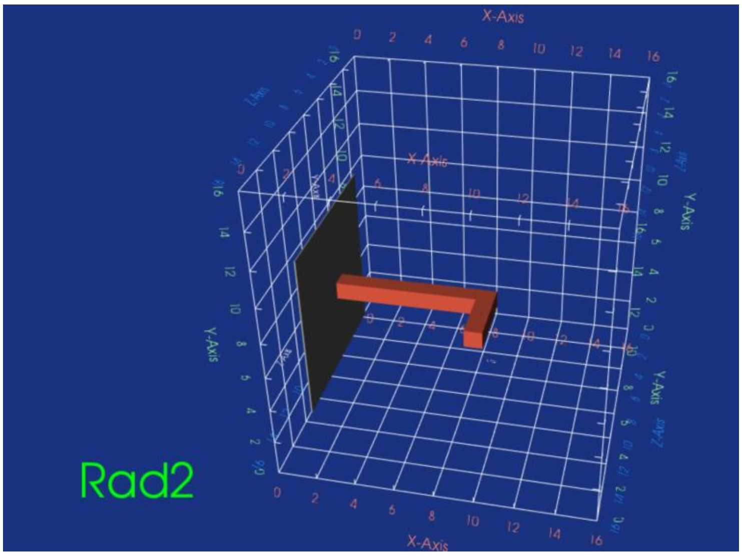
Figure 40



[Source: personal elaboration]

As the Walk_forward, the same is for Walk_Backwards but in the opposite sense. The above image is the step immediately after the first command, the insert. The subsequent step corresponds to a drop to the first level of the previous Strut, rotating its verse of a difference of 90° degrees. This action will be called Rad2, and like previous ones, it will be repeated much time during all the simulation even if in different positions. It is important to note how the 3D grid has been developed, thanks to a useful VTK source called *vtkSmartPointer<vtkCubeAxesActor>*. An easy axes management is possible, defining sizes, orientation, colors, and much more. This source, too, needs to be added as Actor on the Renderer. This one also offers the possibility of setting the Camera suitably with *Azimuth* and *Elevation*.

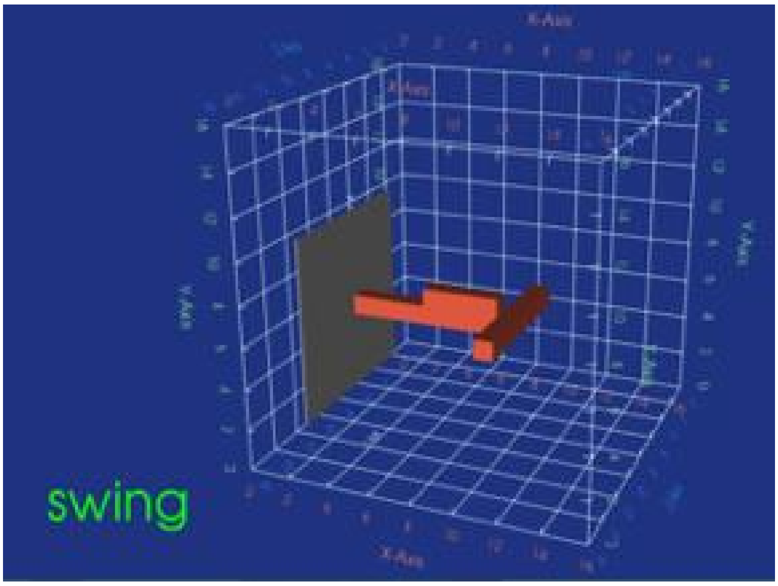
Figure 41



[Source: personal elaboration]

Moving fast to other steps, the other commands remaining are Swing and RadX. Swing can be defined as creating an extension of other Struts, from a unit located above another that is going down to reach the other Strut highness at level zero. On the other hand, RadX is a rotation on the upper level, meaning a Strut direction change but positioned over the first level. The Swing is the fig. 43. For allowing human-computer interaction, it has been set the right arrow and the left arrow to go forward and backward, respectively. This result was possible thanks to the *vtkSmartPointer<vtkRendererWindowInteractor>*, and Callback functions defined one by one for every Strut.

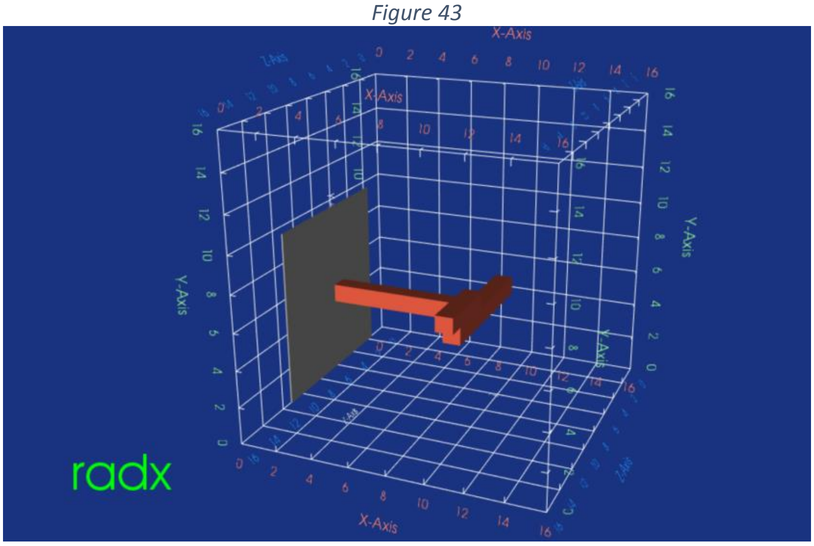
Figure 42



[Source: personal elaboration]

As can be sawed, the Strut has gone down, extending the size of the lower level one. This finding is shown from the two Strut positioned as extremity from a vertical point of view in the X-Axis. On the other hand, RadX is a rotation based on the higher position. The image shows the following action after the Swing, manifesting the change in direction on an upper level. As previously stated, the human-computer interaction it is here possible thanks to Callback functions. In VTK this type of function is realized through three different parts: *Keypress Callback* functions declared at the start of the program, where are defined parameters as the *caller* and the *clientData; vtkSmartPointer*<*vtkCallbackCommand*> to connect the cube source with the relative Callback function and adding an Observer; other Keypress Callback functions where the main logic is written. Here, calling a particular Strut and relating that to a keypress event as of right or left arrows, it has been modeled the state structure allowing this software to work correctly. From a state to another, a Strut position will change, going ahead if the state number is increasing by pressing the right arrow and will go backward if the number will decrease by pressing the left arrow. In this way, the repetition of single movements can be executed many times, consequently allowing experts to improve their planning. This structure has been realized not only for cubes but for text too. In fact, for each state, not only a Strut movement is happening, but also a change in the textbox to show the corresponding command being executed. However, the state amount resulting is higher than plan steps. This result is why in the software, this is needed to perform each movement separately since in some state's number was happening more than just one. Switching those particular states by adding new ones has allowed executing a proper simulation where all Struts commands are sequential.

