ANNEX 4

Reviews of REELER concepts and robot typologies

Annex 4: Reviews of REELER concepts and robot typologies

In this annex, we present our analysis of two different ways of understanding the term robot: i) a material entity, ii) a conceptual entity. In the second part of the annex, we present our robot typology, meant to show the breadth of the robots studied, as well as shine light on how varied robots are.

1.0 Robot understandings

1.1.0 Opening

Robot is a pivotal concept for the REELER project. It is also the material object of analysis in our empirical research. REELER focuses on robots as a point of departure because robots are increasingly expected to co-exist with or replace humans. A review and deeper analysis of the theoretical understandings of what a robot is or can be is pertinent for REELER's objective to close the proximity gap in human-robot interaction design and development, and to ensure a more responsible, ethical uptake of new robots by affecting the process of robot design.

The purpose of this chapter is to provide an overview of various understandings and representations of what a robot is. Over the next years, these definitions will, together with our empirical studies, inform the research work in the REELER project and yield new conceptualizations. An explosion of the number of robotic devices in our workplaces and private homes, with increased intelligence and autonomous behaviour, is envisaged to take place in the next ten years and as many as 40% of the work done today by humans will be replaced by robots and automated processes (Osborne and Frey, 2013; Osborne, Frey and Bakhshi, 2015). Bulgheroni also illustrates the increasing number of sold industrial and service robots since 2003 (Bulgheroni 2017, 6). If we are facing a robot revolution, a review and deeper analysis of the theoretical understandings of what a robot is or can be, is thus pertinent for REELER's objective to close the proximity gap in human-robot interaction design and development to ensure a more responsible, ethical uptake of new robots by affecting the process of robot design.

Our attention is directed towards robots, but since the terms robot and robotics are often being used synonymously, some of our examples will come from discussions of robotics as well as robots. Robotics is the discipline and craft of designing robots and here we find a focus on the technical aspects of the robot: "Robotics, intended as 'the branch of technology that deals with the design, construction, operation, and application of robots'[1] is a wide, complex and multidisciplinary matter (Bulgheroni, 2017) while a robot is defined, in the Collins English Dictionary, as 'a machine, which is programmed to move and perform certain tasks automatically'. Put differently, "Robotics can be defined as the study of mechanical engineering, electrical engineering, electronic engineering and computer science and is a broader way of looking at developments. An autonomous, self-driving car may or may not be a robot, depending on your interpretation of the definitions, but robotics is definitely involved in its design process."

As noted by roboticists themselves, it is impossible to capture what a robot is - even as a technical definition – not least because of the high pace of developing new robot technology.

"Illah Nourbakhsh, a professor of robotics and director of the CREATE Lab at Carnegie Mellon University, writes in Robot Futures (2013): "[N]ever ask a roboticist what a robot is. The answer changes too quickly. By the time researchers finish their most recent debate on what is and what isn't a robot, the frontier moves on as whole new interaction technologies are born'."
(Robertson 2014, 573)

The technical and industry-sourced definitions tend to be surface descriptions and categorizations of the robot as it is designed or as it is intended for use – the robot's blueprints. The technical perspective does not include the continuous transformation and interpretation of the robot when it is a technology-in-use – the robot's cultural becoming. The latter perspective is more complex but important. STS (see section 15.0 Science and Technology Studies in Deliverable 2.2) perspectives add this processual dimension to current technical understandings of the robot by considering the human factor, robots in research, media, economy and politics. In our preliminary EPPI search in Scopus, Eric and Anthrosource, there are no other studies like REELER that within a single research frame address diversity in both how robots emerge in the world of the technical design and when embedded (or envisioned as embedded) in situated practice.

1 http://www.leorobotics.nl/definition-robots-and-robotics

Albert Borgmann describes these two dimensions of any technology, which therefore also include robots, in his article 'Technology as a cultural force':

"My suggestion is that for a proper understanding of our cultural malaise we have to get a grip on technology as a cultural force. But what is technology? In its narrow sense, it is an ensemble of machineries and procedures. Take its most recent instance — information technology. On the hardware side, there are chips, discs, screens, keyboards, and fiber optic cables.…We can call this the engineering sense of technology. What interests social theorists is the effect that these machineries and procedures have had on our way of life. Social theorists are interested in technology as a cultural force."
(Borgmann 2006, 352-353)

To capture the implication of robots as a cultural force, we approach this review by distinguishing between the robot as a *materiality* (the technical, engineering sense) and the robot as a *concept* (the social-scientific and societal understanding).

The review begins with a historical account of the simultaneous development of robots as complex work machines and as reimaginings of the human in stories and in material form. We then move on to the technical definition and categorizations of robots from the robotics community in section 3.4 Robot as materiality. We draw on the governing standards for robotics, which are rooted in machine automation and we include various definitions from robotics associations.

From here, we explore the very many representations of robots discussed in the social sciences, primarily, but also draw on empirical representations in the media, in fiction and in politics. While the technical and industry-sourced understanding tends to relate to industrial and professional service robots, the STS perspectives take a special interest in studies of social and humanoid robots and apply a broadened definition of social robotics based on an expanded understanding of social interaction:

Since the two dimensions – understanding robot as either materiality or concept – tend to merge, we note in our conclusion that a discussion of robots as both materiality and concept is indeed needed in a comprehensive outline of robot definitions. From our preliminary searches, it seems there are no other studies like REELER that address diversity in both how robots emerge in the world of the technical design *and* how robots evolve when embedded (or envisioned as embedded) in situated practice. In our continued work, we will discuss how the REELER project can further develop the analytical work with this core concept.

By incorporating the historical, technical, social and political perspectives, we hope to present a balanced and nuanced definition of what a robot is. Based on our initial work, we have found that robot technologies are varied and changeable and so we do not aim for a stable definition of robot, but a state-of-the-art understanding of robot and robotics at this point in time.

1.2.0 Methodology

The review of robot definitions involved an extensive EPPI-inspired search on the concepts *robot* and *robotics*[2] as its point of departure. We searched the databases SCOPUS, AnthroSource and ERIC (the US Department of Education database) for the terms *robot* and *robotics*, alone and in combination with other REELER relevant terms like *collaborative learning, STS, education*, etc. We sometimes found that additional search terms limited the search unnecessarily. Depending on the databases disciplinary focus, the additional keywords elicited different results. For instance, because ERIC is a database for education / pedagogy, the inclusion of *learning* and *education* was redundant and their inclusion actually omitted results relevant for REELER. As *robot* is at the center of REELER's research, this review builds on a number of searches for our many selected concepts. (*See APPENDIX 1, section i. Robot as Materiality and Concept* for an overview of the various search hits.)[3]

This review of robot definitions is, however, not only based on classical EPPI-inspired database queries. It is also informed by our experiences with roboticists and robots in the field, by our project partners, by empirical data retrieved from websites and media representations, and by reviewing selected, relevant peer-reviewed and non-peer-reviewed literature. When we moved into reviewed representations of robots in the media, politics and work, we found it necessary to break with the selection criterion of only including peer-reviewed literature. This was necessary because we are including legal documents and journalistic publications that are not necessarily peer-reviewed; yet, the representations of robots in these areas are very important for REELER's work on ethical implications of robots in society and have thus been included in this review.

Moreover, this chapter also draws on expertise knowledge of the REELER researchers.[4] Thus, the insights presented in this review do not come from single articles but from our combined readings and discussions. From this approach, merging the database searches on robots with the REELER researchers' respective experiences and our deep readings of our selected articles, we have developed our understanding of not just the concept of robot as it emerges in the EPPI-inspired search, but also from empirical representations in diverse fields. (For more detailed description of our multi-method search methodologies in e.g. the STS-field, see APPENDIX 1.)[5]

2 See detailed description of the quantitative approach under General Methodology.

3 Appendix 1 can be accessed via the REELER Library (http://reeler.eu/resources/reeler-library/) using the following username: reeler and password: library

4 For example paragraphs and ideas that are under development for the forthcoming publication Hasse, C. *Posthuman Learning* (2018). Routledge: London.

5 Appendix 1 can be accessed via the REELER Library (http://reeler.eu/resources/reeler-library/) using the following username: reeler and password: library

1.3.0 A historical account

The word 'robot' originates from the Czech robota, which is related to Old Slavonic rabota meaning forced labourer. 'Robot' was first used to denote a fictional humanoid in the 1920 play R.U.R. (referring to the factory Rossumovi Univerzální Roboti or Rossum's Universal Robots) by the Czech writer, Karel Čapek (Čapek 1923 - see Richardson 2015 for further details). Čapek's fictional story postulated the technological creation of artificial human bodies without souls, and the old theme of the feudal robota class fit the imagination of a new class of manufactured, artificial workers. The play describes a future, where work is conducted by a sort of 'mensch-machine' – a pre-runner for the human-like robots. As noted by Kathleen Richardson this was however not a comment to the robotification of work, but rather the robotification of humans. "A dominant discussion in the 1920s rested on the mass mechanization of commodity production, which rendered the labourer as another 'cog' in the process, just like a mechanism in the machine" (Richardson 2015, 27).

The story of the robot, however, begins before the concept itself with the development of clockwork-like machines and especially the machines with human or animal like appearances. The machines that many consider forerunners of robots are called 'automata' or 'automate' a term that refer to an engine or a machine that moves by itself (Kang 2011, 140). These automatic machines can be found in many cultures. From the beginning, automata have been entangling material machines and stories of machinelike creatures. There are stories about automata machines in both China, Japan, Arabia and Europe. The Ancient Greeks have a story of the golden and silvery servants created by the blacksmith God Hephaistos, a mechanical dove created by Archytas around 400 BC and the famous story of Pygmalion, the king of Cyprus, that see a perfect statue of a woman brought to life. Some reject the Pygmalion myth as part of the history of robotic imaginaries because Pygmalion's statue is not brought to life by human ingenuity, but by a divine interference and the result is a real life woman and not a mechanical being passing for a woman (Kang 2011, 16). In Japan the prime example of automata are the karakuri dolls from the 17th century, mechanical dolls that can move and poor tea from the teapot. Karakuri both refer to the mechanisation of the artefacts and their deceptiveness as they pretend to be living, even if their livelihood is in fact a deception (Shea 2015).

In Europe, automata at first included watches and other clockworks. Automata were self-moving machines created through human ingenuity, but they soon became deceptive devices, made to appear real while in fact they were mere machines. In Europe in the 17th and 18th century, some of the great watchmakers of the time began to create automata in the shape of animals, women and children. Contrary to the machines of the budding industrial age, these machines had no apparent purpose than to 'wow' their audience. They were "marvel and mirror machines" designed to create a sense of awe in an audience (Hasse 2018 forthcoming).

One of the most famous watchmakers was the Swiss Pierre Jaquet-Droz (1721-1790 who together with his son Henri-Louis Jaquet-Droz and (and helpers like Jean Leschot) created three ingenious automata: a boy who can write, a boy that can draw, and a female musician. The writer (completed in 1792) can dip a quill pen in an inkwell and his glass eyes follow the movement at the as it writes a text with up to 40 characters over four lines. This innovative capability came from a kind of programming desk, which was a pre-runner for modern computers. Another creator was the French Jacques de Vaucanson who created three equally famous automata, two musicians and a 'defecating duck' that could stretch its neck and take corn from the audience hands, 'eat' and 'digest' it and finally defecate to the great amusement of onlookers (Riskin 2003).

Today's machine meaning of robot has since evolved to include other forms of automation, but often the robot as a concept retains inspiration in human form and function: "Since R.U.R., the meaning of "robot" has become closely associated with intelligent machines with biologically inspired shapes and functions, particularly humanoids," (Robertson 2014, 574).

There are historically some ambiguities in the concept of 'robot' that is connected to the difference between the discussions of the creation of artificial life raised in philosophies, stories, plays and movies and the technicalities of self-moving clockworks and other machines. Robots in Capek's play refer to biologically created machine-men – and more men-like machines than machine-like men. This is also the case in another famous depiction on the first robot on the screen – the mother of all robots, Maria, in Fritz Lang's movie Metropolis from 1927. Here the humans are like robotic slaves, and the real robotic machine is a creation of the mad scientist Dr. Rotwang who has taken the appearance of a sweet young woman and applied it to a seductive robot to trick nobility and workers in Metropolis alike. This way of viewing the boundaries between humans and machines as blurred had evolved since the philosophies in the 17th century increasingly, following Rene Descartes, began to see Man as a bodily machine with an immortal soul. Some even went so far, as Julien Offray de la Metrie, to see Man as an almost entirely mechanically determined being (Campbell 1970). Capek's R.U.R. could be read as a critical commentary to this development as the robots in his play were biologically formed workers for the factory work. He never envisioned robots as real metallic machines and reacted strongly when the robots in his play were represented by metallic creations (Richardson 2015, 28).

The automata and robots were increasingly created in a dialog between stories and materiality, which respectively influenced each other. Some of these stories convincingly depicted robots as 'living' creatures with should and consciousness, others where critical and other stories more ambiguous. In the latter category, we find the story by the German writer E.T.A. Hoffmann who wrote the story "Die Automate", published in Germany in 1819. In the story, two young men see and discuss a machine named "The Talking Turk". This 'Turk' was modelled after the real machine "The Turk" which had been devised by the Hungarian Baron Wolfgang von Kempelen and

later sold to the Austrian musical engineer Johan Mäelzel. In Hoffmann's story, one of the young men suspects a hoax and is very critical of the mechanical inventions. Lewis does not see these mechanical devices as anything close to a human being but claims that they can "scarcely be said to counterfeit humanity so much as to travesty it - mere images of living death or inanimate life are in the highest degree hateful to me," (Hoffmann 1819/1908/2010). He continues:

"For you may notice that scarcely any one talks, except in a whisper, in those waxwork places. You hardly ever hear a loud word. But it is not reverence for the Crowned Heads and other great people that produces this universal pianissimo; it is the oppressive sense of being in the presence of something unnatural and gruesome; and what I most of all detest is anything in the shape of imitation of the motions of Human Beings by machinery. I feel sure this wonderful, ingenious Turk will haunt me with his rolling eyes, his turning head, and his waving arm, like some necromantic goblin, when I lie awake of nights; so that the truth is I should very much prefer not going to see him." (Hoffmann 1819/1908/2010)

Even so, the story ends without a revelation of the hoax and upholds a kind of mystical atmosphere around the 'Turk'.

The real chess-playing Turk machine won over many skilled chess-players, including Napoleon and the inventor of the principles behind computing Charles Babage, before it was revealed that it was a hoax. Contrary to the real autonomous mechanical musicians and defecating duck which had so captivated Europe, this skilful machine turned out to be built so a human being (a good chess player) could be placed in a hidden room from where the chess pieces were moved through strings (Kang 2011, 180).

It was partly due to the success of these marvels that the concept of 'automata' became connected to later robots which resembled lifelike creatures (Kang 2011, 7). Robot as a technical term for an autonomous machine seems to connect to the automata is of the 17th century; but, in stories, as well as in material form, robots were gradually partly freed from the entanglement with real human biology (mensch-machine). Though human and animal forms became a model for many robots, humans were no longer seen as machines - because robots came to fill this space as 'the mechanical human'.

In both stories and real life, the concept of robots came to have two meanings referring back to this history of automata: one is an autonomous machine that like a clockwork can perform work, the other is a reflection of the human in material novelties and in fiction.

Robots as machine work and labour. Automatic clocks did perform work previously done by humans (measuring time by watching stars etc.) or beyond human capability (measuring time minute by minute). Over time the machinery was refined and connected with artificial intelligence and other new inventions – but the robots used for work remained 'robots as tools and labour'. These robots had a postwar proliferation into factories in the industrial world. They were not designed to resemble humans or animals but to perform work previously done by humans and surpass human capability for work (as in the automobile factories of the 1950s). They were often thought of as a kind of 'slave' labour, like the R.U.R. workers created to be of the purposeful service of humans (Richardson 2015). These industrial robots were developed with purposes, like Unimate, the first industrial robot, which was created to work on the General Motors assembly line in 1961. This machine was not computer controlled but ran on a magnetic drum. From the beginning the industrial robots were thought of literally as 'helping hands' or arms (Siddique 2017, 3).

In 1968 the researcher Marvin Minsky created a computer controlled device with 12 joints known as the Tentacle Arm. This machine ran on hydraulics not electricity followed in 1969 by the Stanford Arm, which was the first electronic computer controlled robotic machine. In 1970, the robot Shakey "combined multiple sensor inputs, including TV cameras, laser rangefinders, and bump sensors to navigate" (Siddique 2017, 3). In the 1970s, "German based company KUKA built the world's first industrial robot with six electromechanically driven axes, known as FAMULUS. In 1974, David Silver designed the Silver Arm. The Silver Arm was capable of fine movements replicating human hands. Feedback was provided by touch and pressure sensors and analyzed by a computer. The SCARA (Selective Compliance Assembly Robot Arm) was created in 1978 as an efficient, 4-axis robotic arm. Best used for picking up parts and placing them in another location, the SCARA was introduced to assembly lines in 1981. The Stanford Cart successfully crossed a room full of chairs in 1979" (Siddique 2017, 3-4).

Robots as marvel and mirror. Another continuation from the automata-days were the 'robots as marvel and mirror'. Today many robots are objects of modernity that reflect on what it is to be human (Richardson 2015, 24). The same mechanisms in automatic clockworks of humanlike automata were refined with new machinery and inventions, but the robots developed were still used to make humanoid machines that mimics the human or animal body, their movements and increasingly also human intelligence. The world's first anthropomorphic robot (not an automaton) was the so-called "intelligent robot WABOT (WAseda roBOT) started aiming to develop a personal robot, which resembled a person as much as possible. Four laboratories in the School of Science & Engineering of Waseda University joined together on the WABOT project in 1970. In 1984 Wabot-2 was revealed capable of playing the organ. Wabot-2 had 10 fingers and two feet. Wabot-2 was able to read a score of music and accompany a person." (Ref). These humanoid robots were more tools for research explorations than machines created with a specific purpose in mind. These machines were to explore what life is by using the robot as a scientific mirror that could be used to explore the old Cartesian ideas.

Thus, what make these two historical lines of development of robots distinct from each other is the function of the robots:

the mere machines were robots meant to work for humans as robots in a car factory or industry without emphasizing human-like features and with specific tasks. The other line of humanoid robots was created without express purpose to denote a kind of deceptive device pretending to be real like the automata, but simultaneously acted as an exploration tool for scrutinizing what makes a human or an animal different from a machine.

Though these two concurrent histories of the robot can be seen as distinct regarding function and form, they are now increasingly merging both in stories and in real-life machines. Even machines in factories are now developed to be human-like and intelligent – and the humanoids are increasingly placed in real life situations to perform job functions such as receptionists (see the following sections).[6] The following sections explore the robot as both automation of work and as a mechanical reflection of the human; as a contemporary confluence of imagination and machination.

1.4.0 Robot as materiality

Robots are material artefacts - they are made of materials shaped by humans in the context of their environments. Materials, according to Tim Ingold (following James J. Gibson), can be defined as the stuff things are made of that have three inherent properties: they exist in a medium (e.g. air), they have a substance (e.g. the 'heaviness of a stone), and surfaces (a wet or dry stone) (Ingold 2007). The roboticists as makers of material artefacts, "joins forces with [the materials], bringing them together or splitting them apart, synthesizing and distilling, in anticipation of what might emerge," (Ingold 2013, 21). These processes of making are part of the field of robotics, what Borgmann (2006) refers to as an engineering culture. Robotics includes both the craft of creating robots (the practices) and the roboticists, who are the human engineers, IT-experts and so on conducting this work (the practitioners). These engaged engineering experts form what Jean Lave and Etienne Wenger (1991) called a "community of practice", constructing certain understandings through their shared activities. Indeed, roboticists seem to share a more pragmatic approach to robots than the general audience, seeing them as less 'humanlike' and more like pieces of machinery.