Figure 43



[Source: personal elaboration]

However, through this simulation has been possible to continue the research about path optimization performed by other experts in PDDL. From the 2+1 program, observing movements and robots with eyes and not only supposing them, but it has also been the key to realize the sequent path, a complete 3D simulation. Best results are coming from joining efforts from different subjects, and this is why by using a graphical simulator, researchers more accessible find answers to their problems. In conclusion, thanks to a simulation of 38 steps forward and 38 steps backward, it has been provided the first 3D support to sustain planning-problem and PDDL arguments and studies.

The source code of this program has been published on GitHub and can be retrieved at the following link:

https://github.com/MikeRendine/3D-graphical-simulator

4.6 3D Plan graphical simulation

The last simulator has been developed from a complete 3D path calculation, since during its formulation has been taken in account vertical movements and other two angles too. In this representation, Struts can perform rotation on the Y axe and reaching a highness level greater than the 2+1 version. Moreover, other angles are 450° and 540°, providing a proper prototyping. The other difference from the previous one is that this one has been written from what learned by the previous simulation and consists in many other steps than 2+1 version. In fact, the path is composed by 84 steps and also this program is able to execute each movement going ahead and with a return. A textbox is still linked to show which command is being elaborated. As before, the main part of this software is the state structure realized through Callback functions, which is what allows every Strut to move forwards and backwards on the right or left arrows press event. It is important to note how this simulation modeling is highly more complex than the previous one, since must be managed much more robots performing actions that are more synergic and switching more often from a Strut to another. The plan used to realize the graphical simulation is:

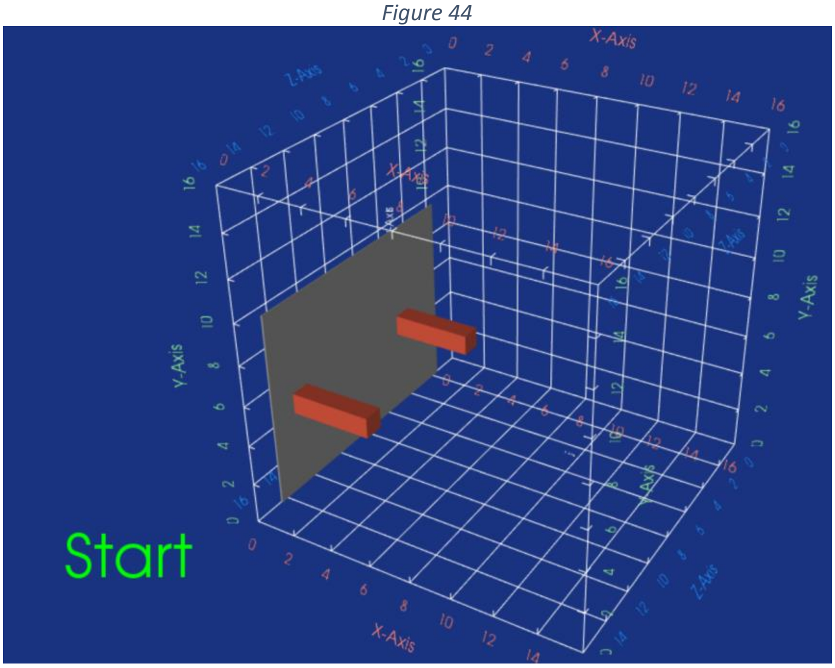
```
(insert 0c 8c 1c 0c 3c 0ang 17 16)
(rad2 0c 8c 1c 4c 8c 0c 3c 5c 0ang 270ang)
(insert 0c 8c 1c 0c 3c 0ang 16 15)
(radx 0c 8c 1c 4c 7c 1c 3c 4c 0c 0ang 270ang)
(walk_backward 4c 7c 1c 4c 8c 1c 4c 5c 0c 270ang)
(insert 0c 8c 1c 0c 3c 0ang 15 14)
(rad2 4c 8c 1c 4c 4c 0c 5c 7c 270ang 0ang)
(radx 0c 8c 1c 4c 7c 1c 3c 4c 0c 0ang 270ang)
(insert 0c 8c 1c 0c 3c 0ang 14 13)
(walk_backward 4c 7c 1c 4c 8c 1c 4c 5c 0c 270ang)
(radx 4c 8c 1c 5c 4c 1c 5c 8c 0c 270ang 0ang)
(radx 0c 8c 1c 4c 7c 1c 3c 4c 0c 0ang 270ang)
(walk_backward 4c 7c 1c 4c 8c 1c 4c 5c 0c 270ang)
(walk_backward 5c 4c 1c 4c 4c 1c 8c 7c 0c 0ang)
(rad2 4c 4c 1c 8c 4c 0c 7c 7c 0ang 90ang)
(insert 0c 8c 1c 0c 3c 0ang 13 12)
```

(radx 4c 8c 1c 5c 4c 1c 5c 8c 0c 270ang 0ang)
(rad1 0c 8c 1c 4c 8c 1c 0c 4c 3c 0ang 450ang)
(walk_backward 5c 4c 1c 4c 4c 1c 8c 7c 0c 0ang)
(radx 4c 4c 1c 8c 5c 1c 7c 8c 0c 0ang 90ang)
(walk_backward 8c 5c 1c 8c 4c 1c 8c 7c 0c 90ang)
(rad2 8c 4c 1c 8c 8c 0c 7c 5c 90ang 180ang)
(radwn 4c 8c 1c 5c 8c 1c 5c 4c 8c 0c 0ang)
(walk_backward 5c 8c 1c 4c 8c 1c 8c 7c 0c 0ang)
(radx 4c 8c 1c 8c 7c 1c 7c 4c 0c 0ang 270ang)
(swing 8c 7c 1c 8c 3c 0c 4c 0c 270ang 270ang)
(insert 0c 8c 1c 0c 3c 0ang 12 11)
(rad1 0c 8c 1c 4c 8c 1c 0c 4c 3c 0ang 450ang)
(insert 0c 8c 1c 0c 3c 0ang 11 10)
(radwn 4c 8c 1c 5c 8c 1c 5c 4c 8c 0c 0ang)
(swing 5c 8c 1c 9c 8c 0c 8c 12c 0ang 0ang)
(rad1 0c 8c 1c 4c 8c 1c 0c 4c 3c 0ang 450ang)
(radwn 4c 8c 1c 5c 8c 1c 5c 4c 8c 0c 0ang)
(walk_backward 5c 8c 1c 4c 8c 1c 8c 7c 0c 0ang)
(rad1 4c 8c 1c 8c 8c 1c 0c 4c 7c 0ang 450ang)
(insert 0c 8c 1c 0c 3c 0ang 10 9)
(walk_forward 0c 8c 1c 1c 8c 1c 3c 4c 0c 0ang)
(walk_forward 1c 8c 1c 2c 8c 1c 4c 5c 0c 0ang)
(walk_forward 2c 8c 1c 3c 8c 1c 5c 6c 0c 0ang)
(rad1 3c 8c 1c 7c 8c 1c 0c 4c 6c 0ang 450ang)
(rad15 7c 8c 1c 8c 8c 5c 5c 4c 450ang 180ang)
(insert 0c 8c 1c 0c 3c 0ang 9 8)
(radx 0c 8c 1c 4c 7c 1c 3c 4c 0c 0ang 270ang)
(walk_backward 4c 7c 1c 4c 8c 1c 4c 5c 0c 270ang)
(insert 0c 8c 1c 0c 3c 0ang 8 7)
(radx 4c 8c 1c 5c 4c 1c 5c 8c 0c 270ang 0ang)
(radx 0c 8c 1c 4c 7c 1c 3c 4c 0c 0ang 270ang)
(insert 0c 8c 1c 0c 3c 0ang 7 6)
(walk_backward 4c 7c 1c 4c 8c 1c 4c 5c 0c 270ang)
(walk_backward 5c 4c 1c 4c 4c 1c 8c 7c 0c 0ang)
(radx 4c 4c 1c 8c 3c 1c 7c 0c 0c 0ang 270ang)
(walk_backward 8c 3c 1c 8c 4c 1c 0c 1c 0c 270ang)
(rad1 8c 4c 1c 8c 5c 1c 0c 4c 1c 270ang 450ang)

(radx 4c 8c 1c 5c 4c 1c 5c 8c 0c 270ang 0ang)
(radx 0c 8c 1c 4c 7c 1c 3c 4c 0c 0ang 270ang)
(walk_backward 4c 7c 1c 4c 8c 1c 4c 5c 0c 270ang)
(swing 4c 8c 1c 4c 9c 0c 5c 12c 270ang 90ang)
(insert 0c 8c 1c 0c 3c 0ang 6 5)
(radx 0c 8c 1c 4c 7c 1c 3c 4c 0c 0ang 270ang)
(insert 0c 8c 1c 0c 3c 0ang 5 4)
(radx 0c 8c 1c 4c 9c 1c 3c 12c 0c 0ang 90ang)
(walk_backward 4c 7c 1c 4c 8c 1c 4c 5c 0c 270ang)
(walk_backward 5c 4c 1c 4c 4c 1c 8c 7c 0c 0ang)
(swing 4c 4c 1c 3c 4c 0c 7c 0c 0ang 180ang)
(radx 4c 8c 1c 5c 4c 1c 5c 8c 0c 270ang 0ang)
(insert 0c 8c 1c 0c 3c 0ang 4 3)
(walk_backward 5c 4c 1c 4c 4c 1c 8c 7c 0c 0ang)
(rad1 4c 4c 1c 8c 4c 1c 0c 4c 7c 0ang 450ang)
(rad15 8c 5c 1c 8c 4c 5c 7c 4c 450ang 90ang)
(radx 0c 8c 1c 4c 7c 1c 3c 4c 0c 0ang 270ang)
(walk_backward 4c 7c 1c 4c 8c 1c 4c 5c 0c 270ang)
(radx 4c 8c 1c 3c 4c 1c 5c 0c 0c 270ang 180ang)
(insert 0c 8c 1c 0c 3c 0ang 3 2)
(walk_backward 3c 4c 1c 4c 4c 1c 0c 1c 0c 180ang)
(rad1 4c 4c 1c 5c 4c 1c 0c 4c 1c 180ang 450ang)
(radx 0c 8c 1c 4c 7c 1c 3c 4c 0c 0ang 270ang)
(walk_backward 4c 7c 1c 4c 8c 1c 4c 5c 0c 270ang)
(rad1 4c 8c 1c 4c 4c 1c 0c 4c 5c 270ang 450ang)
(rad15 5c 4c 1c 4c 4c 5c 7c 4c 450ang 0ang)
(insert 0c 8c 1c 0c 3c 0ang 2 1)
(walk_backward 4c 9c 1c 4c 8c 1c 12c 11c 0c 90ang)
(rad1 4c 8c 1c 4c 7c 1c 0c 4c 11c 90ang 450ang)
(rad1 0c 8c 1c 4c 8c 1c 0c 4c 3c 0ang 450ang)
(rad15 4c 7c 1c 4c 8c 5c 5c 4c 450ang 270ang)

As previously stated, the total cost for this plan is 84 and involves two more commands than the 2+1 version. These two are relative to vertical movements, and this plan corresponds to an almost complete definitive version of the Struts path plan. For this reason, many other robots are included reaching an amount of 17 Struts involved. That means a significant size of the developed program, since managing so many different robots is difficult and because there are so many movements that have to be executed by each one of these seventeen robots. What is resulting is an incredible row length, manifesting 84 steps forward and 84 steps backward for a total over 160 movements performed. The result obtained is subsequent in the initial state inside the room.

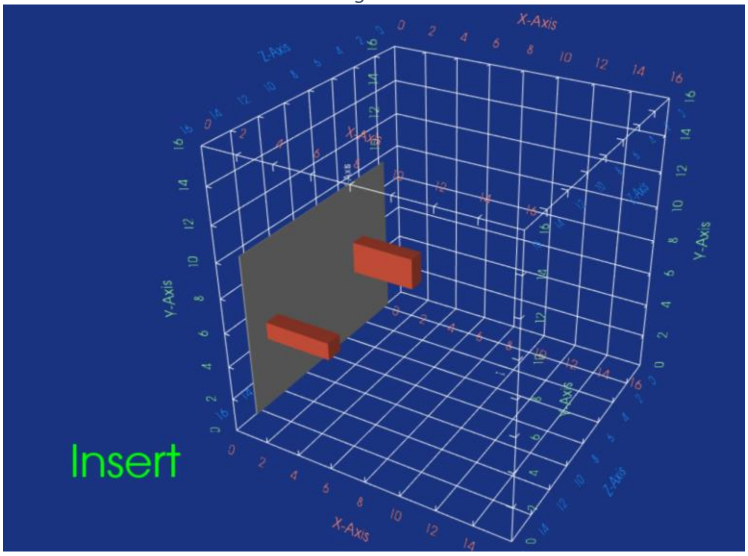
Figure 44



[Source: personal elaboration]

From a different initial position, chosen by researchers as estimated through PDDL, this simulation starts with two Struts placed in the room near the wall. The cube grid remains the same, as for other aspects of the simulation program. The only thing changing from the previous one is the plan and how experts have introduced vertical movements, 450°, and 540° angles degrees. The first step, here, corresponds still to an Insert command but will go differently in the next positions. As before, have been declared *vtkSmartPointer<vtkCubeSource>* representing Struts in the main. In every case, in this software, their number is more than double the previous one. A wall cube has been defined, too, in order to offer a proper room simulation. Above the main, *Keypress Callback* functions and all different libraries needed are included.