1.4.1 Defining robots

While shared understandings emerge through practice, they can also be codified and shared in more formal ways. International organizations, such as the International Organization for Standardization (ISO) and the Institute of Electrical and Electronics Engineers (IEEE), produce regulatory standards for robotics. These standards are informed by declared common understandings termed ontologies:

"Ontologies are information artifacts that specify in a formal and explicit way the domain knowledge shared by a community. The availability of well-founded methodologies allow us to develop ontologies in a principled way. The artifacts that result from this process ensure mutual agreement among stakeholders, increase the potential for reuse of the knowledge, and promote data integration."
(Fiorini 2015, 3)

In the ISO standards used in relation to robots and robotic devices operating in both industrial and non-industrial [i.e. service] environments, we find the most basic technical definition of a robot:

"A robot is an actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks. Autonomy in this context means the ability to perform intended tasks based on current state and sensing, without human intervention." [7]

Paragraph 2.28 of that same ISO standard defines smart robots as *"a robot capable of performing tasks by sensing its environment and/or interacting with external sources and adapting its behaviour. As examples, the standard gives an industrial robot with a vision sensor for picking up and positioning an object, mobile robots with collision avoidance and legged robots walking over uneven terrain,"* (Nevejans 2016, 10). Bulgheroni explains that for a robot to work as described above, four main subsystems are developed: *"sensors used to perceive the surrounding environment; actuators, e.g. servomotors, to interact with the environment; a control structure i.e. the brain of the robot; the mechanical structure of the robot itself"* (ibid. 2016, 2).

The IEEE offers a compatible, but broader, definition as part of their standard ontology:

"Robot: *An agentive device in a broad sense, purposed to act in the physical world in order to accomplish one or more tasks. In some cases, the actions of a robot might be subordinated to actions of other agents, such as software agents (bots) or humans. A robot is composed of suitable mechanical and electronic parts."*
(IEEE 2015, 5)

Similar representations and perceptions of the robot have been observed in the robotics field and in related research. In an overview of a technically-informed taxonomy of robots, Bulgheroni (2016) includes an emphasis on the robot as materiality. Bulgheroni explains that the main technical classifications of robots aim at describing working features of the machine or its application area and build on features of the robots which are not linked to interaction with humans, but are technological features facilitating the assigned task (2016, 1). This attention to the materiality is also evident in Fiorini et al.'s article 'Extensions to the core ontology for robotics

6 Selected in part from the forthcoming publication Hasse, C. Posthuman Learning. Routledge: London

7 ISO-Standard 8373:2012 Robots & robotic devices: https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en

and automation' when they state that: "Our definition of robot emphasizes its functional aspects. For our general purposes, robots are agentive devices in a broad sense, designed to perform purposeful actions in order to accomplish a task," (Fiorini et al. 2014, 4). Another advocate for describing and perceiving robots as materiality is Nathalie Nevejans, who is an appointed expert on law and ethics in robotics by the European Commission. In her discussion of the 'European civil law rules in robotics', she presents the robot as a lifeless material artefact when providing definitions like, "a mere machine, a carcass devoid of consciousness, feelings, thoughts or its own will … just a tool … inert … inhuman … nonliving, non-conscious entity" (Nevajans 2016, 15-16).

While there are some commonalities across these regulatory and industry-inspired definitions, the term robot is constantly being negotiated, even within the robotics community. The IEEE makes the claim that "The term robot may have as many definitions as there are people writing about the subject. This inherent ambiguity in the term might be an issue when specifying an ontology for a broad community. We, however, acknowledge this ambiguity as an intrinsic feature of the domain" (IEEE 2014, 4). Nevejans points out the wide range of technical or industrial definitions and categorizations of robot:

"A common definition would appear to be essential. Yet defining robots is no easy task in the absence of any real consensus within the global scientific community. Current research believes that a robot, in the broad sense, should fulfil several conditions, and consist of a physical machine which is aware of and able to act upon its surroundings and which can make decisions. Only some robots may also have the ability to learn, communicate and interact, and may even have a degree of autonomy," (2016, 10).

These diverse perceptions of the material robot come through in the various categorizations made by roboticists. These categorizations indirectly define what a robot is by defining robot subtypes and functions.

1.4.2 Categorizing robots

The robot's historical development from machine automation is evident in the current regulatory and industry standards for robotics. The ISO standards for robots are found within the ISO sections governing manufacturing automation and under the title "Industrial robots. Manipulators" – despite these standards covering many classes of robots being used in many different industries.[8] From there, the robots are generally divided into two categories, industrial robots and service robots, which can then be subdivided into many classes of robot, including social robots (ibid; Bertolini 2016). The following categorizations of robots, seem to stem from this initial differentiation between industrial and service robots, but there is some variation among these classifications.

In Bertolini et al.'s article on why current legal, insurance, and regulatory structures related to robotics, robots are also categorized into industrial and service robots, like the ISO standard does. Then, industrial robots are separated into caged and collaborative robots: "It is possible to distinguish two main typologies of industrial robots: robots operating in isolation from human beings, usually constrained inside protective cages; and "collaborative" robots, which are designed to interact physically with workers, such as Baxter by Rethinking Robotics or UR5 by Universal Robots," (Bertolini et al. 2016, 383). They offer a broad definition of service robots: "A service robot 'is a robot that performs useful tasks for humans or equipment excluding industrial automation application'. An example of service robot for non-professional use is Roomba by iRobot," (ibid., 384). They go on to identify a number of sub-categories under service robots such as: "chore robots", "entertainment robots", "educational robots" and self-driving cars (ibid., 384).

In the overview by Bulgheroni (2016), robots are categorized by three primary distinctions: 1) based on the mechanical structure of robots 2) based on the working environment and 3) Following the ISO nomenclature robots are grouped in industrial robots and service robots that are also separated in personal service robots and professional service robots.

Turning to empirical examples from the industry/robot communities, we find categorizations that are not concordant taxonomies, but illustrate rather Bulgheroni's point that in practice, robots categorizations are diverse. The following selections exemplify the consistent, but subtly diverse definitions found in the field.

IEEE. The IEEE's robot ontology[9] distinguishes robots first by their level of autonomy: automated robot; fully autonomous robot; remote-controlled robot; robot group; robotic system; semi-autonomous robot; tele-operated robot. Then, the robot is distinguished by its various parts: robot actuating part; robot communicating part; robot processing part; robot sensing part. (IEEE 2015, 5)

SPARC The robotics association euRobotics categorizes robots according to "end-user market domains" in their Strategic Research Agenda[10] – a document which provides recommendations for EU Commission funding. These domains consist of: logistics & transport, commercial, civil, consumer, agriculture, healthcare, manufacturing. The report then specifies robot applications for each domains. Essentially, their classifications are first by industry, then by robot service/purpose. Within the same report, there are listed four basic characteristics of robots that distinguish them: where they work, how they interact and collaborate with users, their physical format, and the primary function they perform.
(euRobotics AISBL 2014)

8 ISO Technical Committee 299, Robotics; https://www.iso.org/committee/5915511/x/catalogue/

9 IEEE Standard robot ontology http://ieeexplore.ieee.org/document/7084073/

10 euRobotics Strategic Research Agenda http://roboproject.h2214467.stratoserver.net/cms/upload/PPP/SRA2020_SPARC.pdf

Robotics Today is an open international publishing platform for robotics. Like euRobotics, the website categorizes robots by application, first by sector/industry, then by particular task/application.[11]

IFR International Federation of Robotics separates industrial robots from service robots and lists a range of subcategories for service robots of which the main groups are "Personal / Domestic Robots and Professional Service Robots." [12]

From a review of regulatory standards, ontologies, and the definitions and categorizations found within the robotics communities, it is clear that there is a focus on the robot as a material – a summation of its parts, defined by its application or function in the world. The focus on the robot as a tool and as a complex machine mirrors the historical development of the robot from advanced automated machines. In the following section, we present the robot as inspired by the parallel history of development of the man-like machine in an exploration of the human-machine boundary.

1.5.0 Robot as concept

Another way of defining robots is through how they are being perceived and conceptualized. The philosophical understanding of a concept is *"an idea or mental image which corresponds to some distinct entity or class of entities, or to its essential features, or determines the application of a term (especially a predicate), and thus plays a part in the use of reason or language"*. (Oxford Dictionary)

In the following sections, we will explore these conceptions through three areas dealing with robots as a cultural force. We first look at how the social sciences, together with roboticists of social robots, reconceptualise 'robots' in multifaceted ways that underline the social and gendered aspects rather than technical aspects. Next, we touch upon existing perceptions and conceptions of robots, including: the role of popular media in both the creation and analysis of robots, the ways humans anthropomorphize robots and understand the human-robot boundary, and how these conceptions are negotiated through legal and political actions. Finally, we move on with a presentation of some of the analytical perspectives used to study robots in the social sciences.

1.5.1 How robots are defined by STS scholars

The Science and Technology Studies (STS) loom large when it comes to redefining robots in a broader sense than their material and technical aspects. The focus has not been on robots as automated *work and labour* with a focus on form and functions of robots. Rather, social scientists have been particularly interested in exploring robots as *marvel and mirror* with a focus on socially and philosophically oriented definitions, such as a robot's ontological status. As such, studies have centred on the implementation of service and social robots, or on the laboratories of these robots, rather than on industrial robots..

STS studies in robotics have been interested in why some roboticists – like Cynthia Breazeal, Rodney Brooks, and Hiroshi Ishiguru, for example – attempt to create humanlike robots as 'marvel and mirror' that deliberately play with imitations of human features without endowing these robots with any specific function (e.g. Breazeal 2003). Social scientists have also studied attempts to implement these robots in everyday settings, even if these human-like robots have no apparent functions (Bruun et al. 2015). While it remains uncommon for social scientists to work directly with roboticists (and especially concerning industrial robots), some have followed roboticists in their laboratories observing them where they develop their robots (e.g. Richardson 2015). Yet here too, the focus remains on social robots.

True to their interest in ontological categories and conceptualizations of social appearances, STS scholars have tried to make a number of distinctions between humanoids and other robots, and within the 'humanoid' species they have identified different subtypes. The following definitions are drawn from STS studies:

Cyborg. In the STS field the concept of robot has been connected to the concept of a cyborg, which is a transversal figure breaking down boundaries between the social and the material - thus breaking down Durkheim's 19th century understanding of the social as strictly human (Richardson 2015, 12). The cyborg is a figure that connects machines and humans in 'trickster like' ways, where boundaries between conceptual and material figurations cannot be expected to be fixed and unmovable – concepts and materials move each other (Haraway 1991).

Humanoid. Humanoid robots can be any robot with a human-like form (anthropomorphic) and human-like movements (anthropomimetic), and is the umbrella term for a number of concepts defining humanoid robots into subcategories.

"To be called a humanoid, a robot must meet two criteria: it has to have a body that resembles a human (head, arms, torso, and legs) and it has to perform in a human-like manner in environments designed for the capabilities of the human body, such as an office or a house. Most Japanese humanoids are gendered female or male. Some humanoids are so lifelike that they can actually pass as human beings—these robots, which are always gendered, are called androids (male) and gynoids (female)."
(Robertson 2014, 574)

Androids and gynoids. All androids and gynoids are humanoids, but not all humanoids are androids or gynoids. An android or gynoid will be defined by their respective male or female gendered appearances, reflecting normative conceptions of gendered human form. Androids and gynoids can

11 Robotics Today website: http://www.roboticstoday.com/robots/by-category/

12 International Federation of Robotics website. https://ifr.org

also sometimes be named *replicants*. Like the wax-dolls that also inspired the automata figures, the android and gynoids will be clad in soft humanlike skin and have very real looking eyes. One humanoid robot, the life-like Jia Jia, entertained the wowed audience at a Chinese robotics fair by recognizing faces, demonstrating micro-expressions by moving eyelids and lips, and 'talking' - her creators programmed her to say "Yes, my lord, what can I do for you?".[13] Other famous examples of these robots are the creations by the philosopher roboticist Hiroshi Ishiguru, director of the Japanese Intelligent Robotics Laboratory. In this laboratory, Ishiguru has created many humanoid robots, some of which are both android and – a new categorization – the geminoid (Bartneck and Kanda 2009).

Geminoid. The geminoid is a robot that is created as a literal doppelgänger. Ishiguru, for instance, created the robot Geminoid HI-1, which has the same features as its creator and is presented dressed in the same clothes. It may also 'speak' with his voice and replicate some of his movements. Like many robots from Ishiguru's lab, HI-1 it is remotely controlled and thus gives an impression of being an autonomous being. Through its motion-capture interface, it can imitate Ishiguro's body and facial movements, and can reproduce his voice in sync with his motion and posture. Ishiguro hopes to develop the robot's human-like presence to such a degree that he could use it as a proxy to teach classes remotely, lecturing from home while the Geminoid interacts with his classes at Osaka University (Bartneck and Kanda 2009).

Whereas the technical definitions focused on the automated work machine, the thus far limited study of robotics in the social sciences have focused on the recreation of the human in the machine. However, with the increase in AI technologies in robotics (see section 9.0 Artificial Intelligence), the interest of the social sciences may extend beyond humanoid robots to other robots that may not resemble human form, but have some semblance of human function. STS scholar Lucy Suchman describes such a situation in which our perception of robots as social might be broadened by increasingly intelligent machines: "In introducing the actions of a user, the [human-machine] environment becomes not only a physical but also a social one, requiring the interpretation of the user's actions and an assessment of the user's understanding of his or her situation," (2007, 55-56). Studies and definitions of other (and as yet, more prolific) robot types are still needed within the social sciences, which is one of the objectives of the REELER research.

In the following section, we explore the role of popular media, human interaction, and political and legal actions in forming these conceptions of robots, and how these ideas inspire debate into a robot's ontological status of existence in relation to our own.

13 https://www.youtube.com/watch?v=ZFB6lu3WmEw

1.5.2 How robots are perceived in social spaces

The attribution of social agency to robots occurs in social spaces with human actors – for instance, when we incorporate our imaginaries from popular media, when we ascribe human characteristics to robots, or when we proffer legal statuses upon them. Thus, the definition of a social robot can be expanded by our practices with other classes of robot. The focus in the social sciences thus far on humanoid social robots can be attributed to the way in which they have differed from industrial robots in how they are created to engage humans 'as if' the robots were human counterparts. Roboticist Cynthia Breazeal claims that:

"Autonomous robots perceive their world, make decisions on their own, and perform coordinated actions to carry out their tasks. As with living things, their behaviour is a product of its internal state as well as physical laws. Augmenting such self-directed, creature-like behaviour with the ability to communicate with, cooperate with, and learn from people makes it almost impossible for one to not anthropomorphize them (i.e., attribute human or animal-like qualities). We refer to this class of autonomous robots as social robots, i.e., those that people apply a social model to in order to interact with and to understand. This definition is based on the human observer's perspective."
(Breazeal 2003, 168)

As Suchman (2007) and Breazeal (2003) point out, social robots are social not because of their designed function but because they are situated in social spaces with human social actors.

Based on the work of Harold Garfinkel (1984), Lucy Suchman (1988), and Weizenbaum (1976), Cognitive scientist Morana Alač, together with Javier Movellan, and Fumihide Tanaka, concludes that "the meaning of action is constituted not by an actor's intentions but through the interpretative activity of recipients," (2011, 895). This suggests that a robot's actions, and thus the robot itself, are not defined solely from how it is designed and programmed, but also how it is perceived by those who interact with it. "The robot is not treated as a social creature in the absence of coordinated interactional practices," (ibid, 914).

Alač et al. explain how important it is for robots so be perceived by human observers to resemble a thing that can 'think' and 'make decisions' in order to be ascribed social agency (2011). The robot is defined through the ways in which the people around it interact with it and perceive it. The technical definition of social agency in social robotics is focused on human-robot interaction based in "the robot's physical body; of foremost importance are the robot's appearance, the timing of its movements, and its accompanying computational mechanisms," (Alač et al. 2011, 894).

However, Alač et al. suggest that the social agency is not rooted in the hardware and software – the material – itself, but is a product of the human interactions and social arrangements of the robot's environment. "The robot's social character thus

includes its positioning in the space and the arrangement of other actors around it, as well as its interlocutors' talk, prosody, gestures, visual orientation, and facial expressions," (2011, 894). Here, the authors point to the importance of understanding that the transformation of the robot as a material artefact into an agential artefact depends upon humans being engaged in interaction and subsequently interpreting the human-robot configuration as social interaction. Thus, social spaces, including the context in which a robot is embedded and the humans with which the robot is engaged, define the robot by contributing to the way the robot is perceived.

Even if both some roboticists and social scientists (like Breazeal and Suchman) agree that social spaces and engagements with human actors are an important part of what constitute the sociality of robots, the empirical studies of how robots are perceived and defined in actual daily practices is still an emergent field. In especially Scandinavia we do, however, find a field of studies of social robots implemented in the everyday lives of healthcare and schools where humans 'stretch' themselves to accommodate the robotic newcomers in their everyday practices (e.g. Bruun et al. 2015, Hasse 2013, Hasse 2015, Leeson 2017, Esbensen et al. 2016). In these studies, the focal point is to make use of ethnographic fieldwork to get a sense of how robots affect the people when they engage with robots without any experimental setting to be considered – or, in other words, when we study how humans and robots engage each other in everyday life situations. In the United States and in relation to the field of HRI (Human-Robot Interaction) we also find empirical studies of social robots, but they are often tied to empirical on-site experiments where social scientists work with roboticists (e.g. Sabanovič et al. 2013, Alač et al. 2011).

Furthermore, most of these studies are in healthcare or education. We have, in our search, not found studies of how humans in 'real-life' or robots in the wild settings engage with robots in factories. When it comes to robots in small, medium size and big industries the effects of robots are not studied with ethnographic methods (see ANNEX 2 and Part II of Deliverable 2.2 for a more extensive explanation of ethnographic methods and case studies).[14]

5.2.1 The Hollywood effect

One social space in which robots have been defined is in the cultural imagination, inspired by science fiction stories and movies. Robots have appeared as both heroic and villainous characters since the 1920s when Fritz Lang's Maria in Metropolis stood out as the 'mother of all female movie robots' (Richardson 2015). They have been present throughout the last century with figures like Star Wars' C3PO (1977), Robocop (1987), Blade Runner's replicants (1982), and more recently the female rebel Ava from the movie Ex Machina (2014) or the cartoonish Wall-E (2008) and Big Hero 6's Baymax (2014).

Just as these cultural imaginaries sparked the notion of *robot*, they have continued to shape our understandings of the robot. "Capek's graphic portrayal in R.U.R. of the end of bourgeois humanity at the hands of a violent robot-proletariat helped to shape Euro-American fears about robots that persist to this day," (Robertson 2014, 574). Whereas Euro-American representations have maintained a tendency toward robot revolt scenarios, Japanese representations have shifted in response to political and cultural events. "From the 1920s to the present day in Japan robots have been cast as both threatening and helpful to humans. Since the 1960s, however, when the state embarked on a policy of automation over replacement migration to extend the productivity of the domestic workforce, the general trend in Japanese popular media and culture has been to characterize robots as benign and human-friendly," (Robertson 2014, 574).

These different cultural interpretations of the fictional robot are reflected in science fiction writing of the time. American writer Isaac Asimov and Japanese manga artist Tezuka Osamu each crafted laws of robotics governing human-robot interaction long before the technologies were developed to make such interactions possible. "Tezuka and Asimov were socialized in cultural settings differently shaped by World War II and its aftermath, a fact reflected in how they imagined and described the relationship between humans and robots in their literary work," (Robertson 2014, 583). Asimov's laws drew on the threat of a Frankenstein scenario in which the robots turn against their creator, as in Čapek's R.U.R. In contrast, Tezuka's addressed "the integration of robots into human (and specifically Japanese) society where they share familial bonds of kinship and perform familial roles," (Robertson 2014, 584). Returning to Robertson's writings *Robot Rights*, the ways in which robots are interpreted and regarded in Japan – in contrast to their reception in Europe and the U.S. – demonstrate how media representations reflect and reproduce our cultural imaginaries. These cultural imaginaries can influence roboticists' notions of robots and their reproductions of notions of the human through robotics (Suchman 2007). Further, these representations and imaginaries can shape our interactions with robots (ibid.), our regulation of robots (Robertson 2014), and the creation of our common life-worlds (Hasse 2015). Representations of robot within popular media have informed perceptions of robots among layman as well as roboticists.

Recalling the EU Parliamentary resolution "Civil Law Rules on Robotics", fictional robots were referred to in the resolution itself and throughout the workshop discussion at the European Robotics Forum. The first line in the resolution's introduction begins: "From Mary Shelley's Frankenstein's Monster to the classical myth of Pygmalion, through the story of Prague's Golem to the robot of Karel Čapek, who coined the word, people have fantasized about the possibility of building intelligent machines, more often than not androids with human features" (European Parliament 2017). These historical understandings are met with contemporary depictions of robots, resulting in certain popular understandings about what a robot is and

14 ANNEX 2 can be accessed via the REELER Library (http://reeler.eu/resources/reeler-library/) using the following username: reeler and password: library

what a robot can do - one workshop participant described this as the "Hollywood effect":

"Last year there were eleven movies in Hollywood that were talking about robotics and AI. And it starts cuddly and nice at Baymax or Hero Number Six, I think it's called in the US. So a Baymax movie, a Disney movie. Then you have Avengers, Age of Ultron – a nice cool action movies. Up to Her and Ex Machina. But eleven movies put robotics and AI and science fiction, for example in this form, in the heads of people. So this leads, on the one hand, to a completely distorted view on the state of technology today. People believe this is going to be real in ten years. We know how hard that is, but they don't."
Dominik Boesl, KUKA Robotics and Robotic Governance Foundation (ERF 2017)

However unrealistic these popular media inspired imaginaries may be, they have very real implications as Jennifer Robertson stresses: "It remains the case, however, that these metaphors and symbols predominate in the government, the corporate sector, and even the robotics industry, and their influence and impact…cannot be overestimated," (2014, 583). The effects of popular media on cultural imaginaries and ultimately on perceptions of the robot can be seen in the debates within academic literature and within EU political discourse over the ontological status of the robot.

5.2.2 Anthropomorphism and ontological status

Social scientists ask questions about how our perception of robots affects how we interact with robots and how we incorporate robots into our practices. From the perspective of *multistability*, these interactions not only inform our understandings of ourselves and the robots, but can actually shape bodies and beings. With that in mind, we turn to the work of Jennifer Robertson on robots in Japan. Robertson emphasizes the importance of sociocultural practices and interpretations of the material artefact. Roboticists and other humans, Robertson included, tend to ascribe human characteristics to the robot and tend to understand the robot through understandings of beings (whether human, non-human, or quasi-human).

Robertson, in her work on robot rights, contrasts the ontological debate of human exceptionalism in Europe and the U.S. to the Shinto-inspired acceptance of robots as beings in Japan.

"Recent Euro-American literature on robot rights can be characterized as divided along the lines of a Manichean debate about living vs. nonliving, human vs. nonhuman. Scholars from across the disciplinary spectrum have proposed legal precedents based on analogies between robots and animals and even between robots and disabled (or differently abled) humans. Some have also proposed treating robots as occupying a "third existence status" that fits neither the category of human nor that of machine….Efforts to categorize robots as constitutionally separate from humans are shared by neither the Japanese public (at least those persons polled on the subject) nor Japanese roboticists, who proceed from the position that organic and manufactured entities form a continuous network of beings."
(Robertson 2014, 593-595)

What a robot is, whether it is a being or a non-being, is a significant debate. Robertson notes that "Like the history and development of dogs, cats, horses, and other domesticated animals the history of robots is inextricably entwined with the history of humans. The acceleration of robotic technologies and advances in artificial intelligence have moved the idea of robot rights out of science fiction and into real time," (2014, 593). Here, Robertson conflates the debates over human-animal exceptionalism and human-nonhuman exceptionalism. The human-animal debate, acknowledges that all animals are beings, whether or not they are persons. The human-nonhuman debate, involves first acknowledging a robot (or nonhuman) as a *being*, then as a *person*. In Japan, robots are accepted as beings, even as members of the family. There have been instances in which robots received citizenship, a family name, human parentage, and even a date of "birth" (Robertson 2014).

In Europe, a type of electronic personhood was considered in the debates preceding the recent EU Parliamentary Resolution regarding regulating robots under civil law:

"[The EU Parliament] calls on the Commission…to explore, analyse and consider the implications of all possible legal solutions, such as creating a specific legal status for robots in the long run, so that at least the most sophisticated autonomous robots could be established as having the status of electronic persons responsible for making good any damage they may cause, and possibly applying electronic personality to cases where robots make autonomous decisions or otherwise interact with third parties independently."
(European Parliament 2017, 59.f)

In a workshop at the 2017 European Robotics Forum, Karin Röhricht of Fraunhofer IPA led a discussion of this resolution. The topic of robot ontology came up early in the workshop:

"Then we have this debate between human and machine – where does a machine end, where does human behavior begin? Some people answered me that a machine cannot and will not be a human, and a civil law is made for citizens and not for machines. Because humans have this sort of self-awareness that machines cannot have, so already a civil law itself is inappropriate for machines. And the fact of liability is also a human invention related to the self-awareness, so it doesn't fit to robots."
(Karin Röhricht, Fraunhofer IPA and euRobotics, ERF 2017)

Robertson expects the debates over being/personhood to continue with the coming advances in artificial intelligence (see section 9.0 Artificial Intelligence): "As robot intelligence continues to develop, debates in Euro-American circles between supporters and opponents of human exceptionalism, or the idea that humankind is radically different and separate

from the rest of nature and other animals, will become more contested," (2014, 576).

Whether or not we acknowledge the robot as a human or a being, by ascribing human characteristics to the robot and using anthropomorphic language when discussing robots, we perpetuate the idea that a robot might fit that "third existence status." Robertson herself, like the roboticists she studies, uses anthropomorphic language when referring to robots, including gendered pronouns and human verbs. This type of language indicates personhood or being by:

– ascribing roles: worker, caregiver, student, housesitter, sibling, child, playmate, companion, citizen
– ascribing agency: robots are said to learn, interact, think, know, work, heal, care, calm, cheer
– ascribing characteristics: social, intelligent, chatty, emotional, personality, consciousness

(excerpted from Robertson 2014)

Another way robots are anthropomorphized is by ascribing social behaviour to programmed or performed behaviours – the result of human labours, but ascribed to the machine. Lucy Suchman describes the reliance of the MIT robot Kismet on its human operators. Just as her notions of Cog were transformed by her "backstage" encounter, so were her experiences with Kismet.

"Those lessons require that we reframe Kismet, like Cog, from an unreliable autonomous robot, to a collaborative achievement made possible through very particular, reiteratively developed and refined performances. The contrast between my own encounter with Kismet and that recorded on the demonstration videos makes clear the ways in which Kismet's affect is an effect not simply of the device itself but of Breazeal's trained reading of Kismet's actions and her extended history of labours with the machine. In the absence of Breazeal, correspondingly, Kismet's apparent randomness attests to the robot's reliance on the performative capabilities of its very particular "human caregiver'."
(Suchman 2007, 246)

Cynthia Breazeal, of MIT's Artificial Intelligence Lab and the aforementioned Kismet robot, writes about social robots and, indeed, ascribes various social classifications to robots, answering her own question: "To what extent is the robot a full-fledged social participant?" (2003, 168). She claims to base the following four levels of social participation on the human's ability and desire to anthropomorphize the robot and socialize with it, but the language she uses ascribes social agency to the robots:

Socially evocative: the human attributes social responsiveness to the robot, but the robot's behavior does not actually reciprocate…more invested in their creation's "lifespan".

Social interface: uses human-like social cues and communication modalities in order to facilitate interactions with people… This class of robot tends to value social behavior.

Socially receptive: benefit from interactions with people…robots that learn from interacting with people…tends to be more perceptive of human social cues…They are socially passive, however, responding to people's efforts at interacting with them but not pro-actively engaging people to satisfy internal social aims.

Sociable: socially participative "creatures" with their own internal goals and motivations… to benefit itself (e.g., to promote its survival, to improve its own performance, to learn from the human, etc.)… Such robots not only perceive human social cues, but at a deep level also model people in social and cognitive terms in order to interact with them.

(Selected excerpts from Breazeal 2003, 169)

Breazeal goes on to describe Kismet, their own "sociable" robot: "A person can infer quite a lot about the robot's internal state by interpreting its gaze and the manner in which it moves its eyes – i.e., what Kismet is interested in or what it is reacting toward," (173). Breazeal's representation of Kismet the reiterative process that Lucy Suchman (2007) described, in which a roboticist creates a robot to simulate something human, then interprets the programmed responses as human behaviour.

Tony Prescott, professor of cognitive neuroscience and director at Sheffield Robotics research institute, writes about the debate over a robot's ontological status from an STS perspective that is maybe more technical than humanist. Rather than fitting robots into the dichotomous categories of human vs. nonhuman, or living vs. mechanical, he suggests a liminal status of being – "more than machine but also less than human," (Prescott 2017, 144). Jennifer Robertson (2014) had noted that a third existence status emerges in response to how we interpret the robot – what a robot is depends on what we perceive it to be. Prescott adds to this argument, suggesting both a perceived liminal status ("how robots are seen") and an actual liminal status ("what robots are") (2017, 144). He presents a robot that is both socially constructed and mechanically determined (2017).

"Whilst most robots are currently little more than tools, we are entering an era where there will be new kinds of entities that combine some of the properties of machines and tools with psychological capacities that we had previously thought were reserved for complex biological organisms such as humans."
(Prescott 2017, 146)

Prescott's secondary argument is that whether a robot is perceived as just a tool or as a social agent, real ethical issues will arise from the robot's increasing blurred status of being [Figure 1].

How ontological (o) and psychological (p) perspectives on robots can combine (after Kahn et al., 2007). Note that only one quadrant of this table (I) is addressed in the EPSRC principles, but that II, III, and IV are all possible, at least theoretially.	
I. Robots are just tools (o), and people will see robots as just tools unless misled by deceptive robot design (p). *Ethical illues: We should address human responsibilities as robot makers/users and the risk of deception in making robots that appear to be something they are not.* **This is the position of "the principles".**	**II.** Robots are just tools (o), but people may see them as having significant psychological capacities irrespective of the transparency of their machine nature (p). *Ethical issues: We should take into account how people see robots, for instance, that they may feel themselves as having meaningful and valuable relationships with robots, or they may see robots as having important internal states, such as the capacity to suffer, despite them not having such capacities.*
III. Robots can have some signficant psychological capacities (o) but people will still see them as just tools (p). *Ethical issues: We should analyse the risks of treating entities that may have significant psychological capacities, such as the ability to suffer, as though they are just tools, and the dangers inherent in creating a new class of entities with significant psychological capacities, such as human-like intelligence, without recognising that we are doing so.*	**IV.** Robots can have some significant human-like psychological capacities (o), and people will se them as having such capacities (p). *Ethical issues: We should consider scenarios in which people will need to co-exist alongside new kinds of psychologically significant entities in the form of future robots/AIs.*

Figure 1 Ethical issues related to perceived/real ontological status of the robot (Prescott 2017, 145)

Prescott's point about perceptions of ontology mirrors Robertson's point about perceptions from popular media, however unrealistic a perception might be, the perception itself is real and has effects. When robots are perceived as having human form or function, they can take on a different ontological status – a topic that has been recently debated in the political-legal sphere.

5.2.3 Political and legal perspectives: negotiating public definitions of robot

The public definition of the robot is negotiated through political, legal, and regulatory. Given the disparate but concurrent imaginary and mechanical histories of the robot, different laws and regulations have emerged with respect to both histories. Asimov's and Tezuka's fictive laws were imagined to govern fictional robots as intelligent beings. Machinery directives and other regulatory standards were written with respect to automation. We are now at a point in time where state-of-the-art robotics fall somewhere between the machinery directives regulating the hardware and the imagined laws regulating the AI. The recent EU parliamentary resolution addresses this pivotal moment in robotics:

"Whereas now that humankind stands on the threshold of an era when ever more sophisticated robots, bots, androids and other manifestations of artificial intelligence ("AI") seem to be poised to unleash a new industrial revolution, which is likely to leave no stratum of society untouched, it is vitally important for the legislature to consider its legal and ethical implications and effects, without stifling innovation."
(EU Parliament 2017, B)

The Civil Law Rules for Robotics resolution finds the current legal framework insufficient for addressing the legal and ethical challenges arising with state-of-the-art robotics and emerging applications of robotics (EU Parliament 2017). The motion for resolution and the first draft of this report was put forth by a parliamentary committee in 2015. This came on the heels of the 2014 conclusion of the EU funded project, RoboLaw, whose arguments closely parallel those in the 2015 motion. Following the initial motion for resolution, a 2016 study was requested to inform the final 2017 report and resolution to the European Commission. The definition and terminology of robot has been the source of much discussion in this period from 2014 to present, as reflected in the recent updates to the IEEE CORA and ISO standards (IEEE 2015, Fiorini 2015) (see section 3.4.1 Defining robots) and as demonstrated in the texts from the aforementioned studies and resolutions (presented in Figure 1 below).

In the RoboLaw project, the authors attempted a definition, but found that the most widely accepted definitions were either too subjective or two broad:

"According to the most widespread understanding, a robot is an autonomous machine able to perform human actions. Three complementary attributes emerge from such a definition of robot [physical nature, autonomy, and human likeness].... An alternative way to make sense of the word robot…would be to look at a robot's main components. Indeed, there is a

widespread consensus among practitioners in describing a robot as consisting of four main elements: sensors, actuators, controllers and power supply. However, the drawback of such an approach is that…too many devices could qualify as robots."
(RoboLaw 2014, 15-16)

In the final resolution presented to the EU Commission, the definition became definitions, plural, and relied on technical definitions:

"Calls on the Commission to propose common Union definitions of cyber physical systems, autonomous systems, smart autonomous robots and their subcategories by taking into consideration the following characteristics of a smart robot: the acquisition of autonomy through sensors and/or by exchanging data with its environment (inter-connectivity) and the trading and analysing of those data; self-learning from experience and by interaction (optional criterion); at least a minor physical support; the adaptation of its behaviour and actions to the environment; absence of life in the biological sense."
(EU Parliament 2017, 1)

Table 1: Definitions across recent documents addressing robots and law in the EU

<table>
<tr><td colspan="2">RoboLaw: Regulating Emerging Robotic Technologies in Europe: Robotics facing Law and Ethics, 2014</td></tr>
<tr><td>Definitions</td><td>"According to the most widespread understanding, a robot is an autonomous machine able to perform human actions. Three complementary attributes emerge from such a definition of robot: They concern:

1) physical nature: it is believed that a robot is unique since it can displace itself in the environment and carry out actions in the physical world. Such a distinctive capability is based on the assumption that a robot must possess a physical body. Indeed, robots are usually referred to as machines;
2) autonomy: in robotics it means the capability of carrying out an action on its own, namely, without human intervention. Autonomy is usually assumed to be a key factor in qualifying a thing as a "robot" or as "robotic". In fact, in almost all dictionaries definitions, including authoritative sources such as the International Standard Organisation (ISO 13482), there is always a reference to autonomy. Finally,
3) human likeness: the similarity to human beings. The idea that a robot should be humanoid in its appearance and behaviour is deeply rooted in the imaginary of people as a result of the effects of popular culture and our tendency to anthropomorphism. However, the design of human morphological and behavioural features may have functional motivations: indeed, the human form and behavior are evidently the best models for solving the problems related to the interactions of the robot with the environment and human beings (Breazeal, 2004)."

(RoboLaw 2014, 15)

"An alternative way to make sense of the word robot, less subjective with respect to the one described above, would be to look at a robot main components. Indeed, there is a widespread consensus among practitioners in describing a robot as consisting of four main elements: sensors, actuators, controllers and power supply. However, the drawback of such an approach is that…too many devices could qualify as robots."

(RoboLaw 2014, 16)

"As a matter of fact, the term "robot" can mean different things to different people, since there is no agreement on its meaning neither among professional users (i.e. roboticists) nor among laypeople. Virtual robots, softbots, nanorobots, biorobotics, bionics, androids, humanoids, cyborgs, drones, exoskeletons are just some of the terms currently used to designate a robot, or some aspects of it, in scientific and popular languages."

(RoboLaw 2014, 15)</td></tr>
</table>

<table>
<tr><td>Taxonomy</td><td>In the framework of the RoboLaw project, instead of attempting to elaborate a new definition of robot, we devised a taxonomy of robotics, which, by classifying the main features of robots, allowed us to make sense of the plurality of uses and applications (Salvini, 2013). The taxonomy consists of six categories or classes, which have been identified by taking into account the most recurring features appearing in definitions of robots:

1) Use or task. It refers to the specific purpose or application for which the robot is designed. Indeed, the etymology of the word (from Czech robota, meaning “forced labour”) implies that robots are meant to carry out a job or service. Potentially robots can be used for ‘any application that can be thought of’ (Murphy, 2000: 16). Conventionally, applications are divided into two macro categories: service and industrial applications.
2) The environment is the outside of the robot, the space where the robot will carry out its actions. Within this category it is possible to make a macro distinction between physical and non-physical environments. In this way, it is possible to bring together robots that operate on space, air, land, water and the human body (or other biological environments) and those working in cyberspace, such as softbot.
3) Nature refers to the way in which a robot manifests itself or exists. Within this category it is possible to distinguish between two main sub-categories determined by the type of embodiment: embodied and disembodied robots. Machines, hybrid bionic systems and biological robots belong to the former sub-class, while software or virtual agents belongs to the latter. In this way, it was possible to avoid discriminating robots by the material they are made of, and therefore enlarge the definition to comprehend software agents (also know as virtual robots or softbots), artificial biological robots, such as nanorobots (Dong, Subramanian & Nelson, 2007) and finally, hybrid-bionic systems, which are made of biological and mechatronic components (e.g. limb prosthesis).
4) Human-robot interaction (HRI). This category takes into account the relationship between robots and human beings. It is a varied category including modes of interaction, interfaces, roles, and proximity between humans and robots.
5) Autonomy specifies a robot degree of independence from an outside human supervisor in the execution of a task in a natural environment (i.e. out of a laboratory). Within this category different levels of autonomy can be included: full autonomy, semi-autonomy and tele-operation. In this way it was possible to consider as robots both autonomous vehicles, such as the Google car (see infra, Ch. 2) and the da Vinci (see infra, Ch. 3), a tele-operated system used for robotic assisted surgery.

Finally and to sum up, the taxonomy points out the peculiarity of each robot, which cannot be discussed in isolation from its task, operative environment, nature, human-robot interaction and level of autonomy.”

(RoboLaw 2014, 16)</td></tr>
<tr><td colspan="2">Draft report with recommendations to the Commission on Civil Law Rules on Robotics
Committee on Legal Affairs, EU Parliament, 2015</td></tr>
<tr><td>Definitions</td><td>“Calls on the Commission to propose a common European definition of smart autonomous robots and their subcategories by taking into consideration the following characteristics of a smart robot:

– acquires autonomy through sensors and/or by exchanging data with its environment (inter-connectivity) and trades and analyses data
– is self-learning (optional criterion)
– has a physical support
– adapts its behaviours and actions to its environment,”

(Committee on Legal Affairs 2015, 6-7.1)

“Definition and classification of ‘smart robots’ A common European definition for ‘smart’ autonomous robots should be established, where appropriate including definitions of its subcategories, taking into consideration the following characteristics:
The capacity to acquire autonomy through sensors and/or by exchanging data with its environment (inter-connectivity) and the analysis of those data;
The capacity to learn through experience and interaction;
The form of the robot’s physical support;
The capacity to adapt its behaviours and actions to its environment.”

(Committee on Legal Affairs 2015, 13)</td></tr>
</table>

<table>
<tr><td colspan="2">Study: European civil law rules in robotics
Commissioned by Committee on Legal Affairs, EU Parliament, 2016</td></tr>
<tr><td>Definitions</td><td>“A common definition would appear to be essential. Yet defining robots is no easy task in the absence of any real consensus within the global scientific community. Current research believes that a robot, in the broad sense, should fulfil several conditions, and consist of a physical machine which is aware of and able to act upon its surroundings and which can make decisions. Only some robots may also have the ability to learn, communicate and interact, and may even have a degree of autonomy.”

(Nevejans 2016, 9)</td></tr>
<tr><td colspan="2">Civil law rules for robotics
EU Parliamentary resolution and report, 2017</td></tr>
<tr><td>Definitions</td><td>“Calls on the Commission to propose common Union definitions of cyber physical systems, autonomous systems, smart autonomous robots and their subcategories by taking into consideration the following characteristics of a smart robot:

– the acquisition of autonomy through sensors and/or by exchanging data with its environment (inter-connectivity) and the trading and analysing of those data;
– self-learning from experience and by interaction (optional criterion);
– at least a minor physical support;
– the adaptation of its behaviour and actions to the environment;
– absence of life in the biological sense.”