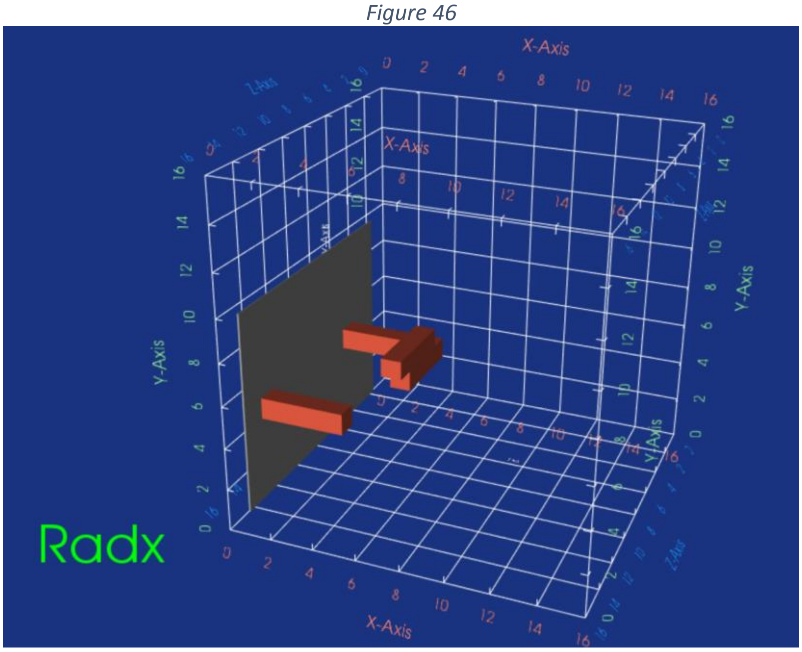
Figure 45



[Source: personal elaboration]

As it is possible to see in fig. 46, after the Insert, the path takes a different orientation, reputed as the best one after experts' analysis. They changed the previous plan since it was found out how structuring in this way was manifesting many benefits. Despite all the aspects inside the simulator that are not changed from the 2+1D version, what is changed is the Struts plan studied. Thanks to the previous simulator, it has been established that path was not optimal, and for this reason, a new approach was needed. This result has been found out with this new plan. As all VTK programs, also this one needed Sources, Mappers, and Actors to be run. The difference from before is that an incredible number of them have been declared here to simulate all this plan. From 3000 rows of the first program, this new arrive beyond 6000.

Figure 46

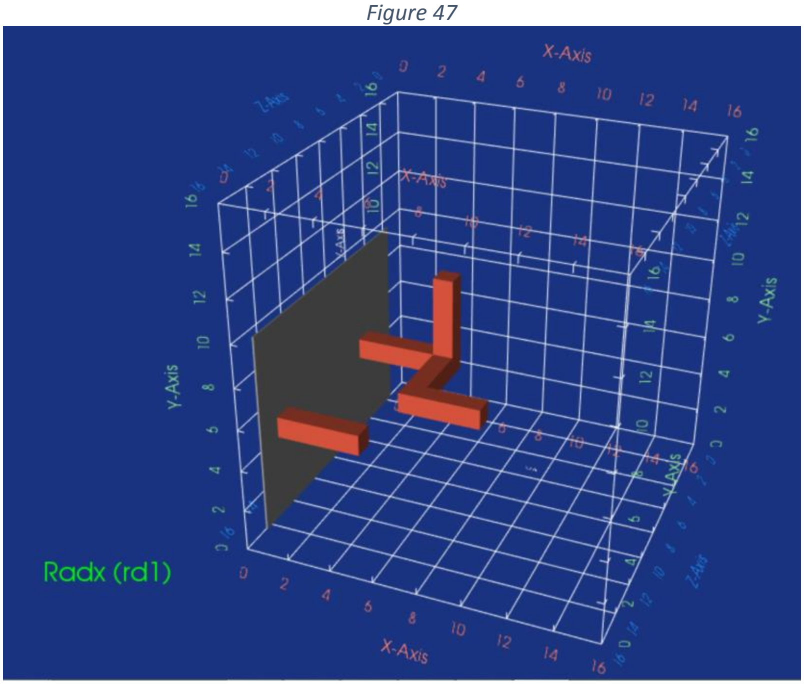


[Source: personal elaboration]

In the next steps of the simulation, Struts will place inside the room, as it is shown in the above image. Many different positions are involved in this simulation, and this is why it is not possible to manifest every single movement. The difference from the previous prototype, until here, is how it is structured in the initial position. While before there were two Struts linked like a queue, here are separated, and the second is not used until the last part. From a length of eight coordinates, the first movement is expressed on just four.

In the following image, it is possible to see the new command regarding vertical movements, called RD1. This one is the first vertical command added in this prototype version where are allowed all types of actions and not only those one without overpassing the second level. Thanks to the new possible actions and remodeling of previous ones, a new plan of 84 steps have been provided in order to develop this simulator. However, the state structure is the heart of this program, too, and customizing the simulation with all these steps resulted in high complexity.

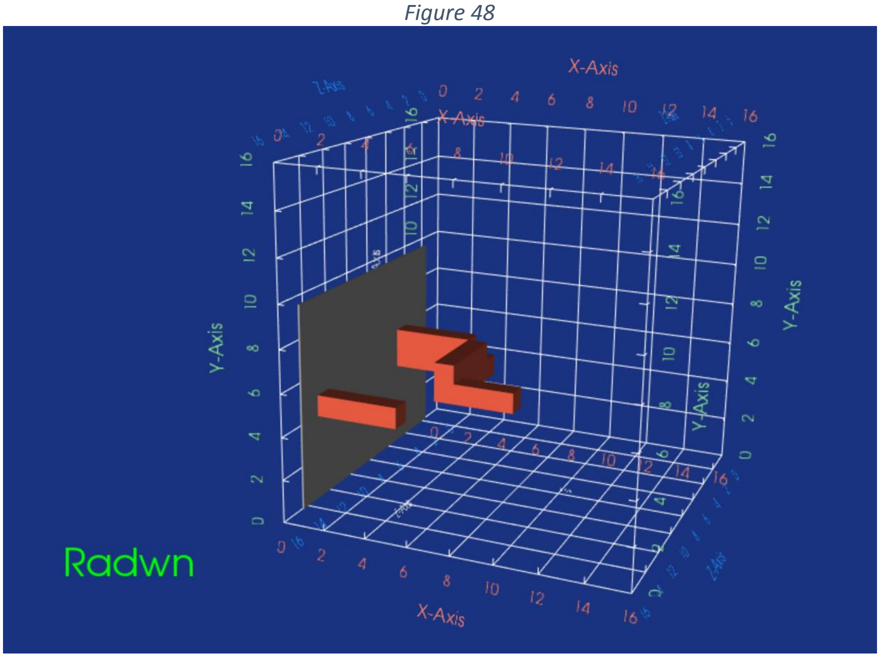
Figure 47



[Source: personal elaboration]

The other new command, related to vertical updates, is the Radwn, since if one Struts is up somehow should be returned down. It is the different command of before since one is needed to act and the other the inverse. For what concerns the state structure, as before the number of states was higher than the plan steps, the same is for this new software. It depends on the synergic degree of Struts movements, i.e., steps executed sequentially one by one from all different robots. When a Strut performs more than one just action, a state linear sequence is sufficient, but when two actions are executed from two different robots, only switching the state number allows not to execute chronologically together those two movements. This result is the reason why in this program, with much more synergy between Struts, the state number has reached a value of 144 steps forward and 144 steps backward. From here, it is clear the complexity of this realistic simulator.