(EU Parliament 2017, 1)</td></tr>
<tr><td colspan="2">The future of robotics and artificial intelligence in Europe
Speech by Director-General Roberto Viola, representing European Commission and DG Connect, 2017</td></tr>
<tr><td>Definitions</td><td>“Let me first clarify what we mean by AI and robotics:

Firstly, we have industrial robots installed on factory floors, carrying out repetitive tasks such as pick and place or transporting goods autonomously. They are programmed to achieve very specific tasks in very constrained environments and usually work behind fences with no human contact.

Increasingly, so-called collaborative robots are deployed on the shop floor which can work in close proximity of humans and do not need a security cage any longer.

A second category consists of professional service robots used outside traditional manufacturing. Typical examples include surgical robots in hospitals or milking robots on farms.

Consumer robots form the third category: they can be used for private purposes, typically at home, like vacuum cleaners, lawn mowers etc.

Finally, there are the purely software-based AI agents. Such systems are used, for example, to help doctors improve their diagnosis or in recommendation systems on shopping websites.

AI-based software, in conjunction with sophisticated sensors and connectivity, is also increasingly used to make all kinds of devices and objects around us intelligent. The most notable example in this context is probably the self-driving car.

While many of these robots and AI systems are impressive and have progressed a lot recently, they are still very far from exhibiting intelligent, human-like behaviour or are indistinguishable from a human. In other words: they don’t pass the Turing test yet. This futuristic vision would need a debate at a different level, including asking very profound ethical questions.”

(Viola 2017)</td></tr>
</table>

There is little consensus among the political and legal texts we've reviewed. This discord is evidenced in recent discussions of the parliamentary resolution itself, which has been hotly debated – not least because of the unsettled definition and ontological status of robots.

In March, several representatives of the REELER project attended the 2017 European Robotics Forum. There were workshops with topics related to specific sectors (Agriculture; Logistics; Maintenance & Inspection; etc.) or to broader topics relating to robotics as a field (AI & Cognition; Ethical, Legal, & Social Issues; etc.). The talk among roboticists and other experts during these workshops reflected the ongoing discussion of the terms robot and robotics.

There was a workshop session on the ethical, legal, and social issues in robotics; the topic was the recent EU Parliamentary resolution regarding the regulation of robotics, "Civil Law Rules on Robotics". The organizer of the workshop opened with a statement defining smart robots and discussing the difficulty of making such definitions:

"The basis for the resolution is also the definition of smart robots. You can see the four main points: it's the capacity to –so the question is 'what is a smart robot or an autonomous robot?' It's the capacity to acquire intelligence through sensors or by exchanging data with its environment, and the analysis of those data. It's the capacity to learn through experience and interaction. It's a form of robot's physical support. Otherwise, we might not be talking about robots, but already in the morning we had the discussion of 'what is a robot?' 'Where are its limits of definition?'" Karin Röhricht, Fraunhofer IPA and euRobotics (ERF 2017)

The scope of definition of *robot* and *AI*, and the wide variety of machines covered by these terms, were recurring themes in this workshop and in others. The resolution itself opens with this statement: "…there is a need to create a generally accepted definition of robot and AI that is flexible and is not hindering innovation ," (European Parliament 2017, C).

During the workshop, Dominik Boesl, speaking on behalf of his organization Robotic Governance Foundation, discussed the importance of having common understandings of robot and other terms, particularly with regard to regulations. Here, he speaks of his experience at a media seminar held in connection with the parliamentary resolution, and of the confusion over the robot concept:

"The second thing is the journalists were completely / well, it is exactly a representation of what you read in the media. They were mixing up software bots and hardware bots. And they were talking about robots that were industrial robots and they put them on the same page with science-fiction like Jetson's Rosie. And the typical question like, "When do we need Asimov's laws?" And if those robots are now going to rampage in the singularity when artificial intelligence gets better and better, and so on. But the first issue, I really think, is we have to – and they've also already mentioned the general assembly on Tuesday – we have to start to inform the general republic. First of all about what the robot is. We don't have to do scientific differentiations, but we really have to explain to them a robot is something that is physical, and a bot or an agent might be something that lives in software. The two together can do something that might have an implication. And maybe they might also form an autonomous system. But all those things were not clear." (Dominik Boesl, KUKA Robotics and Robotics Governance Foundation, ERF 2017)

Boesl points to the entanglement of science fiction, media, and complex composition of robot systems in informing a public understanding of the robot. He tasked the robotics community with informing the public about what a robot is. But even that was not settled among the attendees of the workshop. The topic of robot ontology came up early in the workshop when Karin Röhricht was delivering the feedback euRobotics members had given with regard to the resolution. The members considered the resolution to be too broad in that it addressed diverse classes of robots with the same proposed regulations. As one member expressed, "We're talking about robotic toys compared to robots that can lift two or three or five tons, or whatever. Handling molten steel or self-driving cars at 200 kilometers an hour," (ERF 2017).

Dominik Boesl, again, emphasized the point that there really is no consensus on what a robot is: "So what do we consider a robot? Is it something that lives in software, a smart system? Is it something that lives in hardware? Something that is big? Or is it a general purpose machine, or whatever?" (ERF 2017).

The discussion ultimately lead to a debate over whether current laws and regulations were sufficient to regulate robotics. Some classes of robot are currently certified or regulated under a machinery directive, international standards, and/or defective product laws. These laws regulate robots as machines or products, but the European Parliament found such governance insufficient. In their 2015 draft resolution, the committee suggested that robots be governed under a civil law as an agential entity:

"Whereas the more autonomous robots are, the less they can be considered simple tools in the hands of other actor… as a consequence, it becomes more and more urgent to address the fundamental question of whether robots should possess a legal status."(Committee on Legal Affairs 2015, 5.S)

The proposal also proposed that third existence category which Jennifer Robertson (2014) had discussed:

"Whereas, ultimately, robots' autonomy raises the question of their nature in the light of the existing legal categories – of whether they should be regarded as natural persons, legal persons, animals or objects – or whether a new category should be created, with its own specific features and implications as regards the attribution of rights and duties, including liability for damage." (Committee on Legal Affairs 2015, 5.T)

And while this notion of personhood was ultimately limited in the final draft of the resolution (see comparison in Table 2), it remained a heated topic of debate at ERF.

Table 2 Liability and personhood, European Parliamentary resolution

2015 Draft Resolution	2017 Final resolution
"Whereas the more autonomous robots are, the less they can be considered simple tools in the hands of other actor (such as the manufacturer, the owner, the user, etc.); whereas this, in turn, makes the ordinary rules on liability insufficient and calls for new rules which focus on how a machine can be held – partly or entirely – responsible for its acts or omissions; whereas, as a consequence, it becomes more and more urgent to address the fundamental question of whether robots should possess a legal status." (Committee on Legal Affairs 2015, 5.S)	"Whereas the more autonomous robots are, the less they can be considered to be simple tools in the hands of other actors (such as the manufacturer, the operator, the owner, the user, etc.); whereas this, in turn, questions whether the ordinary rules on liability are sufficient or whether it calls for new principles and rules to provide clarity on the legal liability of various actors concerning responsibility for the acts and omissions of robots where the cause cannot be traced back to a specific human actor and whether the acts or omissions of robots which have caused harm could have been avoided." (European Parliament 2017, AB)
"Whereas, ultimately, robots' autonomy raises the question of their nature in the light of the existing legal categories – of whether they should be regarded as natural persons, legal persons, animals or objects – or whether a new category should be created, with its own specific features and implications as regards the attribution of rights and duties, including liability for damage." (Committee on Legal Affairs 2015, 5.T)	"Whereas, ultimately, the autonomy of robots raises the question of their nature in the light of the existing legal categories or whether a new category should be created, with its own specific features and implications." (European Parliament 2017, AC)
"…creating a specific legal status for robots, so that at least the most sophisticated autonomous robots could be established as having the status of electronic persons with specific rights and obligations, including that of making good any damage they may cause, and applying electronic personality to cases where robots make smart autonomous decisions or otherwise interact with third parties independently." (Committee on Legal Affairs 2015, 12.31.f)	"…creating a specific legal status for robots in the long run, so that at least the most sophisticated autonomous robots could be established as having the status of electronic persons responsible for making good any damage they may cause, and possibly applying electronic personality to cases where robots make autonomous decisions or otherwise interact with third parties independently." (European Parliament 2017, 59.f)

The language of legal status and personhood clauses was changed in the final draft to omit the phrases "whether robots should possess a legal status" and removed all mention of particular existing legal categories (natural/legal person, animal, or object) and associated rights, duties, or obligations (European Parliament 2017). Although this notion of electronic / legal personhood was ultimately limited in the final draft of the resolution, it remained a heated topic of debate at ERF. Karin Röhricht, reported on feedback that euRobotics had received regarding the EU resolution:

"Some people answered me that a machine cannot and will not be a human, and a civil law is made for citizens and not for machines. Because humans have this sort of self-awareness that machines cannot have, so already a civil law itself is inappropriate for machines. And the fact of liability is also a human invention related to the self-awareness, so it doesn't fit to robots."
(ERF 2017)

Andrea Bertolini, who participated in the EU-funded RoboLaw project was also present at the ERF workshop and had this response:

"Like 'Civil laws are not made for machines or robots, but only for human beings' – clearly whoever said that never opened a book of law or civil code. Because in the civil code you'll find a lot of laws about things, regulating things. And civil law precisely addresses the relationship between human beings and human beings and things. So it makes sense. Product liability that some of you mentioned, is actually a part of laws that fall within civil law. So it makes no sense."
(ERF 2017)

The contestation of the political understanding of robot, as a mere tool or as a being, is evidenced in the changing language from the 2015 draft resolution, through the 2016 study, and ultimately in the final 2017 resolution. Nathalie Nevejans, author of the 2016 study, was vehemently opposed to the idea of electronic personhood, calling it "as unhelpful as it is inappropriate," (14).

"Yet how can a mere machine, a carcass devoid of consciousness, feelings, thoughts or its own will, become an autonomous legal actor? ...it is impossible today — and probably will remain so for a long time to come — for a robot to take part in legal life without a human being pulling its strings."
(Nevejans 2016, 15)

Nevejans attributes the resolution's proposed personhood to an understanding of the autonomous robot that she considers inaccurate:

"In reality, advocates of the legal personality option have a fanciful vision of the robot, inspired by science-fiction novels and cinema. They view the robot — particularly if it is classified as smart and is humanoid — as a genuine thinking artificial creation, humanity's alter ego. We believe it would be inappropriate and out-of-place not only to recognise the existence of an electronic person but to even create any such legal personality. Doing so risks not only assigning rights and obligations to what is just a tool, but also tearing down the boundaries between man and machine, blurring the lines between the living and the inert, the human and the inhuman."
(Nevejans 2016, 15-16)

Nevejans' strong objections are reflected in the more conservative language used in the final 2017 resolution.

What these deliberations show are the processes of negotiation that are underway between technical, legal, and political actors in Europe to define what a robot is. There is a push and pull between defining the robot on the basis of its material being (i.e. the robot as materiality) and on the basis of its social, cultural, and agential being (i.e. the robot as a cultural force). Considering the legal, ethical, and human implications of discordant notions of the robot, it is essential to extend our understanding beyond technical ontologies, beyond legal definitions, beyond fantastic imaginaries, and beyond humanoid-centric social understandings. To truly understand the concept of robot, we must consider both the material machine and the human context in which it is created and embedded.

1.5.3 How robots are conceptualized in STS research

From the various perceptions in social spaces, we've seen that a robot is constantly shifting between being perceived as a material and a socio-cultural artefact. Through social science research, we can come to understand the robot as both materiality and concept. In the social sciences, robots are never seen as stand-alone autonomous beings, but as embedded in networks, cultures, and contexts. Thus, STS scholars concur that robots do not exist as autonomous entities. Within STS however, scholars differ in whether they emphasize the importance of culture and context or rather see robots as embedded in flat networks of humans and non-humans. The STS perspectives, used to study robots in social spaces, can be roughly divided into the following analytical approaches: social and spatial arrangement/interaction, STS-network analysis, multistability and the robot 'becoming', humanizing the robot-other, and the robot as a social construction. When robots are seen as contextualized and cultural, as in the cultural constructivist perspective, there is an emphasis of historical developments as well as an acknowledgement of humans as perceptual participants and observers. In studies of the agency of humans and non-humans, like robots, may be acknowledged, but human perception is an important aspect of how robots gain agency. In the network analysis both humans and non-humans are salient as social actors that create and engage with each other. The network analysis is more descriptive and focus equally on the agency of non-humans and humans without granting the humans a particular social and perceptual position in the analysis.

Though studies of robots only occupy a small subfield in STS, it is a proliferating field, which has raised many questions about sociality and relevant conceptualizations in relation to human-machine entanglements.

5.3.1 Network analysis

Empirical studies of robots follow different analytical strategies in the social sciences. In the field of STS there is an ongoing development and debate of analytical concepts and approaches to studies of technology like robots. Some scholars in this field, like Karen Barad and Bruno Latour, have questioned the usefulness of concepts like culture and context in relation to technology because these term refer to explicitly human realms of perception – and many STS scholars do not privilege the perception of the humans in their theorizing.

Since the 1990s many STS-analyses of technology have been engaged in what is known as network-analysis – often inspired by a so-called 'flat ontology'. The focus is on agency. Humans are not granted a more important position than non-humans in the creation of the agency of humans and non-humans entangled in networks (Latour 2005). When looking to robots as 'mirrors' of humankind the configurations created by humans and non-humans alike are both material and conceptually distributed in networks.

In her 2007 book *Human-Machine Configurations*, Lucy Suchman explains how certain understandings of humanity inform the production of robots, which then reproduce these understandings of humanity and the subsequently intertwined understandings of robots. This tangled process is best understood by her theoretical grounding in network analysis inspired by Bruno Latour's ' actor-network' approach.

Suchman's book is primarily about artificial intelligence and smart machines in general, but many of her arguments are directed at robotics or are relevant to robotics. One primary argument in Suchman's book is that ideas about what a robot is and about what a human is are woven together through roboticists practices and humans' inherently social interactions with robots (Suchman 2007).

"Just what it means to be humanlike, and how the boundary between humans and nonhumans is correspondingly drawn and redrawn, is of course one of the matters in question. A central premise of this book is that projects in AI and robotics involve a kind of doubling or mimicry in the machine that works as a powerful disclosing agent for assumptions about the human. [Footnote: I need to make clear that I am not suggesting, as do roboticists themselves, that these projects work as scientific models of the human but rather, that they make evident how roboticists imagine humanness.]."
(Suchman 2007, 226)

To define the robot as an autonomous social agent based on its material components involves cutting it from this social network in which it is embedded. "In the case of the robot, or autonomous machine more generally (as in the case of the individual human as well), this work takes the form of modes of representation that systematically foreground certain sites, bodies, and agencies while placing others offstage," (283). In this way, a robot can either be understood as a material artefact cut from the network, or as a sociocultural artefact embedded in its world, in relation to the humans and nonhumans it is engaged with.

Suchman demonstrates these notions with her descriptions of the robots Cog and Kismet, of MIT's Artificial Intelligence Laboratory. Her initial understandings of what these robots were and of what these robots could do, were based on media representations, scientific papers, and the observed interactions between particular people with these particular robots. "Pictured from the 'waist' up, Cog appears in media photos as freestanding if not mobile, and Kismet's Web site offers a series of recorded 'interactions' between Kismet and Breazeal as well as between Kismet and selected other human partners," (Suchman 2007, 237). When Suchman visited these robots in person, no longer cut from the environment or people with which they are entangled, a new understanding developed:

"We were, however, able to visit the inanimate Cog sitting in a corner of the lab. Although still an imposing figure of a robot, what struck me most powerfully about Cog was the remainder of its "body" not visible in media portrayals. The base of Cog's torso was a heavy cabinet from which came an extraordinarily thick sheaf of connecting cables, running centaurlike to a ceiling-high bank of processors that provided the computational power required to bring Cog to life. Seeing the robot "at home" in the lab, situated in this "backstage" environment, provided an opportunity to see as well the extended network of human labours and affiliated technologies that afford Cog its agency, rendered invisible in its typical media staging as Rod Brooks's singular creation and as an autonomous entity."
(Suchman 2007, 246)

This experience illustrates the role of the robot's network or context, including the humans and nonhumans that make up the network, in forming an understanding of the robot itself.

It has been argued that the division between social and material should be dissolved all together as the social is material and the material social (Latour 2005). Along these STS lines we should be aware of the 'agentic cuts' we make, when we create analytical dichotomies between subjects and objects like robots and humans (Barad 2007). This analytical point refers to the way materials merge with human perception and conceptualization without taking a point of departure in humans as the observers.

However, Suchman offers a way out of the predicament when she says that we need: "a story that can tie humans and nonhumans together without erasing the culturally and historically constituted differences among them ... [and] to keep in view ... the ways in which it matters when things travel across the human-artifact boundary" (Suchman 2007, 270). The cultural constructivist perspective perhaps offers the cultural emphasis that the flat agential model lacks.

5.3.2 Cultural constructivist perspective

Like Jennifer Robertson, Selma Šabanović (2014) writes about the social construction of the robot in Japan. Robertson links social acceptance of robots in Japan to Shinto beliefs and to linguistic and cultural conceptions of life and being. Šabanović contributes to this culturally produced understanding to include the political practices which actively shape particular notions of the robot: "The presentation of robots as endemic to local culture is the product of continuing efforts by the government, industry, and academia to encourage popular acceptance of robotics," (2014, 343).

Šabanović goes through specific robot cases to illustrate how the robots are not only products of Japanese culture, but through the practices of roboticists in Japan, these artefacts produce and reproduce certain aspects of Japanese and robotics cultures. She argues that roboticists use their robots and the understandings they produce as political technologies. "The examples of PARO, HRP-2, and kansei robotics present robots as cultural products, performers, and subjects and show how robotics researchers use their cultural standpoint to provide epistemological grounding and social justification for robotics," (359).

Finally, Šabanović supports the idea which Lucy Suchman presented of the human being reflected and reproduced through robot development: "Focus on robotics design as a process of cultural repeated assembly therefore calls for reflection on how the cultural models embodied by and embedded in robots affect people's evolving sense of their relational and cultural selves" (359). Where Robertson presented social construction, Šabanović incorporates the cultural and political into constructions and reproductions of the robot and, consequently, the human. The STS perspective on multistability extends both arguments to include the materiality of the technology in these processes.

5.3.3 Multistability and the robot "becoming"

Another analytical approach which may prove useful for the

REELER project is the postphenomenological concept of 'multistable technology'. A robot from this STS perspective is not a stable artefact, as noted in Cathrine Hasse's text *Multistable Roboethics* (2015). "Neither human nor technology act separately from each other but create each other through processes of 'multistability'," (Rosenberger 2014, in Hasse 2015).

Suchman (2007) had presented a temporal understanding of a robot as it is situated in its network, where the understanding of the robot develops with an understanding of its context. Along the same vein, Cathrine Hasse explains how "technology is embedded in life-worlds of inter-engaging humans and technologies (Ihde 1990)" and how through processes of multistability, the robot and the human create each other (Hasse 2015, 171). This understanding of the robot in the throes of becoming takes into account material, cultural, and political dimensions. "Stability is not embedded in the "thing" but in the material as well as traditions and relations following embeddedness in cultural use," (172).

Hasse gives the example of the Paro and Silbot robots, in use in Danish care facilities. Both robots instigated changes in the workplace to accommodate the robots into their cultural communities. In the case of Silbot, the robot itself had to be adapted to fit the setting. It had come from Korea with programmed interactions perceived as rude in Denmark and had to be "stabilized through re-programming," (180). With Paro, the staff made their own accommodations in their interactions with the robot, with its care, and with their combined interactions with the 'citizens' of the care facility.

"The staff and citizens have to do a lot of hard work to include these bodies in their local amalgamation. Even when "corrected" the staff and citizens have to keep learning how to stabilize this new category of being. Even so the presences of the robots are never questioned. In the process robot, staff and citizens gradually became stabilised bodies in an amalgamation including material bodies as well as ideas of a robotic future."
(Hasse 2015, 181)

The staff and the robot were materially and conceptually changed by their shared social interactions. These processes of multistability, of co-constitution, and of reproduction of particular understandings of both the robot and the human self, evoke the history of the 'marvel and mirror' robot as an exploration of the human-machine boundary.