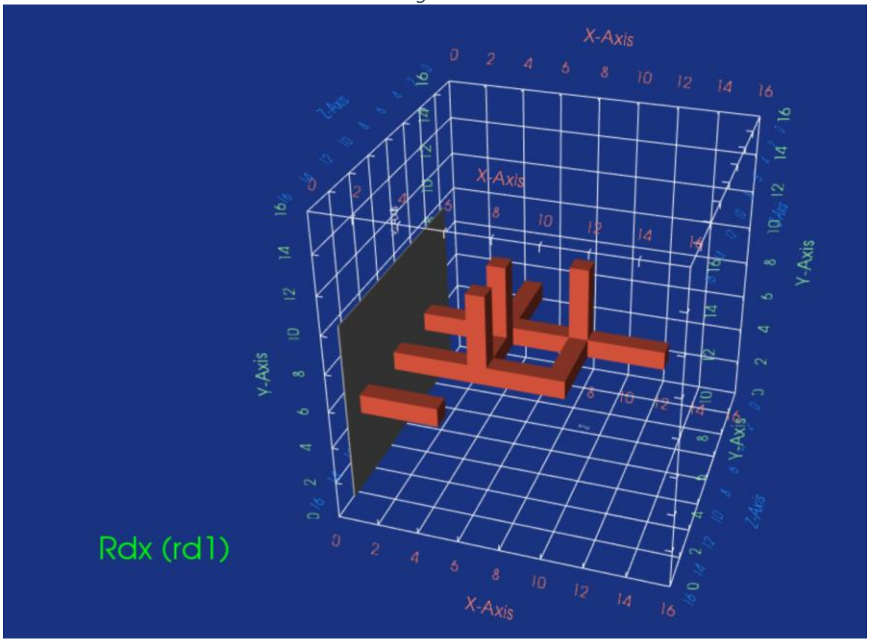
Figure 48



[Source: personal elaboration]

After this, many steps are performed due to plan complexity and the interaction between all the 17 different Struts. The difficulty is coming from the synergy between different Struts, having to execute an action possible only following another action of a different robot. Since the result is to construct a full cube building where MTB can walk on, a state near the final state is the following. From here, it is possible to see part of the construction that all 17 Struts will participate in building. Vertical movements are assuming great importance since the MTB should reach high areas were to execute actions. To understand all command executed, also a textbox with command name is shown, and it works with a state structure too. Since the state is 144, as was stated before, the textbox has been modeled for all those times too.

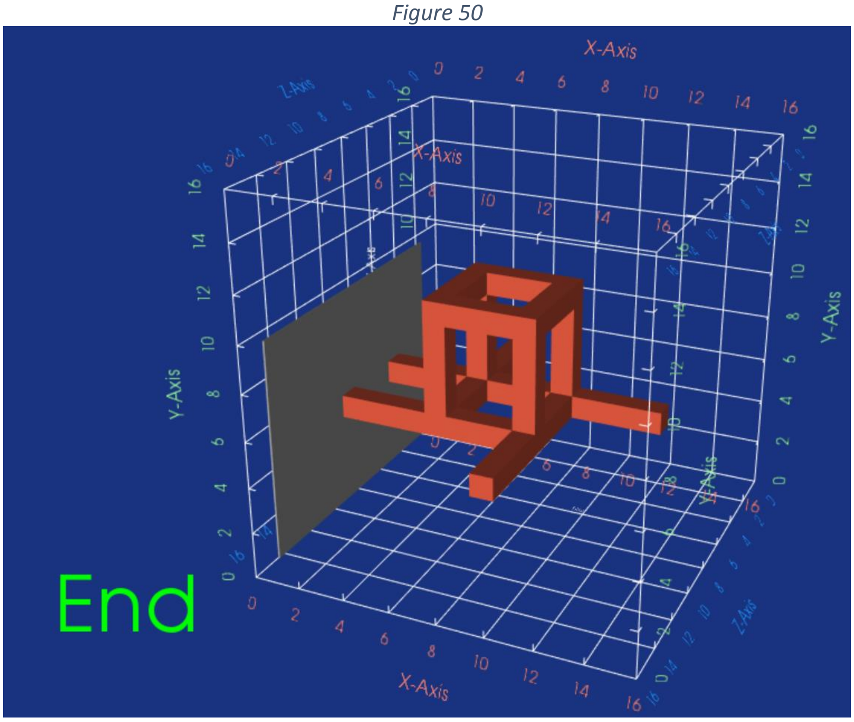
Figure 49



[Source: personal elaboration]

Finally, the last position is the full cube needed for the MTB to perform its actions inside each required position in the room. Many steps have been executed to achieve the target that is the best and optimal solution for Struts, to create a valid path autonomously. This final state is emerging from Struts synchronization, by the succession of a single command executed by a robot, immediately followed by another command executed by another Strut. Only in this way has it been possible to realize a structure as the one manifested in the following image. For achieving this target, an interaction was needed, and as before, this has been set with keypress events related to right and left arrows. For coding this functioning, Callback functions have been used here too in the same way of the previous software: defined at the start, connected with the object in the middle, and set the main state logic inside the end part.

Figure 50



[Source: personal elaboration]

Here represented, there is the final state of the full cube. On this, MTB will walk and perform its actions inside the room, and this is developed just for this particular application. After this start with the first implementation, Connect-R will also be based on different and various environments. Each situation will be needed to study externalities and write an optimal plan, able to be executed efficiently. Measures, sizes, and obstacles will have to be defined and analyzed to perform excellent service for each application. This finding is just the start of what Connect-R will offer in the future and to all possible implementations for what will be used.