This approach to multistability in robotics takes the technical understanding of a material artefact and incorporates the sociocultural interactions that continuously shape the robot in its process of becoming. With this and the other STS perspectives, we have seen how a robot can be defined as both materiality and concept, and how this integrated definition is constructed within the cultural and social spaces from which the robot is inextricable.

1.6.0 Areas of Impact

1.6.1 Robots at work

The main area where roboticists' creations are used is in industrial work and areas tied to the labor-market. As mentioned in the opening of this chapter, many economists forecast that robots will enter the labour market in unprecedented ways within the next 20 years and as many as 40% of the work done today by humans will be replaced by robots and automated processes (Osborne and Frey 2013). Likewise, the article 'Robot Revolution' [15] in the Guardian noted that because the pace of disruptive technological innovation has gone from linear to parabolic in recent years, we are facing a paradigm shift which will change the way we live and work. However, other voices, such as Wajcman (2017), pose a more critical and nuanced stance to this forecast.

Nourbakhsh (2013) and Ford (2015), among others, describe how the development in productivity, GDP, employment, and income from 1953 to 2011 in the US changes in the 1980s, where median household income starts to level off although productivity and GDP continue their upward arc. In the mid-1990s, "employment flattens as GDP and productivity continue even faster growth" (Nourbakhsh 2013). Among the scholars referenced in this section seems to be agreement that this radical change in the dynamics of productivity and employment is most likely triggered by the fast-developing technological innovation and slow-changing human society.

"The end-of-work argument has been made by, among many others, economist John Maynard Keynes, management theorist Peter Drucker, and Nobel Prize winner Wassily Leontief… [T]here has been relatively little talk about the role of acceleration of technology. It may seem paradoxical that faster progress can hurt wages and jobs for millions of people, but we argue that's what's been happening. … The root of our problems is not that we're in a Great Recession, or a Great Stagnation, but rather that we are in the early throes of a Great Restructuring. Our technologies are racing ahead but many of our skills and organizations are lagging behind."
(Brynjolfsson and MacAfee 2011, 10)

So, which roles are robots expected to overtake and how do scholars in the field of economics describe these robots and the expected impact? In this section, we take a closer look at robotics technology with relation to economic prospects and impact on human employment.

6.1.1 Gains by introducing robots

First, we will look at the incentives for introducing robot, knowing that the impact is likely to be structural underemployment. Here, efficiency is a recurring key word. However, *efficiency* does not always equal high quality. In some areas of work, robots will be mediocre compared to human standards for

15 https://www.theguardian.com/technology/2015/nov/05/robot-revolution-rise-machines-could-displace-third-of-uk-jobs

many years. Nevertheless, Nourbakhsh argues, [service] robots will be implemented "not because they advantage the customer, but because they save money for a corporation".[16]

In other job categories, robots will clearly outperform humans by being more effective partly because they "… have the ability to work continuously, and as they become more flexible and easier to train for new tasks, they will become an increasingly attractive alternative to human workers, even when wages are low." (Ford 2015, 11)

Another example comes from US textile and apparel exports, which rose by 37 percent to a total of nearly $23 billion between 2009 and 2012. "The turnaround is being driven by automation technology so efficient that it is competitive with even the lowest-wage offshore workers. … While a robot like Baxter can certainly eliminate the jobs of some workers who perform routine tasks, it also helps make US manufacturing more competitive with low-wage countries." (Ford 2015, 9)

However, Martin Ford also points to other differences between humans and robots that make robot technology competitive: "Robotic production might be viewed as more hygienic since fewer workers would come into contact with the food. Convenience, speed, and order accuracy would increase, as would the ability to customize orders." (Ford 2015, 15)

Another incentive is the notion of robots relieving people from hard and tedious work; an argument that can be found both in economics and the social sciences. Lucy Suchman, for instance, writes: "Just as the dream of the robot worker was to relieve us of hard labor, or of the contingencies of managing others so engaged, so the dream of agents at the interface promises to relieve us from having either to perform the mundane work involved in providing services for ourselves or to negotiate the moral dilemmas and practical inconveniences of delegating that work to others who might – more and less faithfully – represent us," (Suchman 2007, 224). And Brynjolfsson & MacAfee point to the relation that "[p]eople get bored, people get headaches. Computers don't." (2011, 18). The notion of relief, or being freed-up, is presented as another positive impact, particularly in connection with routine, low-wage, low-skill jobs, which tend to be viewed as inherently undesirable, at least in advanced economies (Ford 2015).

6.1.2 Affected sectors

Robots and robot technology are increasingly deployed across nearly every sector of the economy, and agriculture stands out as the one that has undergone the most dramatic transformation due to technological progress. The service sector is mentioned as one that will see the greatest impact in the near future. One area which holds great potential for automation processes and robotics technology is the production of fast food, where gains such as accuracy, high hygiene and speed are robot qualities are stressed. The other major concentration of low-wage service jobs is in the general retail sector.

Ford (2015) notes that three major forces are likely to shape employment in the retail sector going forward. "The first will be the continuing disruption of the industry by online retailers like Amazon, eBay, and Netflix [i.e. online retailers]." Not only the cashiers are expected to be replaced by robots, but the tradition warehouse worker will be superfluous as online shopping tends to lead to fully automated warehouses.

"The second transformative force is likely to be the explosive growth of the fully automated self-service retail sector—or, in other words, intelligent vending machines and kiosks." Again, restocking is expected to be highly automated and the "… third major force likely to disrupt employment in the retail sector will be the introduction of increased automation and robotics into stores as brick and mortar retailers strive to remain competitive."
(Ford 2015, 16-19)

Other sectors are the legal and financial sectors. To take the latter first, stock market trades heavily rely on automated trading algorithms. Though one may argue that algorithms and information technology are strictly speaking not robots, they are an integral part of robotics. Ford (2015) describes how the speed of this robotics technology clearly outperform humans when the average time to execute a trade dropped from about 10 seconds to just 0.0008 second between 2005 and 2012. And he reminds us that "robotic, high-speed trading was heavily implicated in the May 2010 'flash crash' in which the Dow Jones Industrial Average plunged nearly a thousand points and then recovered for a net gain, all within the space of just a few minutes." (Ford 2015, 55)

Computational pattern recognition abilities are already being exploited by the legal industry where, according to one estimate, moving from human to digital labour during the discovery process could let one lawyer do the work of 500: "From a legal staffing viewpoint, it means that a lot of people who used to be allocated to conduct document review are no longer able to be billed out" (John Markoff 2011).

6.1.3 Types of robots and work tasks

When looking into the type of robots that are primarily discussed as having an impact on world economy we see that the humanoid robots play a more limited role than industrial, service robots and collaborative robots. Our empirical data also hold examples like Martin Davies of Guidance Automation who at the European Robotics Forum 2017 equated automation to the introduction of the weaving loom, which he claimed increased efficiency and relieved the workers of certain work, yet stated that: "Robots will take your jobs, but it won't be humanoid." Although the humanoid, social robots are not deem to impact labour market. Wajcman touches upon the bewitching and somewhat misleading nature of the termi-

16 Nourbakhsh (2013). It's Time to Talk about the Burgeoning Robot Middle Class. MIT Technology Review. https://www.technologyreview.com/s/514861/its-time-to-talk-about-the-burgeoning-robot-middle-class/

nology characterizing these types of robots when she writes that "the author [i.e. New Scientist (16 July 2016)] makes the point, familiar to sociologists of science, about the powerful role of metaphors in persuading us that these machines are acquiring human capacities." (Wajcman 2017, 3). Note that Wajcman tend to describe these as *machines*.

In addition to automation, information technology, artificial intelligence, algorithms and visual recognition typically come up as areas within robotics that are, and will become, heavily influential. "Penetration of robots and artificial intelligence has hit every industry sector, and has become an integral part of our daily lives" (The Guardian 2015) which points in the direction of robots not only doing manual jobs, but with the development of artificial intelligence increasingly performing analytical tasks once seen as requiring human judgment. Ford writes that "[o]ne of the most important propellants of the robot revolution may turn out to be "cloud robotics"- or the migration of much of the intelligence that animates mobile robots into powerful, centralized computing hubs. …. The impact of cloud robotics may be most dramatic in areas like visual recognition that require access to vast databases as well as powerful computational capability." (Ford 2015, 21)

Nonetheless, the current types of work tasks typically carried out by robots are manual and repetitive such as "moving boxes with maximum efficiency" (ibid., 5), wherefore the sectors or job categories to be mostly affected in the near future by robotics technology seem to be low-skilled factory work.

Yet, not all low-paid jobs that require modest levels of education and training in the service sector fall within the risk-category. Job categories such as cleaning, gardening, carers, bar staff or cooks are deemed hard to replace because machines have difficulties replicating the movements of humans in everyday tasks.

"Humanoid robots are still quite primitive, with poor fine motor skills and a habit of falling down stairs. So it doesn't appear that gardeners and restaurant busboys are in danger of being replaced by machines any time soon. And many physical jobs also require advanced mental abilities; plumbers and nurses engage in a great deal of pattern recognition and problem solving throughout the day, and nurses also do a lot of complex communication with colleagues and patients."
(Brynjolfsson and MacAfee 2011, 18)

In fact, it is argued that overtime, and with the estimated rapid developments in AI, the jobs most likely to be threatened by technology are not only those with a high level of routine, but also higher-skill occupations with a certain degree of predictability (Ford 2015, xiv-xv) as we saw in the above-example from the legal sector. "The hard problems that are easy for AI are those that require the application of complex algorithms and pattern recognition to large quantities of data … such as calculating a credit score or insurance premium, translating a report from English to Mandarin Chinese, or managing a stock portfolio."[17]

Many robots are designed to collaborate with humans e.g. in factories along assembly lines, others are intended to be operated by humans e.g. in health care and education. A voice from our empirical data is Dominik Boesl of Robotic Governance Foundation, who argues that the future will bring more examples of collaborative and/or changed work routines than simply replacement: "We are currently seeing exactly that fear and anxiety that, for example, secretaries had some years ago when the computer was established. So they were like: 'Oh, give me my typewriter back' or 'It will destroy my job'. No, it just changed the job. And this is exactly the same thing that's happening today," (ELS workshop, ERF 2017).

Nourbakhsh describes a potential human-robot interaction in work-related context as one where the human brain (as long as artificial intelligence is not more advanced) will be used to 'step in' when needed: "A whole factory of thinking humans could be replaced by unthinking robots so long as they had that drone interface, asking for just-in-time problem-solving help from a human supervisor when needed. Give companies a great human-robot interface and a whole pallet of dumb robots, and you still have an underemployment crisis." [18] Though Nourbakhsh's purpose here is to show that even without intelligent robots we still face an underemployment crisis, a crucial ethical issue is also that Nourbakhsh assumes robots will be able to judge (or has been properly programmed to react) when human intervention is needed.

Nevertheless, the literature holds several cases where companies invest in robots with the purpose of replacing humans, as in fully automated warehouses like Ocado or Momentum Machines co-founder Alexandros Vardakostas comment: "Our device isn't meant to make employees more efficient. … It's meant to completely obviate them," (Ford 2015, 12).

Certain areas of the labour market do, however, seem to be relatively resistant to the robot revolution, viz. creativity and art. "And for all their power and speed, today's digital machines have shown little creative ability. They can't compose very good songs, write great novels, or generate good ideas for new businesses." (Brynjolfsson and MacAfee 2011, 19).

6.1.4 The broader work-related impact of robots

The forecast of our economic prospect is often gloomy, stating for instance that: "virtually every industry in exist-

17 Elliot, I. (2017). The new robot revolution will take the boss's job, not the gardener's' In: The Guardian https://www.theguardian.com/business/economics-blog/2017/jan/22/the-new-robot-revolution-will-take-the-bosss-job-not-the-gardeners?CMP=share_btn_link

18 Nourbakhsh (2013). It's Time to Talk about the Burgeoning Robot Middle Class. MIT Technology Review. https://www.technologyreview.com/s/514861/its-time-to-talk-about-the-burgeoning-robot-middle-class/

ence is likely to become less labour-intensive, and many of the jobs created in recent years are low-paying, manual or services jobs which are generally considered 'high risk' for replacement". (The Guardian 2015) This leaves us with a real threat of, what Brynjolfsson and MacAfee define as, technological unemployment (Brynjolfsson and MacAfee 2011) also referred to as structural underemployment (NB. reference) and a highly polarized labour. Though the REELER project has decided not to look into robots with potential dual use, it is relevant to include views on the role of robotics and military for our economy. Nourbakhsh writes for instance that "[f] unding flows from industry and military sources that have specific, self-serving criteria for innovation and impact. The agenda is set by the availability of money, and so the holders of the purse have disproportionate power over the direction of our robot future" (Nourbakhsh 2013a, 111-112). He continues to argue that "[i]nstitutions benefit [from robotics technology], but the problem is that their goals never align perfectly with those of society as a whole. In fact, further empowerment of corporations can cause *disempowerment* in communities as new technologies *asymmetrically* and opaquely confer the power to shape information and manufacture desire.," (ibid, 110).

The robot revolution is described as an era that will fundamentally change the relationship between workers and machine and our most basic assumptions about technology: "[T]hat *machines are tools* that increase the productivity of workers. Instead, machines themselves are turning into workers, and the line between the capability of labor and capital is blurring as never before". (Ford 2015, xii) Moreover, Brynjolfson & MacAfee note that because of the nature of the current technological progress "there's never been a better time to be a worker with special skills or the right education, because these people can use technology to create and capture value. However, there's never been a worse time to be a worker with only 'ordinary' skills and abilities to offer, because computers, robots, and other digital technologies are acquiring these skills and abilities at an extraordinary rate," (Brynjolfson & MacAfee 2016, 10).

As mentioned earlier, Judy Wajcman (2017) presents, together with John Urry, a critical response to the futurist discourse of robot technology (including IT, AI, machine learning, Big Data and affective computing) taking over labour market leaving humans redundant, and argues that "… the most efficient future lies with machines and humans working together. Human beings will always have value to add as collaborators with machines," (Wajcman 2017, 5). Wajcman points to one area, in particular, of the labour market, which is seldom mentioned in the economic accounts of robots and work, that is unlikely to be affected by robot technology; viz. the classical 'female professions' or 'softer professions' involving emotional, relational work such as nursing. Rather than dreading structural unemployment as a consequence of the technological development, she notes that agents in this field (social scientists, politicians and economics) ought to direct attention toward "the dominance of a small number of corporations who have this computing power and about the social consequences thereof." (ibid., 6)

1.6.2 Robots in healthcare

When the science fiction inspired humanoids now begin to 'spill out' into the real world of humans – they are expected to participate in everyday settings – for instance, in health care centres. Contrary to the humanoid robots on display in the media, these robots have to live up to scrutiny. In everyday human-robot interactions, the smooth operations of the humanoid become more problematic than when presented in movies. The machines may make strange sounds or drop dead in the middle of a sentence when the power goes out (Hasse 2013). For those who have actually met these humanoid robots and have tried to engage with them in health care centres, the experience has been one of disappointment. The social robots are not created with a particular purpose – and the staff expect them to be able to help with multiple tasks. When the robots fail to provide general help, the staff have to be inventive to try to come up with purposes for the robots (Bruun et al. 2015). Despite their underwhelming debut, social scientists, like roboticists, continue to write about 'a robotic movement' (Turkle 2011) tied to the humanoid rather than to industrial robots.

Many STS studies focus on studies of roboticists and on media representations of social robots. However, in Scandinavia we do find a rich field of studies on social robots implemented in healthcare settings where humans 'stretch' themselves to accommodate the robotic newcomers in their everyday practices (e.g. Bruun et al. 2015, Hasse 2013, Hasse 2015, Leeson 2017).

The roboticist Ishiguru, for instance, has made a humanoid robot by the name of Telenoid (different models have different suffixes like R1 or R4) which is meant to figure as a 'generalised human' (Leeson 2017). Contrary to the Ishiguru geminoids, these robots have been sold to public institutions like healthcare institutions in Denmark.

Like other robots sold to be used in healthcare, the Korean Silbot, e.g. (see Hasse 2015), the Telenoid was not invented with any intention to provide healthcare. It was developed as a telecommunication system, then it was tested as a kind of teacher's companion in schools (Yamazaki et al. 2012a; Ogawa et al. 2011a) and on elderly people in a shopping mall (Ogawa et al. 2011b) and only as a later option was it involved in care facilities (Yamazaki et al. 2012b; Yamazaki et al. 2012c).

The robot is about the size of a child, all white, and teleoperated. Just like the Geminoids, the Telenoids depend on being wired up with a human operator who, like the chessplaying human in the Turk, is hidden from view. This method is known as a 'Wizard of Oz' technique, referring to "that man behind the curtain" in that the robot is tele-operated by a hidden operator who also speaks through the device (cf. Goodrich and Schultz 2007, 252).

The Telenoid robot was originally expected to be a welcome new kind of 'mobile' that would give the persons communicating an embodied feeling of their counterparts. However, the purpose with these robot when implemented in the Danish health care systems is not at all clear, although the robot is adapted for use in a both Danish nursing home and activity centre for cognitively disabled individuals. In a multisided ethnographic study the Danish anthropologist Christina Leeson followed "the experiences of the people who are introduced to robots and encouraged to evaluate and use them in their daily lives" and found that:

"Telenoid was not imported because consultants had a clear idea of how to put it into use in the Danish healthcare sector. On the contrary, Telenoid materialized in the Danish healthcare sector because the consultants saw the robot as an opportunity to establish important collaborative ties with the Japanese roboticists. 'This is a research project where we have an open and curious approach to what might work', stated, Jens, the manager of the consultancy before receiving Telenoid. 'We really wanted to work together, so now we must try to identify some scenarios where people can benefit from it.Telenoid is one of those kinds of technologies where we cannot automatically predict its potential so we must see what we can get out of it'.
(Leeson 2017, 5-6)

1.6.3 Education and robots

Very few studies have been made studying how robots are actually used in schools, but our research has shown particular interest in using robots for learning purposes in STEM-related areas. There seems to be a rise in the use of robots in schools (see EPPI search data in APPENDIX 1 of Deliverable 2.2) [19]. "Robotics and computer programming initiatives for young children have grown in popularity over the past 5 years as new products for young learners have emerged on the commercial market," (Elkin, Sullivan, & Bers 2016, 169-170). In this section, we explore trends in the use of robots and robotics in education.

A review of roughly 200 abstracts and selected full texts revealed threads of determinism and normativity regarding robots and robotics within education literature. The bulk of the articles focused on A) outcomes of current use of robots in education, and B) how to effectively incorporate robots into education. There was little mention of whether educational robots should be used in schools and the justification for *why* we should use educational robots or robotics largely relied on future-oriented determinist arguments. This excerpt from a study on the attitudes toward educational robots illustrates this orientation toward technology and the future:

"The proliferation of technology shapes todays school and classroom activities. Projectors, laptops or smart boards have become quite common in education. Students and educators face the challenge of incorporating the most recent technological developments into learning and teaching processes. Latest advances in the field of educational technologies try to integrate robotic companions into learning contexts."
(Reich-Stiebert & Eyssel 2015, 875)

There are diverse claims regarding the utility of educational robots and robotics. Robots have reportedly been used in schools: to foster creativity (Nemiro, Larriva, & Jawaharlal 2017), to build teen futures (Wallace & Freitas 2016), to promote social-emotional development (Chernyak & Gary 2016), to develop scientific research skills (Datteri et al. 2013), . These outcomes are used to justify the use of robots, without consideration of the financial, psychological, or societal costs.