The source code of this program has been published on GitHub and can be retrieved at the following link:

https://github.com/MikeRendine/3D-graphical-simulator

4.7 Struts planning-problem and PDDL

In order to program the Struts path plan, team experts have adopted the Planning Domain Definition Language (PDDL). It is a recent attempt to standardize the planning domain, and problem description language, invented by Drew McDermott in 1998, and STRIPS, ADL, and many others form it. Before this date, many different languages were used to code Artificial Intelligence problems, and there was an issue with them regarding the planning competition since autonomous system performance was estimated on benchmark problems. This effect was meaning difficulty in Artificial Intelligence progress, due to efforts from various people working on different languages, not having the possibility to join their findings and comparing their discoveries. The result was PDDL development, and it was the key to open the International Planning Competition (IPC) in years from 1998 to 2000. This solution is an attempt to standardize AI planning languages and a common standard for problem definition. Through PDDL, Artificial Intelligence progress has done many steps forward, uniting, and concentrating the efforts of all minds coming from all over the world.

"*The adoption of a common formalism for describing planning domains fosters far greater reuse of research and allows more direct comparison of systems and approaches, and therefore supports faster progress in the field. A common formalism is a compromise between expressive power (in which development is strongly driven by potential applications) and the progress of basic research (which encourages development from well-understood foundations). The role of a common formalism as a communication medium for exchange demands that it is provided with clear semantics.*[37]"

However, PDDL benefits come from how it is structured its functioning and from an accessible model subdivision of the planning-problem among:

- Domain description
- Problem description

This separation means an intuitive and easy-to-understand differentiation of typical elements characterizing an Artificial Intelligence problem. Single Domain can have more than just one Problem, and connecting them, a PDDL model of a planning-problem is developed. The result offered by this language

[37] Fox, M. (2002). *Modelling Continuous time-dependent Effects.* In academia.edu.

is only a planning-problem model, and to be solved, it needs a planner, a software able to do it optimally through particular planning algorithms. What emerges from the planner is usually a plan, composed of a sequence of actions solving the planning-problem. More in detail, both Domain, and Problem descriptions are translated into PDDL thanks to parameter definition. For what concerns the Domain, they are:

- Domain-name
- Requirements
- Object-type hierarchy
- Predicates
- Actions
    - Parameters
    - Preconditions
    - Effects

After the name attributed to the Domain correlated with the planning-problem, the first step is to introduce requirements that will declare to the planner the elements that the PDDL model is adopting. The following step is defining a class hierarchy as in object-oriented programming (OOP), thanks to types. Even if they are constant and static, with the last two elements come PDDL dynamicity. In fact, predicates correspond to templates for logical facts, and actions are what will effectively happen. It is important to note that actions are composed of three parts: parameters that will be analyzed, preconditions allowing executing the action, and the effects connected to what has been done.

On the other hand, there is the Problem description of the planning-problem, and it is structured with other model-elements. They are:

- Problem-name
- Domain-name
- Objects
- Initial state
- Goal state

As before, a problem-name definition must be done. Moreover, since the Problem description depends on the Domain description, its name should be declared. Objects own a crucial role since they are the real elements for the planning-problem that should be conjectured. The last two aspects are the states of how the planning-problem must be at the start and the end. In this way, all possible combinations are attempted until reaching the goal needed.

For what concerns planners, they are tools related to PDDL required to elaborate the optimal plan regarding the planning-problem defined. They have separated software developed to solve PDDL models, and they work through search algorithms. By customizing planners, it is possible to declare the best search path algorithm wanted and not only standard ones.

However, PDDL is playing a vital role inside the Connect-R project, being used to plan the Struts sequence of actions. Through its implementation, project signs of progress are going really fast, and results are starting to come, reaching almost the end of this phase. Nevertheless, what should happen if a different standard was used to program Connect-R? In the next paragraphs, it will be taken into account the experimental attempt to develop a parallel solution that can be substituted for what PDDL and planners offer. In this way, a benchmark will be performed, showing differences and why PDDL has been chosen as the AI standard language.

4.8 Benchmark: PDDL or ad-hoc software?

During the six months at the Royal Holloway University of London, the second type of task executed was related to the development of a parallel system capable of simulating opportunities offered by PDDL and relative planners. The purpose of this comparison is to evidence why PDDL has been chosen by experts, showing possible advantages and disadvantages in using a different language. The subject of this benchmark is Connect-R, meaning the calculation of the Struts autonomous path developed with PDDL. Its result will be compared to the output of the ad-hoc software realized, showing strengths and weaknesses.

This parallel solution has been developed, taking into account both the PDDL model and planner, i.e., the problem definition and the search algorithm needed to provide an optimal plan. In order to write this, it was needed a different system able to integrate those two parts and to offer a unique solution. For developing this program, it has been chosen to use the Java programming language and the Eclipse IDE. This alternative software has been realized and tested two times in different cases. The prototype was addressed to solve the Logistic case, a typical example of the logistic problem. The second one was implementing the Connect-R case, and it has offered an alternative solution to PDDL and planners to solve Struts' optimal path.

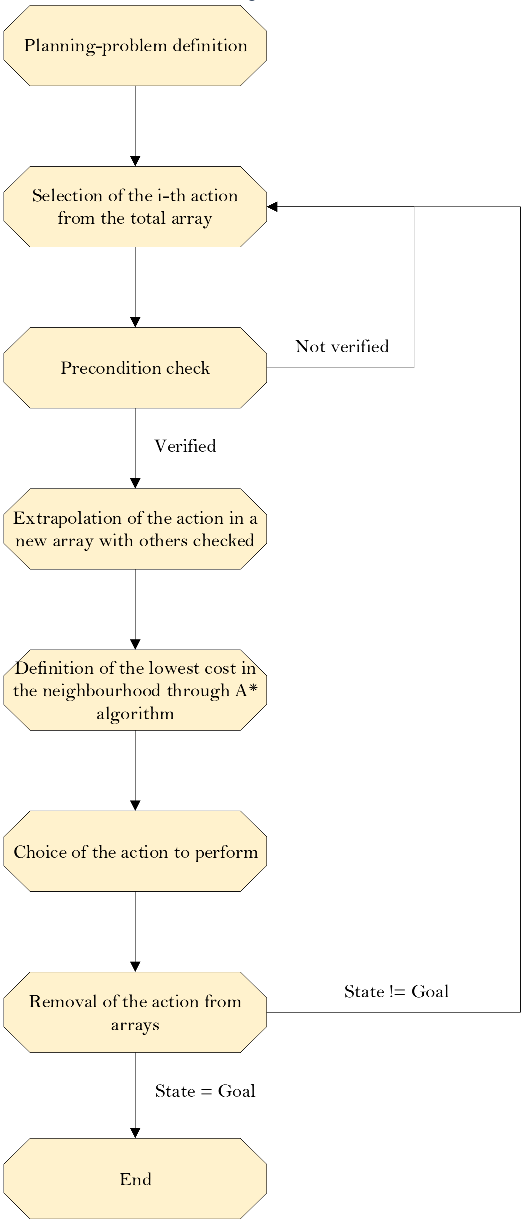
More in detail, to develop this program, two approaches have been taken:

- Translating the PDDL problem definition, to specify the case
- Executing a proper search strategy to find the optimal result, as a planner

For providing an effective and well-performing integration, it was needed to adapt all the aspects coming from PDDL into a different form and, subsequently, permit the autonomous choice of the optimal actions plan. For realizing this program, four classes have been created: State, Node, Action, and Main. In the State class is defined which parameters compose a state, i.e., where Struts are located in that particular moment. In the Node class, there is the constructor of a node, containing state, action e the relative cost. In the Action class, there are action preconditions beyond the constructor. Lastly, in the Main class is to write the main logic, defining the problem by actions, objects, and states from a side, and the iterative mechanism of an optimal path search strategy from the other.