Another portion of the literature identified certain challenges or barriers to the implementation of educational robots in schools. These studies did not consider whether parents, educators, or children ought to accommodate robots – rather, research centered on solving the problems of acceptance, teacher competency (Bianco 2014), and other barriers. The justification for pushing for acceptance and implementation is often based on the normative or determinist idea that robots are the future; an example is seen in the aforementioned study on attitudes towards robots:

"In light of the fact that in the near future robots could also become part of various educational settings in Germany and throughout Europe, it may prove fruitful to explore attitudes toward robots that serve the purpose of supporting teachers as assistants to facilitate various learning activities."
(Reich-Stiebert & Eyssel 2015, 876)

The authors do not acknowledging the teachers', parents', and children's non-acceptance as a potential reason for not implementing the robots. Rather, they position their research as support for strategies for implementation in the face of resistance:

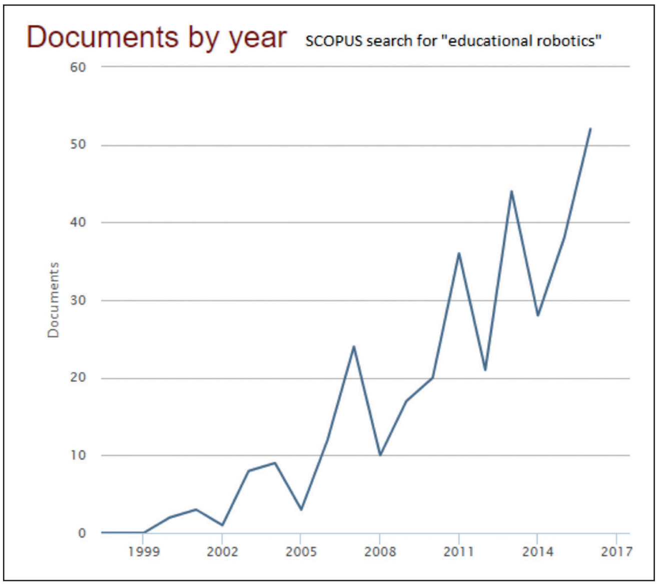
"Findings from our research could help to implement educational robots in line with the expectations of potential end-users. To illustrate, an implication of this is the option to introduce education robots into the school context primarily in STEM-related subjects before expanding the use to more social and cultural subjects."
(Reich-Stiebert & Eyssel 2015, 886-7)

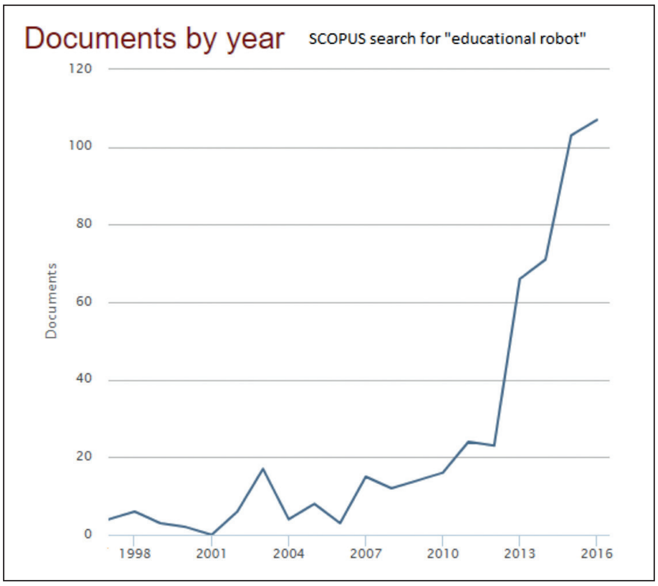
After a deeper look into the literature, there seem to be two primary approaches to practices involving robots in the classroom, *educational robotics* (as a field) and *educational robots* (as a tool). While mentions of *educational robotics* in academic literature has been steadily on the rise since the millennial turn, there has been a dramatic rise in mention of *educational robots* since 2012 (See Figure 1). This may indicate an increased number of commercially available educational robots (Elkin, Sullivan, & Bers 2016) or increased use of robots: "Introducing robotics in schools becomes popular nowadays and

19 See APPENDIX 1, section i. Robot as Materiality and Concept for an overview of the various search hits.

there is a larger and larger variety of commercial edutainment robots available in the market," (Basoeki et al. 2013, 51).

Figure 1 Trends in mention of 'educational robotics' and 'educational robots' [SCOPUS search for the specified terms]





Although *educational robotics* generally refers to a field of practice and *educational robots* generally refers to a class of machines applied in schools, these terms are not mutually exclusive. An educational robot being used to teach lessons in programming would qualify that particular practice as educational robotics. Likewise, educational robotics kits being used in classrooms might also be termed educational robots.

Educational robotics is a subject area based on the constructionist approach, suggested by Seymour Papert in the 1980s, in which children design, build, and program robots (Lye, Wong, & Chiou 2012). Educational robotics might include the use of the LEGO Mindstorm series, for example. Reported learning outcomes from these practices are typically robotics-specific technical skills, such as programming concepts and skills (Elkin, Sullivan, & Bers 2016). Some more general outcomes reported are: getting girls interested and engaged in STEM practices (Gomoll et al. 2016), improving preschoolers' sequencing abilities (Kazakoff, Sullivan, & Bers 2013), and developing collaboration skills (Yuen et al. 2014).

Educational robots, on the other hand, tends to refer to commercial robots put to a wide variety of applications in education. The outcomes from the use of *educational robots* seem to be more diverse than the reported outcomes of *educational robotics,* because there can be great variety in the type and application of the robot. From the use of humanoid robots as English-language learning partners (Mazzoni & Benvenuti 2015) to the use of robot platforms for distance-learning (Yun, Kim, & Choi 2013), robots have already been used in many applications in educational settings: to be programmed by children (Elkin, Sullivan, & Bers 2016), to teach children (Kwok 2015), as a telepresence interface (Yun, Kim, & Choi 2013), or as a teaching tool for other outcomes (Datteri et al. 2013.). Some reported outcomes are: increased language acquisition (Mazzoni & Benvenuti 2015), improved performance and decreased social anxiety in children with autism (Warren et al. 2015; Kaboski et al. 2015), enhanced learning motivation and performance (Hung et al. 2013).

Whether used as a field of study or as a tool with various applications, for both robotics and robots, there seems to be an uncontested push for robots in the classroom. This trend aligns with political emphases on STEM education and on the digitization of the workforce. Within the European Union, there are policies and strategies to prepare people for "modern society".[20] The EU Commission claims to be "developing policy and supporting research to make learners fit for 21st century life and work." [21] Accordingly, they've established the Digital Skills and Jobs Coalition, which has the goal of "developing digital skills to enable all citizens to be active in our digital society." [22] Under the EU Commission's broader Digital Single Market strategy, coding is called "the 21st century skill": "Coding is the literacy of today and it helps practice 21st century skills such as problem solving, team work and analytical thinking." [23] These digital-future oriented policies and strategies include plans for educating children. The EU Commission set this goal for the member states: "To provide citizens with the digital skills they need for their lives, we need a modern

20 "Digital Skills Policy." 2017. *European Commission Strategy: Digital Single Market.* Updated 16 May 2017. Accessed 23 May 2017 from: https://ec.europa.eu/digital-single-market/en/policies/digital-skills

21 [ibid; see previous]

22 "Digital Skills and Jobs Coalition." 2017. European Commission Strategy: Digital Single Market. Updated 16 May 2017. Accessed 23 May 2017 from: https://ec.europa.eu/digital-single-market/en/digital-skills-jobs-coalition

23 "Coding – the 21st century skill." 2017. European Commission Strategy: Digital Single Market. Updated 16 May 2017. Accessed 23 May 2017 from: https://ec.europa.eu/digital-single-market/en/policies/digital-skills

education and training system that equips young people with the skills they need to thrive in the digital environment," (Digital Single Market Strategic Group 2017).

A Danish report on robots in schools show that out of 272 Danish schools, 239 either use of plan to use robots for educational purposes. The same report also shows, however, that when ethnographic studies are conducted in schools with robots, the didactical considerations of what the children should learn from robots are rather vague (Esbensen 2017).

1.7.0 Conclusion

In this review, we have seen that understandings of what a robot is largely inspired by historical fantasy, interpreted through cultural imaginaries, transformed by media representations, legitimated by regulatory standards and parliamentary resolutions. As noted robots , and made material through incorporation into human social spaces. Robots are notoriously hard to define, both due to rapid changes in their material components and to conceptual diversities over time and across disciplines. Our understanding of the robot, the central concept in REELER, is therefore bound to change with our ongoing research.

What we may note for now is that within the robotics community, there is some agreement, but no consensus, on the technical definition rooted in the ISO definition (see section 3.4.1 Defining robots). Although it may appear to provide a very basic and precise definition, some vagueness also lies implicit in its terminology like "Intended tasks". "Intended by whom?", we may ask. The robot, affected stakeholders or the roboticists? Moreover, the wording "without human intervention" is vague. Does it disqualify an object as a robot if a human is somehow 'intervening'? That would rule out most of the machines called robots today as humans are involved in engaging and intervening with the robots in a multitude of ways.[24] Although the regulatory definitions aspire to be as precise as possible, we (coming from a social scientists conceptual perspective) note that a term like "an environment" in the ISO standard may be perceived differently from a technical compared to a social scientific point of view. In the social sciences 'an environment' will include humans, other non-human material and to some extent even human perception – with no exclusion of 'human intervention'.

This review has also shown that social scientists seem to have been less occupied with studies of industrial robots (with specific purposes) and more interested, like the media, in social robots, which tend to be created without a specific purpose other than an ongoing (philosophical) exploration of what makes machines humanlike (like the robots created by Ishiguro). Thus, the discussions from the historical epoch of automata still seems to be ongoing. Though the purposeful and clockwork precise industrial robot seem to have little in common with humanoids like Jia Jia, it is the concept of 'robot' and the urge to explore how humans may be replicated that tie these materialities together. In the STS field, these materializations are perceived as created by roboticists, like engineers, engaging in a particular engineering practice. Once created, the robots can be perceived as a cultural force. Robots are imagined and imbued with stories and fantasies; an aspect which is also underlined in the discussions of robots as legal entities in the political arena. This is for instance the case, when policy-makers note that there is a widespread understanding of a robot as "an autonomous machine able to perform human actions" (See 3.5.2.4 Political and legal perspectives). These perspectives seem largely informed by robots as a media phenomenon, and that cultural force of robots has a real effect and impact on labour markets, politics and economy – all of which is also part of the REELER study.

In politics, there is less focus on empirical studies of how most robots, whether claimed to be social or not, do have a direct social impact on people's lives in a wide arrange of everyday life situations from health, education to work life. Instead, media representations and economic surveys seem to be the primary basis for debates. This might be why politicians are prone, like many other people, to have an unrealistic understanding of robot capabilities, whereas the roboticists themselves seem much more pragmatic. Turning to the roboticists, they also seem to lack knowledge from ethnographic practice studies of perceived effects of robots in their design processes.

This lack of empirically based insight has ethical implications and should be addressed by social scientists versed in explorations of social spaces. However, SSH-research is still only an emergent field in robotics with an unexploited research potential of collaboration between SSH and robot engineers. Even if some roboticist agree with social scientists that social robots are "situated in social spaces with human social actors" (See 3.5.1 How robots are defined by STS scholars) this acknowledgement has yet to be attributed to *all* robots, whether social or not. Here social scientists seem to lack a focus on robots that are not defined as social.

The REELER project has thus identified a need for ethnographic studies that explore how people in real life situations (not formed by external experiments) engage with, or envision themselves engaging with, robots in day-to-day situations. To follow robots, as well as ideas about robots, out into the world where they meet and engage with other human practices than those found in the engineering sciences, is indeed very relevant to the REELER project. It will open for deeper understandings of how robots (beyond any claims) function and affect human lives, which is part of the REELER project's ambition.

24 Inspired by discussion at LEO Center for Service Robotics' website: http://www.leorobotics.nl/definition-robots-and-robotics

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2.0 Introduction to robot typology

Robots are everywhere in public discourse. In the European Parliament, policy makers discuss whether robots should have rights and responsibilities. In popular series like Westworld or Humans, androids perfectly mimic humans and blur the lines between synthetic and biological. In promotional content from robot companies such as Boston Dynamics, robot dogs and humanoids are seen roving the world in human(dog)-like fashion.[25]

However, not all robots are humanoids, not all robots are able to move, and few (if any) robots can reasonably be considered potential candidates for rights and responsibilities. As such, the robots that are part of the public discourse make up only a fraction of the robots currently deployed all over the world, engaged in performing widely varying tasks – welding, laying bricks, performing surgery, and teaching, to name a few. In the REELER project, we seek to show the width and breadth of robots by presenting readers with cases encompassing many different types of robots. Different types of robots require different types of discussions and (perhaps) policy interventions. The benefits (and problems) of agricultural robots differ from those of educational robots. For instance, agricultural robots 'overfitted' to a Northern European climate and environment risk widening the economic divide between Northern and Southern Europe, thus counter-acting the EU's agenda of *inclusive growth*. This is not (prima facie) a problem with educations robots, where concerns revolve around changed class-room culture, social norms, and the nature of social interactions. This is a central motivation behind developing the typology of robots studied presented in the following – we want to encourage and help facilitate nuanced discussions of pros and cons of different types of robots, without reversing to stereotypical assumptions about robots, as if it was a monolithic category. However, this is not to say that there are no patterns or similarities across cases. In fact, there are, and we explore and analyse these in our main publication *Perspectives on Robots.*

In the following, we present our typology of robots, and review each type. It should be noted that these reviews were written by different REELER researchers at different times in the project, as such, some reviews are framed differently than others.

2.0.1 Case overview

Between January 2017 and December 2018, REELER researchers conducted 11 ethnographic case studies. Each

25 For an analysis at how particular ways of portraying robots affect public perceptions of robots, *see 8.0 Imaginaries* in our Perspectives on Robots available at our website *responsiblerobotics.eu*.

case was started around a single robot and expanded to include robots of the same type and sector in order to ensure anonymity and greater cross-case validity.

Case robots were selected according to information-oriented selection criteria, for maximum variation and for strategic importance to the general problem: "To maximize the utility of information from small samples and single cases. Cases are selected on the basis of expectations about their information content," (Flyvbjerg 2006, 230).

With this in mind, REELER first mapped robots all over Europe, across various industries, and with various applications, and with varying levels of human proximity. Cases were crafted to be representative of the wide variation identified in the field.

REELER's multi-variation approach (Hasse 2019) included selection for diversity with regard to:

1. *Nationality.* REELER conducted fieldwork in 13 of 28 EU member states, including robots from both robot-heavy and robot-light countries across Europe: Austria, Belgium, Cyprus, France, Denmark, Germany, Ireland, Italy, Netherlands, Poland, Portugal, Spain, UK [26]
2. *Type of robot.* 11 cases were built around a variety of robot types, including both industrial robots and service robots, but also variation within these categories to include collaborative robots, social robots, humanoids, etc.
3. *Sector*. REELER opted to exclude military, space, and undersea robotics for reasons of access and ethics. REELER's case robots were applied in different sectors (*see Figure f.1*):
   Transport (HERBIE),
   Logistics (WAREHOUSE),
   Construction (WIPER),
   Social (BUDDY),
   Collaborative (COBOT),
   Manufacturing (COOP),
   Healthcare (REGAIN),
   Agriculture (SANDY),
   Inspection (OTTO),
   Cleaning (SPECTRUS),
   Education (ATOM).
4. *Organization type/funding*. The cases were initiated by different robot makers (each with their own motives), including public funding organizations, industry associations, start-ups, SMEs, university researchers, etc.

In the end, REELER conducted 11 cases across 7 sectors (11 subsectors), in 13 different European countries. Several robots comprise each case. The case name (e.g., COBOT) refers not to a specific robot, but to a specific case built around a specific *robot type* and *application sector* (e.g., collaborative robots in manufacturing). These cases are referenced throughout the REELER Roadmap and are summarized in this working paper.

Figure 1 – the eleven robot types studied by REELER.

26 Pre-Brexit

2.1. Education – ATOM

2.1.1 Introduction to robots in education

While we often aim to change the world through education, it is also the world that changes education. It has been argued that the main reasons for reforming education are economic and cultural (Robinson 2008). Another factor is of course technology that both shapes and reflects educational trends. As educational paradigms evolve, the tools we use in education also change. In line with the constructivist theory that promotes the idea of learning through making things, and the constructionist paradigm according to which building external artefacts fosters meaning-construction and learning (Kafai 1996), education has assisted the gradual introduction of robots and robotic kits to schools. In general, following computer-assisted learning that started in the 1970s, robots started to appear in schools in the 1980s. This was mainly to support teaching science and technology with the use of traditional robots and robotic kits. With the further development of robotics and related information and communication technologies, since the mid-2000 robots have been endowed with increasingly anthropomorphic forms and functionalities and have found a variety of applications in education (Han 2012).

As discussed elsewhere (Zawieska 2015), educational robotics includes a variety of teaching and design approaches. In general, educational robotics can be divided into "Learning about Robots" and "Learning with Robots" (Han 2009), or "robotics in education" and "robotics for education" (Malec 2001, Shin 2007). Such a distinction vaguely corresponds to the difference between teaching technical vs. non-technical subjects. Teaching technical subjects refers mainly to the field of engineering and IT (Whitman 2013, Bers 2005, Mubin 2013) and it continues to be one of the most common uses of robots in education, known also as "Educational Robotics" (Frangou 2007). Robots have also been used to teach science, e.g. geometry or maths. Thus, robots have often been used within STEM education (Science Technology Engineering Maths), and occasionally within STEAM education (Science Technology Engineering Arts Maths) (Chung 2014, Hamner 2013). Both types of education aim to improve student technological fluency, while also supporting teaching discipline-specific subject (Hamner 2013, Jin 2012). It is worth noting the introduction of robots has successfully raised female students' interest in STEM (Weinberg, Pettibone, Thomas, Stephen, & Stein, 2007). Other educational variants include explicit incorporation of robotics into curricula in the form of SMART education (Science, Mathematics, Art, Robot and Technology) (Hong 2012, Jin 2012). Over time, educational robotics has gained a distinctive disciplinary form and identity and it is now known under such names as "r-Learning" and (Han 2008) "Robot-Aided Learning" (Han 2008, Han 2009) or "Robotics in Education (RiE)" (Botelho 2012).

Depending on robot design and the purpose of use, educational robots can be classified as tools, peers and tutors (Mubin 2013). In other words, robots and robotics kits may have the role of learning materials, learning companions or teaching assistants (Chen 2008), or hands-on versus tutoring robots (Han 2009). Not surprisingly, teaching technology and science typically involve using classical machine-like robots as tools, while non-technical education leaves room for robots in the role of peers and tutors. The latter implies using social robots that resemble human appearance and behaviour to a varying degree and engage socially with humans. Examples of such educational robots vary from toy-like platforms such as iRobi Q or NAO (Miller 2008, Mubin 2013) to more realistic androids, such as Saya (Hashimoto, 2011) (see Fig. 1).

The very concept of r-Learning has been sometimes described in terms of interactions between teaching robots and learners (Han 2012), are teaching robots have been sometimes viewed as synonymous to "anthropomorphic educators" (Han 2012). The type of robots and the subject they help to teach are not mutually exclusive. For example, social robots can be used to teach science and technology (Brown 2013, Mubin 2013), and at the same time, they have been successfully applied to teach foreign languages (Han 2008, Mubin 2013), story-telling (Kory 2014) or music (Han 2009). It is important to note that in addition to facilitating learning of specific school subjects, the use of robots also helps students to develop cross-disciplinary and social skills. This includes problem-solving, team-work skills (Chen 2008, Miller 2008) and 21st-century learning skills (Alimisis 2013, Khanlari 2013). Regardless of the school subject and robot design, robots are seen as a substantial motivational tool in the classroom (Hashimoto 2011, Miller 2008, Mubin 2013) and a new means to foster creativity in students (Alimisis 2013, Khanlari 2013, Botelho 2012). This is particularly important for teaching science and technology, i.e. the educational subjects that receive relatively little interest from students, and yet are of strategical importance for R&D and job market. Last but not least, an important element of educational robotics are national and international competitions, e.g. RoboCup Junior or FIRST LEGO League. Such activities require students of the school and university levels to apply their knowledge in practice to design and build robots or robotic kits as well as work as a team (for a detailed discussion see here (Bredenfeld 2011)

2.1.2 Robots in the educational industry

Educational robotics has quickly become a fast-growing market. The in-depth discussion of the commercialisation of education and turning education into the industry goes beyond the scope of this report. It is worth noting, however, that one of the main factors that significantly increase the chances of commercial success for such a field of robot application is that the use of educational robots is often combined with play and entertainment. The use of toys and games for educational purposes, in particular in pre-school education, and the role of play in children's learning has been long studied (Vygotsky 1978) and widely acknowledged. The toy industry constitutes an important element of both school and home education, and increased benefits from technological developments and online retailing.