In this ad-hoc program, PDDL objects and predicates are represented differently, declaring and structuring objects like arrays, including in them all logical object movements. On the other hand, actions have been defined in a similar PDDL way: they have parameters, preconditions, and effects. When an action is called, if preconditions are verified and if it has the lowest cost, then effects will be added to the state. The key to this program is the collection of parameters inside the states. There are two leading states, an initial and a goal one. For each action applied, parameters inside the initial state will change and stored, and this will be a loop until these will not be the same in the goal state. From a technical point of view, the logic behind this software can be described in some step as it is shown in fig. 52:

Figure 51



[Source: personal elaboration]

The first one is the planning-problem definition. Here have been declared objects movements into an array, all the actions in the plan, the initial, and the goal state. To permit efficient functioning, all of these objects' movements have been parsed through the array position, and actions are all included in an array. After this, there is the main logic that performs calculations finalized to find the optimal solution to the relative problem. This part corresponds to different logical steps coming in sequence. It is, then, introduced the loop that will continue until when the state will become equal to the goal. Inside this, one action per time from the array is checked to verify if satisfy state requirements. If the result is positive, this one will be added into a queue with other possible found out actions. Here, through the application of search algorithms, it is discovered which has the lowest cost of the neighborhood, and the action to perform is chosen. It is important to evidence the elected action removal from these arrays, being no more eligible in the next iteration. At the end of the process, if the state equals the goal, the plan is finished, otherwise it will continue with other actions.

To explain how search strategies have been implemented, recalling Graphs Theory is necessary. Thanks to the implementation of a Node and State classes, it has been possible to perform an autonomous decision system. It calculates all the possibilities that can be performed from the initial condition, storing in the state the action effect, and inserting this state in the new node created each repetition. In this way, a decision three about the problem is drawn independently, deciding the actions sequence with a customizable strategy.

Graph traversals and search algorithms introduced in this ad-hoc program correspond to:

- A*
- Dijkstra

The first one is based on an algorithm finding the optimal path from a starter node to a goal one. It is structured with two parameters "g" and "h", defining them, respectively, as the movement cost from the starter node to the current one and as the heuristic value, estimated in the distance from the current node to the last one. Its formula can be described as:

$$f(n) = g(n) + h(n)$$

It is used to find the shortest path in many various cases, and A* is probably the most common and popular technique used in path-findings. The presence of almost a consciousness is what makes this algorithm so different from others. In this ad-hoc program, "g" has been calculated as the total cost for each action executed from the starter node. On the other hand, "h" is estimated as the sum of the counted difference between the parsed Strut location parameter inside the goal and current state. The result is that, for each node, it is possible to calculate the distance from the end and to provide a heuristic approach to this program. Secondly, the Dijkstra algorithm is based just on finding the minimal path cost. This one is another very trending technique, but differently from A*, it is not considering a heuristic point of view too, and this is why the equation is described as follow:

$$f(n) = g(n)$$

Therefore, it is clear the opportunity of switching from a search strategy to another in order to find out the optimal plan: just by assuming to zero the heuristic parameter, the plan obtained is the one calculated with a Dijkstra technique.

This program is completely adaptable for any kind of planning-problem and can be used or modified with different search strategies very easily. An example, it has been its application first on the logistic case, and after, on the Connect-R plan. From the comparison between this last one and the original version, results are showing why PDDL is the most common standard language for Artificial Intelligence, even if some advantage can come from the ad-hoc version. The first thing needed to pay attention is the difference in code length between the ad-hoc alternative and the classic one. While PDDL is an already structured language for automation problems and its declaration result mainly short, another language like Java does not have direct commands to define what is needed in these types of cases.

In addition, the number of rows written to define the planning-problem as PDDL was already more significant, but since the program developed is comprehensive of the planner part too, his length results immensely more significant than a classic one. This fact means not only a nonoptimal code writing but also a cost-time waste for those stakeholders desiring to invest. Using a different language from PDDL into robotics programming seems then not so well-performing in terms of time and costs. Differently, through the ad-hoc program developed, there is a possibility of an integrated solution, no more depending on two different actors like PDDL and planner. This effect could be translated into a more compact framework and a lower software execution time. Despite this, they are infinitesimal time measures, and this advantage does not have a high impact.

In conclusion, thanks to this experimental comparison between PDDL problem-planning and ad-hoc software, it is clear why this language is predominant and that experts from the Connect-R project have found the best way to develop their own creature.

The source code of this program has been published on GitHub and can be retrieved at the following link:

https://github.com/MikeRendine/ad-hoc-problem-planning

Conclusions

In the discussion, it was exposed to what the student developed to support the development of the project. As for the graphic simulations, three different ones have been created. This effect is due to the continuous updating and improvement of the tasks plan developed by the researchers, who optimized the previous result by graphically visualizing the problem. First, a 2D simulator was created in Java via Java Swing, and then we moved on to 3D modeling through the use of VTK. Two other simulations have been developed here, the first being linked to a structured plan with limitations of vertical movements and degrees of orientation, and the second a version without constraints. The final result is the "full cube" that the Struts will form and where the MTB can move on. As for the second category, the software was created using Java dedicated to being a substitute for the system used by researchers, namely the PDDL and the related planner. In this ad-hoc program, both the critical functionalities of the definition of the typical problem of the PDDL and the search algorithms, such as A-star and Dijkstra, necessary for the resolution of the optimal path were translated. The result emerged is that although the ad-hoc program offers greater compactness and speed of resolution for the problem under examination, the PDDL was created to intervene in these specific cases of robotics. It is, therefore, more suitable, due to the effort necessary to develop a problem and its optimization with a single ad-hoc program, than using the features offered by the PDDL and the planners.

Conclusion

The intent of this paper was traversing a path to analyze Connect-R potential, from both a managerial and a technical point of view. By assessing the scope where this project arises, two different industries have been examined, Artificial Intelligence and Nuclear energy. These circumscribe the external environment in which Connect-R is born, although future emerged perspectives place its applicability range in many other industries and contexts. This project is still experimental, and the candidate has performed several tasks in support of its development during the six months passed at the Royal Holloway University of London. These are robots graphical simulations and a benchmark among the task-planning system currently used by researchers and an ad-hoc one, in order to demonstrate both benefits and disadvantages.

From a discussion of what artificial intelligence represents today and its current applications, it has been tried to locate the context where Connect-R operates. Many completely autonomous solutions have been released in the market, but progress possibility is still vast.