The end market for educational robot varies from pre-school

education to university level.[27] It also covers the consumer domain and domestic applications as well as the educational use of robots in theme parks and museums.[28],[29] This is part of a larger phenomenon known as “edutainment”, i.e. merging of education and entertainment that increasingly relies on the use of digital and emerging technologies. Some market research companies estimate that by 2020 the value of the global educational market will reach USD 6.05 bn.[30] This requires a transformation of the entire education sector and active engagement of different stakeholders, both in the public and private domain. According to the report Global Educational Toys Market 2017-2021 by Technavio[31] one of the major growth factors for the global educational toy market it the innovative STEM learning in K-12 schools. The key vendors operating in this market include Mattel, Toys “R” Us, Engine, Learning Resources and LEGO. Another driving factor in robotics in general and educational robotics, in particular, are start-ups. According to the recent forecasts by International Federation of Robotics (IFR), a number of new start-ups in the field of service robots currently account for 29% of all robot companies, where about 290 out of 700 registered companies supplying service robot come from Europe.[32] It is expected that in the period of 2016-2019 approx. 3 million robots for education and research will be sold, and sales of all types of entertainment and leisure robots will reach 7 million.[33]

27 SPARC The Partnership for Robotics in Europe https://www.eu-robotics.net/cms/upload/downloads/ppp- documents/Multi-Annual_Roadmap2020_ICT-24_Rev_B_full.pdf, p. 130

28 Robotics 2020 Strategic Research Agenda for Robotics in Europe https://ec.europa.eu/research/industrial_technologies/pdf/robotics-ppp-roadmap_en.pdf

29 SPARC The Partnership for Robotics in Europe https://www.eu- robotics.net/cms/upload/topic_groups/H2020_Robotics_Multi-Annual_Roadmap_ICT-2017B.pdf

30 Aranca https://www.aranca.com/knowledge-library/blogs-and-opinions/investment-research/robots-in-the- global-education-industry

31 Technavio https://www.technavio.com/report/global-educational-toys-market

32 International Federation of Robotics (IFR) https://ifr.org/ifr-press-releases/P11

33 IFR https://ifr.org/downloads/press/02_2016/Executive_Summary_Service_Robots_2016.pdf

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2.2 Humanoids – BUDDY

2.2.1 Introduction to humanoid robots

Artificial human beings have long been present in human history and imagination. From the mortal creatures made of bronze (Talos), through ivory statues that may become alive (Galatea), to mechanical human-shaped figures (e.g. Al-Jazari's 13th century automaton), the idea of putting life into artificial creations, or at least creating an illusion of life, was being developed and well-known for centuries. For a long time, automata were seen as rarity and constituted the subject of public curiosity, gaining their momentum in the 18th century. In Cook's word, 'It [automaton] was at once an Enlightenment and post-Enlightenment object, a leading representative of eighteen-century Europe's curiosity cabinets, royal amusements, and fairs, as well as nineteenth-century America's emerging urban-industrial landscapes of theatres, exhibition halls and popular museums.' (Cook, 2001: 33).

With science and engineering progressed, the approaches towards automata also changed. The Machine Age along with the changing view of the human being who was now viewed as 'Man a Machine' resulted in a gradual shift towards creating highly-realistic automata which included revealing rather than hiding their mechanisms (compare Fig. 2 and Fig. 3) (before, in the cases as for example that of a famous Mechanical Turk, i.e. Automaton Chess-Player built-in 1770, it took nearly 90 years before its secret was revealed). From the perspective, to explain how an automaton works were to depict the human being. In Kaplan's words, 'What do westerners see when they look inside a human body? They see machines: the most advanced machines of your time. To understand how the heartbeats you must have invented the pump' (Kaplan, 2004)

Starting from the 1940s, robotics emerged. Being a highly multidisciplinary field, its emergence was noted possible before other disciplines advanced, in particular digital computing that allowed to program robots, and hence, endow them with a variety of features automata did not have. The earliest examples of work on modern humanoid robots include research conducted at the Waseda University, Japan in the 1970s and its robot WABOT-1. The 1980s was the time of rapid growth for robotics, including humanoid robotics. For example, this is when Honda developed its first bipedal humanoids. In 1993 the MIT Artificial Intelligence laboratory started the 'Cog project', with the goal to create a humanoid robot capable of 'think' (Kemp *et al*., 2008: 1311). Along with the development of robots that were increasingly capable of communicating interacting socially with human beings, other subfields of robotics emerged, such as Human-Robot Interaction and social robotics. Starting from the 2000s, humanoid robotics has been given a distinctive disciplinary identity. For example, the first IEEE/ACM International Conference on Humanoid Robots took place in 2000. The International Journal of Humanoid Robotics was established in 2004. At the same time, one should remember that humanoid robotics is an 'extremely complex interdisciplinary research field' as humanoids integrate almost all the characteristics of the entire spectrum of robots (Veruggio, 2007). Thus, perhaps more than any other robotics area it remains 'enormous endeavour' (Kemp *et al*., 2008: 1329) for the entire robotics community.

2.2.2 What is a humanoid robot

In general, robots have been often classified according to their area of application and specific tasks they can perform. For example, there have been different safety regulations for industrial robots (ISO 10218-1:2011 & ISO 10218-2:2011), mobile robots (ISO 19649:2017), and also personal robots (ISO 13482:2014). Humanoid robots can potentially be used in a variety of fields, and hence, comply with regulations developed for these specific fields of robotics. Given their resemblance to human beings, as well as their high adaptability, in theory humanoid robots should be able to conduct any type of tasks human persons do, and in fact, there are numerous areas of applications for humanoids, e.g. education, entertainment, arts, household work, medical and healthcare, light automation, space exploration etc. The very motivation for building humanoids may vary widely, from the attempts to better understand human beings to the development of tools that are adapted to human environments (Kemp et al., 2008). Some classifications of humanoids also include humanoid toy robots, which however are viewed here as a separate robot category.

In practice, unlike other types of robots (in particular industrial and mobile robots), humanoid robots have still relatively little practical implementations. It has been argued that 'Humanoids are generalists, often lacking specific tasks or goals' (Thoma *et al.*, 2017). Šabanović' study on HRP2 the robot has proved that 'The task of finding appropriate humanoid applications turned out to be more challenging than making the humanoid itself. The researchers spent two years making the platform and six years unsuccessfully testing out different commercial applications with industry partners' (Šabanović, 2014). This is largely due to the complexity of such systems and difficulty in imitating even as simple human behaviours as walking. The cost of humanoid platforms is also very high. Therefore, with some exceptions (e.g. Robothespian that has been largely used in science museums), humanoid robots continue to serve mainly as research platforms rather than commercial products. One could argue that designing and introducing humanoids to our daily-life environments constitute an ultimate challenge and 'enormous endeavour' (Kemp

et al., 2008: 1329) for the robotics community which applies to a relatively limited part of robotics research.

One way to understand what classifies a robot as a humanoid robot is to discuss robotic platforms in design terms. Humanoids have been typically described as platforms characterised by a set of specific features that emulate human form and behaviour to a different degree.

This includes the following characteristics (Behnke, 2008):

- *Bipedal locomotion*: walking and moving on two legs
- *Perception*: perceiving their own state and the state of the environment
- *Dexterous manipulation*: manipulating with the use of artificial arms and hands
- *Learning and adaptive behaviour*: capable to adapt to changes and learn
- *Human-Robot Interaction*: capable to interact and communicate with humans

Obviously, humanoid design, including robots' form and size, may vary significantly between different platforms. In fact, one of the main difference between different models is the presence or lack of different human-like body parts. Other forms of variation in humanoid robots include different degrees of freedom as well as different sensors (Kemp *et al.*, 2008).

When studying humanoid robots, it is important to emphasise they are not synonymous to social robots. While both share an interest for anthropomorphic design and human-robot interaction, social robotics and humanoid robotics are closely related but different subfields of robotics. The difference is sometimes blurred. For example, on the one hand, one may discuss 'humanoid social robots' (Zhao, 2006) and on another hand, address the two as 'social *and* humanoid robotics' (Restivo, 2001: 2110), i.e. without merging them into one. Both humanoid and social robotics have their own conference and journals. A closer look at the examples of the main topic addressed at the recent conferences dedicated to humanoid robots (see Table 1), social robots and human-robot interaction well-illustrates the difference between these research fields: Humanoid robotics tends to focus on technical aspects of robot development and robotic platforms as such while research in social robotics and HRI pays more attention to the question of robot social interaction with humans and the overall perception of robots by human end-users. In other words, humanoid robotics aims to literally reproduce human appearance and behaviours in robots, and hence, its focus on realistic robot design, while social robotics and HRI research often convey resemblance to humans as a much less accurate way. One should remember, however, that the degree of realism varies widely between different platforms, and a single humanoid may exhibit high realism in some of its characteristics and avoid realism in others (Hanson, 2006). Of course, the platform design significantly influences people's perception of humanness in robots (DiSalvo, 2002).

Table 1 Example of the main themes in recent conferences on humanoid and social robotics

Int. Conf. on Humanoid Robots (HUMANOIDS 2017): [34] Programme at Glance	**Conf. on Human-Robot Interaction (HRI2017):** [35] Keynote Speakers	**Int. Conf. on Social Robotics (ICSR2017):** [36] Programme at Glance – Interactive Sessions
Locomotion and Planning	Social Robots: From Research to Commercialization	Assistive Technology and Healthcare
Grasping and Manipulation	Of Space and Smell: The Strange Evolution of the Human Nose	Language, Vision and Haptics
Body Balancing and Dynamics	Acting, Interacting, Collaborative Robots	Design and Emotion
Learning		Service, Mobile and Multi Robots
System Integration		
Perception		

34 http://humanoids2017.loria.fr/index.html

35 http://humanrobotinteraction.org/2017/programme/overview

36 http://humanrobotinteraction.org/2017/programme/overview

Of course, as already mentioned, humanoid robot design may significantly vary, including in terms of the degree of realism. For example, both NAO and Jules robots have been described as 'humanoids'. Not surprisingly, NAO has also been classified as a social robot, which proves there is no sharp distinction between humanoid and social robot (after all, to be human is also to be social).

2.2.3 Humanoid robot market

Nowadays, there has been an increasing number of universities and companies that have been involved in the development of humanoid robots. While humanoid robots remain a rather small part of robotics research and robotics market, forecasts for future developments predict a significant growth of the humanoid robotics market in a long-run. According to

one of the recently published reports,[37] the humanoid robot market is expected to reach a total market size of US$4.143 billion by 2023, increasing from US$0.624 billion in 2018. The highest market share in 2016 was North America (note that the distinction between different types of robot in Fig. 5 is only approximate since humanoid robots may be also used as rehabilitation robots, socially assistive robots etc.; this proves the difficulty in classifying humanoids).

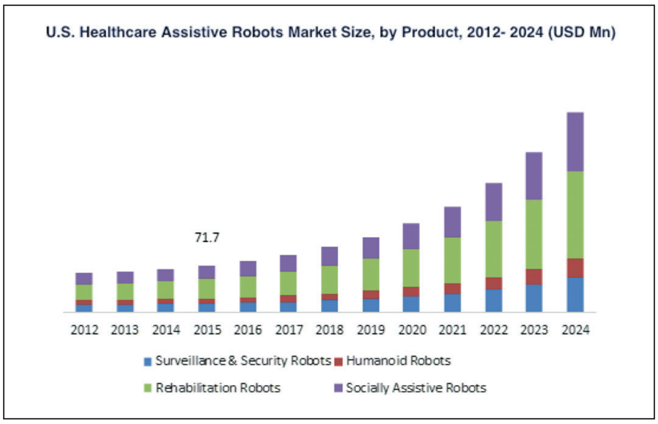

Fig. 5 US market forecast for robots [38]

If we classify humanoid robots as personal robots, the use of humanoids will also significantly grow globally (Fig. 6). However, given the lack of a clear area of application of humanoids, one should carefully analyse any corresponding market forecast. For example, in Fig. 6, the size of 'Personal [robots]' category may be significantly boosted due to the fact it includes entertainment robots, which constitute a very big part of the robotics market (as mentioned above, this study views humanoid toy robots as a separate category of robots). Also, while there is a variety of potential applications of humanoids, given the cost, novelty and complexity of humanoid robotics, it is not clear who will become the main early adopter of humanoids. In any case, it seems that in the not too distant future, humanoid robots have the potential to be widely introduced to our society and go far beyond merely research applications.

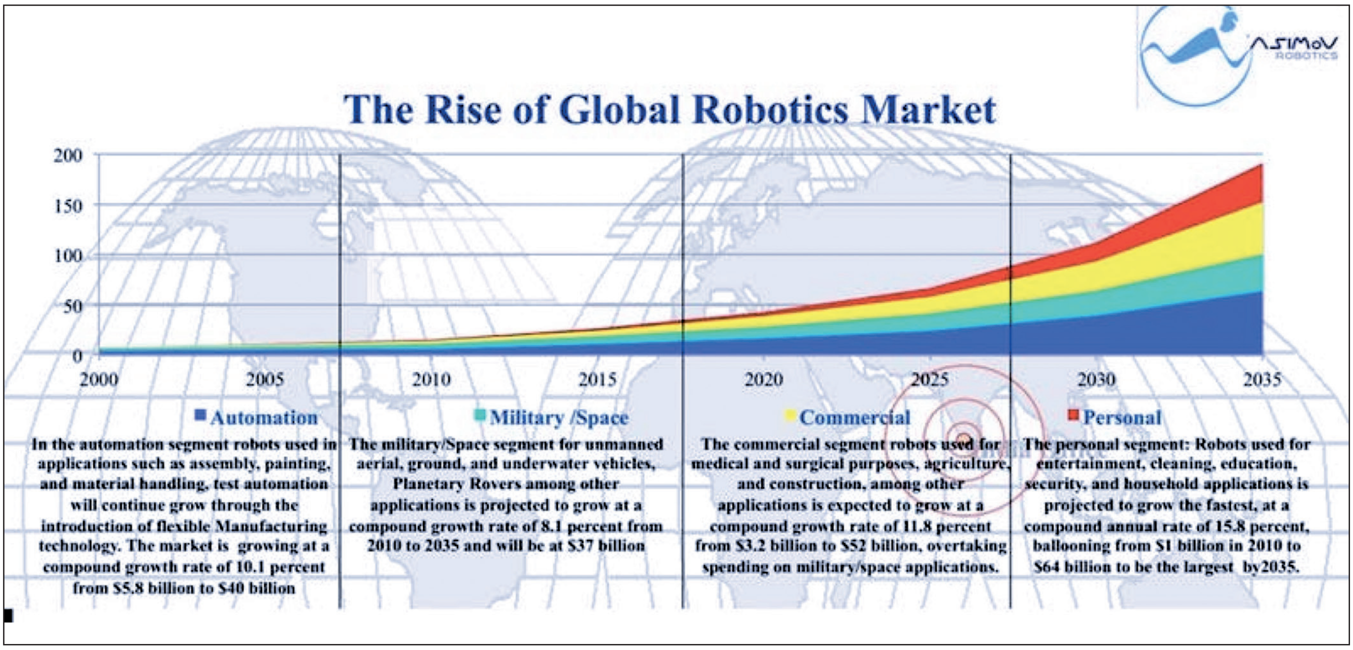

Fig. 6 The rise of the Global Robotics Market [39]

37 *Humanoid Robot Market - Industry Trends, Opportunities and Forecasts to 2023.* Knowledge Sourcing Intelligence LLP, November 2017.

38 Source: Global Market Insights, Inc.

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2.3 Collaborative – COBOT

2.3.1 Introduction to collaborative robots

In earlier times, robots where confined to particular parts of the production line, caged in an separated from human workers. Now, robots have been freed and are, in some cases, working next to or even with humans. This places new demands on workers, who now have to collaborate with robots, and allows for a more dynamic production. In the following, we provide a brieft description and characterization of collaborative robots; their orginins and purpose.

2.3.2 Description of collaborative robots

A collaborative robot is a robot that is intended for physical interaction with humans in a shared workspace. This is a revolution in the field of industrial robotics where robots so far have been designed to operate autonomously behind safety fences for safety reasons and not in direct interaction with humans. The first cobots were invented by the mechanical engineering professors Michael Peshkin and J. Edward Colgate at Northwestern University, Chicago, as the result of a collaboration with General Motors (Engineering.com 2016). A patent was filed in 1999 that defines a cobot as "An apparatus and method for direct physical interaction between a person and a general-purpose manipulator controlled by a computer. The apparatus, known as a collaborative robot or 'cobot', may take a number of configurations common to conventional robots. In place of the actuators that move conventional robots, however, cobots use variable transmission elements whose transmission ratio is adjustable under computer control via small servomotors. Cobots thus need few if any power, and potentially dangerous, actuators. Instead, cobots guide, redirect, or steer motions that originate with the person." At General Motors, the first cobots were developed under the name Intelligent Assist Device (IAD) as lifting devices to improve ergonomics for human workers, but Robotics was the first company to start series production of collaborative robots for industrial use. According to the International Standard ISO 10218, there are four general safety features for cobots (Engineering.com 2016): 1) Safety monitored stop: Cobots must have advanced proximity sensing with a safety monitored stop function that ensures that the robot ceases movement but not shuts down completely when it comes too close to a human. 2) Hand guiding: Hand guiding is a collaborative feature used for path teaching a robot, literally guiding the robot through a sequence of motions required to complete a task, like pick-and-place applications. 3) Speed and separation monitoring: With speed and separation monitoring, cobots slow down more and more as humans approach. 4) Power and force limiting: Force limited collaborative robots can read forces in their joints, like pressure, resistance or impacts using embedded sensors. After feeling a disturbance, the robot will stop or reverse its course.

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2.4 Manufacturing – COOP

2.4.1 Introduction to manufacturing robots

As discussed above, the demand for new means of transportation continues to rise. One of the main solutions that have been investigated by manufacturers to meet such demand is flexible systems that would reduce cost, improve quality and boost productivity (Weber 2015). Such systems include collaborative robots in the first place. In general, the concept of collaboration in the field of robotics applies to a variety of areas, from human-robot teams (Freedy 2007) (G. Hoffman 2013) and collaboration with humanoid robots (G. B. Hoffman 2004) through the use of mobile robots in automation (Surdilovic 2010) to the study and development of single narrowly-defined collaborative tasks. Not surprisingly, the concept of human-robot collaboration requires specific design approaches, such as, for example, human collaborative design (Jeffrey Too Chuan Tan 2009) (Jeffrey Too Chuan Tan 2009). The concept of collaborative robots, or 'cobots', has become popular in relation to industrial applications for robots. It dates back to the late 90' and goes hand in hand with the changes taking

places in approaches towards automation and manufacturing. In general, the goal for collaborative robots is to combine the benefits that come from the human labour and the use of machines, i.e. to 'enable close collaboration between human and robot, in all service and industrial tasks, that require the adaptability of humans to be merged with the high performance of robots in terms of precision, speed and payload' (Cherubini 2016). The corresponding ISO standards[40] define the objective for collaborative robots as "to combine the repetitive performance of robots with the individual skills and ability of people. People have an excellent capability for solving imprecise exercises; robots exhibit precision, power and endurance." Such an approach is closely related to the recently developed Industry 4.0 paradigm according to which 'robots and humans will work hand in hand' (Mohd Aiman Kamarul Bahrin 2016), often in 'smart factories'. Collaboration between robots and humans implies different degrees of physical interaction as well as execution of tasks in a shared time and space. Thus, unlike traditional industrial robots that are typically located in a cage, collaborative robots are designed to work in close proximity of humans. This makes the idea of human-robot collaboration particularly interesting for REELER research. This study focuses on an example of early versions of collaborative robots used in manufacturing.

In recent years, we have seen the advent of a new type of robots used in manufacturing of transportation systems, which works together with human workers in a more dynamic, less production-belt like way. One example is robots for drilling. Given the complexity and specificity of aerospace manufacturing, drilling processes cannot be easily automated with the use of traditional industrial robots. A challenge lies in the size of planes, the number of drilling parts, as well as variability and accuracy required. While some work has been done in this area (Weidong Zhu 2013) (Kihlman 2002) and automated drilling to some extent has already been implemented at some producers, the question of developing collaborative drilling robots is still new.