Through a market analysis on the AI, it has been demonstrated that it has two different impacts on the economy, a direct and an indirect one. While the former directly depends on the actual commercialization of these products and in which sectors have been adopted in a higher measure, the second involves all those consequences deriving from the introduction of automatic systems in that particular industry. Some examples could be possible capital increases due to funding in R&D, generational workforce change, necessary implementation costs, and many other externalities. The result of this analysis concluded an overall positive effect, meaning a general welfare increase.

Despite this, the problem lies in the fact that the positive and negative effects could be asynchronous from a chronological point of view. This result would imply a probable period of stagnation and loss for the economy, even if it healed over time. Other negative aspects that emerged from the affirmation of AI could be the raise of the distance between small and large companies before, but between developing and developed countries too. This reason is why barriers are obstructing AI, as the distrust of companies and resistance to change.

In each case, AI potential emerged from the analysis seems to be only at the beginning, and a long way is going to be required to achieve new goals. One of these will be Connect-R, an AI application of excellent prospects owning the ability to upset many current industries.

The project has been funded by an external government body called Innovate UK. Together with the UK Atomic Energy Authority as an investor, different Universities and companies have been involved in its development. Its first implementation is aimed at the start of 2021, and it is applied to a nuclear decommissioning particular case. The connect-r purpose is to provide structures in extremely unstructured environments, meaning a robotic solution capable of replacing human operators in those working areas that are hazardous and of difficult access for a person. This fact is possible through the high level of task variability and accessibility that this machine can offer.

In order to make feasible this complete autonomous manufacturing in risky contexts, a supporting innovative technical framework allowing to perform those activities is required. It consists of two main concepts, the self-building modularity, and the dualistic logic. While the first one is what permits the full autonomous functioning, the second is what attributes to these machines, their extensive range actions in complex environments. Two different robots with different tasks compose Connect-R: the Multi-task Bot and the Struts.

This event is an excellent innovation since some robotic solution is already adopted in nuclear decommissioning, but no one offers these same key-aspects of this project. All existing technologies are limited to supervised, or remoted control, and workers are always included in their operational process. Results are high costs, involving an expenditure both for robots and for human operators. Thanks to Connect-R, this will be different, proposing a system capable of functioning autonomously with meager implementation costs.

For all these reasons, many other implementation sectors have been hypothesized: Oil and Gas, Mining, Agriculture, and Space. The effects that could be had in these industries would be very positive, representing optimal results in terms of efficiency and safety.

Furthermore, precisely from the prospects is where the greatest strength of Connect-R arrives, i.e., being one day no longer applied only to extreme environments but also to normal activities in the construction sector. The innovation would be shocking and would be even more so from the idea of joining 3D printers to robots capable of independently building any structure.

Focusing on what already exists, the application field for which Connect-R was created corresponds to nuclear decommissioning. The necessity arose from the need to find a way to dismantle those plants that are too old and built with outdated safety procedures, also prompted by the negative reputation that public opinion has of nuclear power.

Nowadays, this type of energy represents one of the significant sources of electricity worldwide. This result shows an excellent application field for our project, being the construction and dismantling of nuclear plants a business valued thousands of millions of euros. This fact depends on the trend of nuclear power in the world market and on its affirmation, being at the center of the current energy issue. The competition over who will be the next successor of fossil-fuel-based energy has emerged very livelily, as renewables are not a solution that is currently able to replace the world's energy needs completely.

Although being both renewable and nuclear "green" energies, the discourse changes when it comes to the ability to support global needs. In fact, nowadays, wind and solar are not yet able to supply the necessary amount of energy with the right reliability. On the other hand, while renewables are precisely sustainable by definition, the same is not the case for nuclear power, which still requires materials such as Uranium to function. Nevertheless, even here, it is possible to solve the problem thanks to alternative materials such as Thorio and Trisio-X. As for costs, both are far-reaching, especially considering also the decommissioning of nuclear plants. However, thanks to new technological solutions such as Connect-R, many steps forward are being made in the way these tasks are performed and in the relative costs. It is, therefore, impossible to say which of these energy sources will take over in the future, but technologies concerning them will undoubtedly play a fundamental role.

Currently, what has emerged is a cut by governments on policies dedicated to renewables in favor of investments in nuclear power, which is currently considered more concrete. In any case, this is not a unanimous point of view, and this can be represented by the difference in positions taken by the UK and Italy. This difference of opinion is due to the negative sides that nuclear power involves, which is the disposal of radioactive waste and the risk of catastrophic accidents as in the past. They represent concrete problems and can be solved only by increasingly innovative technological solutions.

One of these is, therefore, Connect-R, born to be applied to a particular case of nuclear decommissioning. This project is still experimental, and much progress still needs to be made to complete it. To support its development, during the six months spent at the Royal Holloway University of London, different tasks were executed.

For what concerns the graphical simulations, three different simulators have been created. It is important to note that each of these presents a different and updated task execution plan compared to the previous one, also improved thanks to the relative simulator. The object of the simulation is the Struts entry and the consequent arrangement, along with the particular room where it must be adopted for the first time. The first simulator was created in 2D through Java, and the others were created thanks to VTK, an open-source software dedicated to the creation of 3D graphic models. In this way, the 2+1D and the 3D simulator were developed too.

The second category concerns the intent to develop an ad-hoc program comparable to the system now used by researchers to carry out task planning, i.e., the PDDL and planners. The main mechanisms of this language have therefore been adapted to Java, where through the transliteration of some features, it has been possible to obtain the same result. By including in the ad-hoc program both PDDL problem definition and the connected planner strategy, a search algorithm was developed, and the *A-star* and *Dijkstra* algorithms were applied, typical in problems optimal resolution related to the graphs theory required by a planner. The results that emerged demonstrated the complexity of writing such a problem in a language other than PDDL, being explicitly structured for these cases. Despite this, positive results also emerged from using the ad-hoc program developed: while the PDDL and the planner are two sides of the same coin that remain disconnected, in the ad-hoc system, this separation does not exist, thus providing a more compact solution. In addition, benefits also result from the program execution time, being less in the ad-hoc one. However, thinking about using this system instead of the PDDL is impractical, given the big problem of having to write a large amount of code, and that takes a long time. This fact would not happen with the PDDL, presenting pre-established functions and structures for these purposes.

In conclusion, this multiple of view's points analysis has shown how Connect-R places itself at the center of problems concerning Artificial Intelligence and nuclear power, at the same time preparing itself as a solution and a new horizon to be reached in industrial areas. This result is partly due to its business model, being applicable to many different contexts and with huge earning potential, but partly also to the surprising technical skills with which it will be developed. These correspond only to mere predictions, as the times are still immature. Only over time will it be possible to understand whether Connect-R will maintain the original innovation premises from which it starts. Indeed, the potential is enormous, and it is a product that can truly mark a milestone in the future of millions of years.

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