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2.5 Transportation – HERBIE

2.5.1 Introduction to autonomous transportation

Automated driving has been a topic in science fiction at least since the beginning of the 20th century. Intuitively, by autonomous vehicle, we mean vechicles able to function without human intervention and able to move from point A to point B – often through traffic. No such car exists at present, but recent developments in computer vision, powered by the advances in machine learning (more specifically: deep learning), has brought companies like Google, Tesla and Uber closer to realizing the dream of a completely autonomous vehicle. In the following, we outline some of the current state of the art, as well as a concerns surrounding automated driving.

2.5.2 Description of automated robot-cars

The US Department of Defence defined autonomy as "a capability (or a set of capabilities) that enables a particular action of a system to be automatic or, within programmed boundaries, 'self-governing'" (Moniz, 2013 cited from DSB-DoD, 2012: 10). According to the SAE a self-driving car is an 'entire system with at least some parts operating autonomously'. As many contemporary vehicles are scaled up to Level 2/3 autonomy we will explore autonomy from Level 2/3.

- *Level 0* – No Automation
  – Full-time operation by a human driver.
- *Level 1* – Driver Assistance
  – Single driver assistance system (steering or acceleration/deceleration).
- *Level 2* – Partial Automation
  – Driver assistance systems for both steering and acceleration/deceleration.
- *Level 3* – Conditional Automation
  – Automated operation with human driver expected to respond to a request for intervention
- *Level 4* – High Automation
  – The automated operation even if human driver fails to appropriately respond to request for intervention.
- *Level 5* – Full Automation
  – Full-time automated driving system.

(Cited by Borenstein, Herkert and Miller, 2017a p. 69).

Borenstein, Herkert and Miller (2017a), tell us autonomy in cars is already present to some degree, with; "Level 2 automation is already being incorporated into existing commercial vehicle brands including Mercedes, BMW, and Cadillac. The Tesla (Model S) incorporates Level 2 and some aspects of Level 3 automation".The level of autonomy in a vehicle is determined by a 'hands-off' approach. The producers of the technology also face barriers to User Acceptance (UA) and User Experience (UE) integral to the product's design and use (Rödel et al., 2014).

While many aspects of vehicle production are automated, the process of driving of the vehicle is only permitted by an age-appropriate licenced driver on public roads. In the UK, 70% of the population hold driving licenses and there are a further 23 million licensed cars. Car use has increased since the 1960s when only 19% of the population drove cars compared to 72% by 1999 (Dant 2004 p. 4). The licensing system is regulated by an appropriate regulatory body in each national jurisdiction and ensures that new drivers learn procedures and regulations of road safety before allowed to drive. Licenced drivers are responsible for the vehicle's movements while 'behind the wheel', a phrase that may become redundant if autonomous car manufacturers take off. Autonomous cars enter the frame with a significant and well-established infrastructure to address. The vehicle's autonomous ability (ability to perform the actions of the human that is no longer steering the vehicle) is developed in parallel with creating a new regulatory infrastructure of risk, indemnity and liability. Moreover, autonomous vehicle producers reflect on the built environment as well as psychological behaviours, traits, habits and norms of driving behaviours. As of the writing, there is no autonomous car at Level 5 autonomy. Several global car manufacturers, such as GM Motors, Tesla and Ford are paving the way with new technology. The global race to produce the Level 4 autonomous car is underway. Automobiles are powered by combustible engines, but the move towards Hybrid vehicles (a mix of combustible and electric) to electric vehicles is also running parallel with new innovations in autonomous vehicle research and development. For example, the UK and French governments are planning to ban all diesel and petrol combustion vehicles by 2040. Manufacturing companies such as Volvo are following Tesla and moving towards fully electric vehicles. This all indicates that the motoring industry and social norms about driving are undergoing the most profound shift since the invention of the motor car in 1885.

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2.6 Inspection – OTTO

2.6.1 Introduction to inspection robots

With an increasing need to improve the quality of transportation services as well as to fully exploit the existing infrastructure, there has been a growing need to use faster and more efficient inspecting methods that would help to plan maintenance activities, ensure safety and optimise the use of the infrastructure. New solutions include for example the use of lasers to inspect railway geometry that in future may lead to non-contact evaluation of the rail. Another solution is rail robots for automatic switch inspection. For decades, automated and robotic systems have been used in maintance processes in transportation systems (e.g. welding, surface treatment, drilling and riveting, part handling, painting and finishing, etc.), including inspection and quality control. The role of robots in the transportation sector will grow and it will include automated passenger trains, ticketless gates, automatic switch change, surveillance drones, intelligent robots for unloading and sorting freight cargos etc. (RSSB March 2015).

2.6.2 The evolution of insepction robots

Inspection robots constitute a large part of robotics. Some of them have been relatively long in use while others have been still in the phase of development. Many of them are equipped with some degree of autonomy and AI. The advantage of inspection robots is that they can operate in the environments that are hazardous or inaccessible for humans, e.g. to inspect nuclear plants, underwater areas or pipes. Also, inspection robots ensure a high degree of accuracy which is important for inspecting the equipment and infrastructures that may impact human safety. A large part of applications for inspection robots is in the industrial environments. Depending on their purpose of use, inspection robots use different technologies and inspection techniques (e.g. scanning, visual inspection, gathering samples etc.). One of the main industries that use inspection robots is manufacturing, energy and transportation.[41]

The reason for choosing this robot area for research is due to its relevance for public safety as well as potentially high impact on a large group of affected stakeholders who are the passengers and workers employed in the transportation sector. The latter also requires adequate training which per se constitutes an interesting issue for REELER. Last but not

41 Source: https://blog.gesrepair.com/guide-inspection-robots-used-industrial-sectors/

least, inspection robots need to be integrated into the existing well-defined inspection procedures and tools which poses interesting questions about a potentially disruptive role of robotic technologies.

2.7 Healthcare – REGAIN

2.7.1 Introduction to healthcare robots

The field of healthcare have seen an influx of robots in recent times. These are robots designed to replace and support humans in many different aspects of healthcare. From Korean brain training robot, SilBot, to the therapeutic seal Paro, to physical rehabilitation robots to robot surgeons. Such robots range from robots, similar to the those known from industry to social robots meant to engage with patients. In the following, we review some of the concerns surrounding healthcare robots and their implementation.

2.7.2 General concerns

Roboethics is applied ethics that draws from many different fields, in particular computer ethics (Veruggio & Operto, 2008). While to a large extent it concerns robots and the question of programming ethical systems and behaviours into robot applications (Sullins, 2011), its main focus is on human ethics of the robot designers, producers and users (Veruggio & Operto, 2008). Steinert (2014) divided robotics into four areas: (1) robots as instruments; (2) robots as recipients of behaviour that may be regulated by ethical standards; (3) Robots themselves as active moral agents and finally, (4) the influence of robots on society. According to the instrumental view, robots are no different from other tools. The ethical responsibility will be on the human user of the robot. This ethical approach is in opposition with the fourth and last approach that raises questions such as: How will it impact on society when complex tools such as robots replace human functions? This question is related to similar societal questions when machines replaced human labour during the industrialization. However, another question is how it affects us, humans, to interact with tools with human-like features and/or abilities such as socially assistive robots. Several authors describe how the particular complex and autonomous acting of the robots induced experience of agency in humans interacting with them (in.: de Graaf, 2016). Looking further at the impact of robots on society, on one hand the robot designers try to imagine scenarios for their products, recommend and direct future use of the robot. On the other hand, when the robot has been implemented in a social and cultural environment, the environment might begin to alter, both due to the introduction of the robot and because of wider societal changes. On one hand, the robot enters as a technology with agency [ability to act], on the other hand the robot users hold beliefs and preferences, and thus enters the relation with agency as well (de Graaf, 2016). Together, this calls for questions about how the incorporation of robots in daily life and work practices alters existing work practices, professional value positions and human relations. These social-ethical questions are in line with Coeckelbergh (2009), who suggests a redirection of robot ethics towards considering interaction (rather than the robotic mind versus the human mind), towards social-emotional being of humans with robots (rather than the intelligent decision making abilities of the robot), towards considerations about what is good rather than what is right, towards internal ethical criteria of a practice- and culture-sensitive nature rather than general and externally generated ethics standards. Lastly, he proposes a methodological shift from theoretically generated ethics to ethics rooted in experience and imagination.

Based on Asimov's three 'Robotic laws' (the beginnings of robotics in science-fiction have been largely acknowledged, to the point of describing it as "undeniable roots" (Sullin, 2011; Loas *et al.*, 2016) formulates three laws for ethical neurorobotics: (1) There is a need for high benefit/risk ratio, thus combining considerations of effectiveness and safety; (2) The rehabilitation should be thought of as a tool for the therapist, not a substitute; (3) The artificial intelligence of the robot should assist and enhance the decision making of the therapist. Also, it has been argued that so far rehabilitation robotics designers often follow the existing industrial standards and professional codes of ethics. As technology evolves, however, and it increasingly appears on the market, the design and use of robotics technologies will require new approaches and regulations that go much beyond safety concerns (Van der Loos, 2008). Thus, robot-ethics still remain an open question. The following review focuses on the key ethical challenges identified in the field of rehabilitation and medical robotics.

2.7.3 Effectiveness

Rehabilitation robots are medical tools that need to prove their effectiveness in order to be considered ethical to use. Similar to new drugs or medical procedures, medical robots must not harm the patient and be at least as effective as current treatments. However, the effectiveness of robotic rehabilitation compared to therapist rehabilitation is difficult to investigate. One problem is that the treatment needs to be closely tailored to the patient's remaining competencies and needs for support and training, and thus the controlled clinical trial design is not always feasible. A second challenge is that neuro-rehabilitation practice is guided by competing schools of thought in regard of the type and amount of training the patient will benefit from (Datteri, 2013; Loas *et al.*, 2016).

Despite the methodological challenges in the assessment of the effectiveness of robotics technologies in rehabilitation, a number of studies have been conducted in this area. A Cochrane review by Mehrholz *et al*. (2012) concludes that robotic aided rehabilitation have positive effects. However, limitations exist as well. Many studies are pilot studies that mainly investigate whether the particular device is feasible in terms of patient compliance and improvement in motor functioning, without a control group receiving conventional therapy (e.g. Bovolenta *et al.*, 2011; Johnson *et al.*, 2007; Colombo *et al.*, 2007). Some studies of effectiveness are based on healthy subjects (e.g. Riener *et al.*, 2005; Johnson *et al.*, 2008) and their results may not translate into a patient population. Also,

given the novelty and complexity of rehabilitation robotics, the assessment of therapy effectiveness may constitute a serious challenge, where the use of the same robot may lead to different results. For example, on the one hand, Hornby *et al.,* (2008) and Hidler *et al.* (2008) found that even though the rehabilitation robotic exoskeleton Lokomat improves the gait of the patient, the improvements were inferior to improvements from conventional therapy. On the other hand, other studies on Lokomat proved there have been no significant differences between robot- and therapist-assisted groups (Van der Loos, 2008). Johnson *et al.* (2007) comments that even though robotic tools for neuro-rehabilitation show positive results in regard to improvement in improved motor functioning, the improvement did not translate into better real-world functioning. Finally, many effectiveness studies exclude patients with moderate or severe cognitive impairments (e.g. Bovolenta *et al.*, 2011; Liao *et al.*, 2011; Mazzoleni *et al.*, 2013), and thus the effectiveness of robotic aided rehabilitation for stroke patients with cognitive impairments requires further investigations (for a review of clinical studies on the effect of robot-aided therapy on patients with stroke, see, for example, Prange *et al.* (2006) and Kwakkel *et al.* (2008)) .

Assuming the use of rehabilitation robots to be effective, several benefits can be highlighted. One benefit of robotic neurorehabilitation is to relieve the therapist of heavy or repetitive work tasks built-in in rehabilitation work (Datteri, 2013). Furthermore, the robot can function as an enhancing tool of the therapy and/or evaluate and document the treatment by providing graphs and numbers related to the patient's performance (Riener *et al.* 2005). Other benefits may be lowered cost for an equally effective treatment, for example fewer treatments for same result or one therapist supervising three or four patients in robot-aided training (Datteri, 2013; Loas *et al.,* 2016) rather than work with them successively (a decisive economic advantage of rehabilitation robotics, however, is yet to be demonstrated (Van der Loos, 2008)). The patients could even train at home with their robotic device and save money for transport or hospitalization (Loas *et al.,* 2016). In a political environment characterized by perpetual budget cut-downs and rationalizations in hospitals and health services at large, the implementation of rehabilitation robots can be considered ethical if they enable continuation or improvement of the current rehabilitation standard.

2.7.4 Patient safety

Related to effectiveness are considerations of patient safety. Medical robots (e.g. surgery robots) and rehabilitation robots are designed for close human-robot proximity and the ethical question is how to ensure humans (and robots) are not harmed in the close encounter? Datteri (2013) divides the safety question into two different parts: Avoiding harm caused by anomalous robot behaviour and avoiding harm caused by normal robot behaviour. The question of ethical and safe normal robot behaviour he delegates to robot engineers. This line of thinking is related to Cürüklü, Dodig-Crnkovic, and Akan (2012) who advocates for artificial morality to be built-in by engineers to ensure robots behave in accordance with moral standards. The other part of the question is more tricky; "...designers, manufacturers and programmers of robotic systems typically have a fairly precise idea of a set of boundary conditions that must hold for the robot to behave normally" (Datteri, 2013, 142). Unknown or variable environments thus increase the possibilities of harmful human-robot encounters. For the affected groups in the case of neuro-rehabilitation, the tendency of studies to exclude stroke patients with moderate or severe cognitive impairments (as most studies require that participants are able to understand and follow instructions or explicitly exclude patients with e.g. aphasia or attentional impairment) means that this patient group might constitute an 'unknown environment' of the rehabilitation robot. Furthermore, the need for a predictable environment place constraints on therapist activity. To safeguard their patients, they must use the robot in accordance with the intentions of the robot designers.

2.7.5 Socio-ethical issues

Studies on rehabilitation robots, e.g. effectiveness in rehabilitation and safety, need to address more than just a practical impact of robotics. For example, Coeckelbergh (2009) suggest that the impact of the robot on humans may be more a matter of our expectations about robot thinking rather than its actual thinking skills. Thus the therapist's expectations about the skills of the robot may guide her use of it together with her professional knowledge about the robot. In this sense, we should address users' expectations towards robots.

A second issue in the area of socio-ethical issues may be the management of imaginations about cheaper and more effective services that drive the implementation of robots. Datteri (2013) gives the example of a hospital in which surgeons were not allowed enough time to practice with the Da Vinci surgical robot before performing surgery on patients – with fatal consequences for several patients. Thus, the hospital management's ideas about how the robot should be and could be used can create ethical concerns.

A third social ethical issue regards the implications of rehabilitation robots in the work practice – and the wider society. The literature opens up for understanding the robot as a tool, and with the therapist in charge. The therapist decides which rehabilitation/work tasks can be performed by the robot and those that cannot. However, the ability of rehabilitation robots to act partly independently of the therapist opens up for another scenery also mentioned in the literature: the replacement of therapists with robots. At the same time, it has been argued that robots may overtake repetitive tasks and leave more time for therapists to provide actual therapy (Van der Loose, 2008). In addition, changes in the work practice of therapist are mentioned: One therapist supervises several patients. Tele-rehabilitation is another possibility where a therapist located at the hospital supervises a patient training in his/her own home. Thus, as a tool, rehabilitation robots hold the potential to transform work practices of therapists substantially. On the other hand, the development of rehabilitation robots may be driven by societal demands for more effective health care.

Sabanovic (2010) calls forth that ethical issues arise in the robot's interaction with the broader social context as people incorporate the robot in their practices. Her answer is that roboticists, designers and practitioners together need to create normative visions of future robots and the use of robots, and do it early in the process, before the design is constrained by technical choices already made by engineers alone.

Other researchers also elaborate on how social ethical issues emerge from the amalgamation of robot, users and social practices at multiple levels. Moving to a different medical robot, the Da Vinci surgical robot, Abrishami *et al.* (2014) explored how affordances of 'advanced care', 'knowledge exchange platform' and 'competitive advantage' contributed to the demand for and rapid dissemination of the Da Vinci robot. In this process, disadvantages of the robot were eclipsed and in an ethical perspective, it is shown how social forces influenced individual's ethical decisions about which health care procedures to provide, recommend and ask for.

In a societal perspective, Phelan *et al.* (2014) put forward the idea that rehabilitation technologies in their design and promotional material implicitly support disability as an individual and negative state in opposition to normal and preferred ways of functioning. Even though their examples are congenital conditions, the argument can be extended to acquired conditions as well. Many stroke patients will not be able to re-acquire their prior motor (and cognitive) functioning and thus will need to learn to live with their impairments. Drawing the argument closer to robotic rehabilitation, we should be asking is the robot designed and/or used to support the patient to train towards a normal gait pattern or rather towards functional gait, even if the gait pattern is deviant? The very idea of using the term "normal" in the context of assistive robotics and robot-aided therapy is controversial. For example, it has been argued that social robotics typically follows a medical approach towards disabilities, where people with physical or intellectual disabilities are viewed as persons that do not fit the norm (Yumakulov *et al.*, 2012). As a result, improvement is understood mostly as improvement that can be measured over time and it allows people with disabilities to be labelled as "normal" (Yumakulov *et al.*, 2012). One could argue that such an approach is rooted not only in the medical understanding of disabilities but also the engineering approach towards social robotics, with efficiency being the key principle (the latter applies to both robot and human performance). An alternative approach includes using robots to improve the quality of life rather than merely "fix the disability" (Yumakulov *et al.*, 2012, p. 171). From the research presented in relation to socio-ethical issues in the context of rehabilitation robotics, we should reflect on such questions as how will ideas and imaginaries about rehabilitation robots interact with actual robots and change rehabilitation practices? Will the relation between patient and therapist change into a relationship between patient and robot or a threesome of patient, therapist and robot? Will the aim of rehabilitation change in accordance with rehabilitation robot's capabilities?

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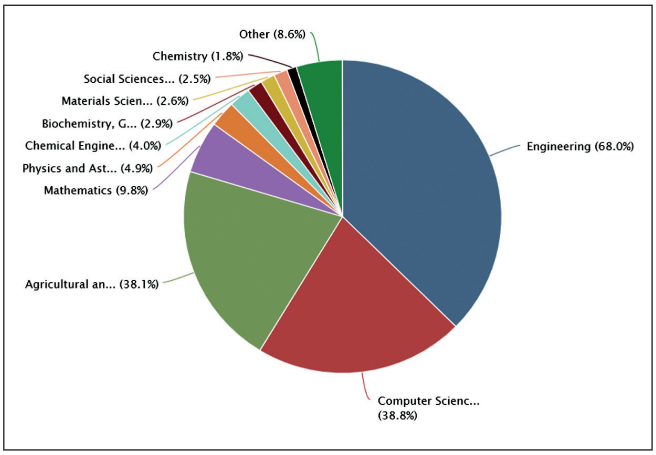
2.8 Agriculture – SANDY

2.8.1 Introduction to Agriculture robots

Since the 1920's vast amount of ressources have been pouted in to the development of agricultural robots. The function of these robots vary, from milking cow, to sowing and harvesting grains, like corn, to picking fruit, watering fields and sorting different kinds of produce. These robots are usually developed for indoor use, where it is possible to control environments very carefully to make it easier for robots to do their jobs. Robots for use outside are challenged by environmental factors not directly under producers control. In the following, we provide an overview of the literature on the subject, as well as look as some ongoing studies.

2.8.2 Evolution of Agriculture robots

The literature review began in the multi-disciplinary database of SCOPUS, the largest abstract and citation database of peer-reviewed literature. In order to get an indication of how the term 'agricultural robot' is spread across years and subject areas, the first search on SCOPUS was conducted for the term "agricultural robot" in 'all fields'. This returned 1110 results. The majority of these documents were related to the subject area of engineering and computer science, whereas 32 documents were placed in the subject areas of social sciences, arts and humanities and psychology.



In SCOPUS, the term "agricultural robot" was first referred to in 1983, while the term "agriculture robot" was first referred to in 1987. This was in an engineering article published in Robotics today (Stauffer 1987) that brings up the recently started developments of applications relating to "mobility in unstructured environments" needed in for instance agriculture, military and space stations. "In general, the robotic systems being developed for use in these newer surroundings are more intelligent and versatile than their industrial counterparts" (ibid. 19). The term 'agricultural robot' is only used few times in scientific literature until 2006, after which the use of the term begins to increase rapidly, peaking in November 2017 with 147 documents (see Figure 8).

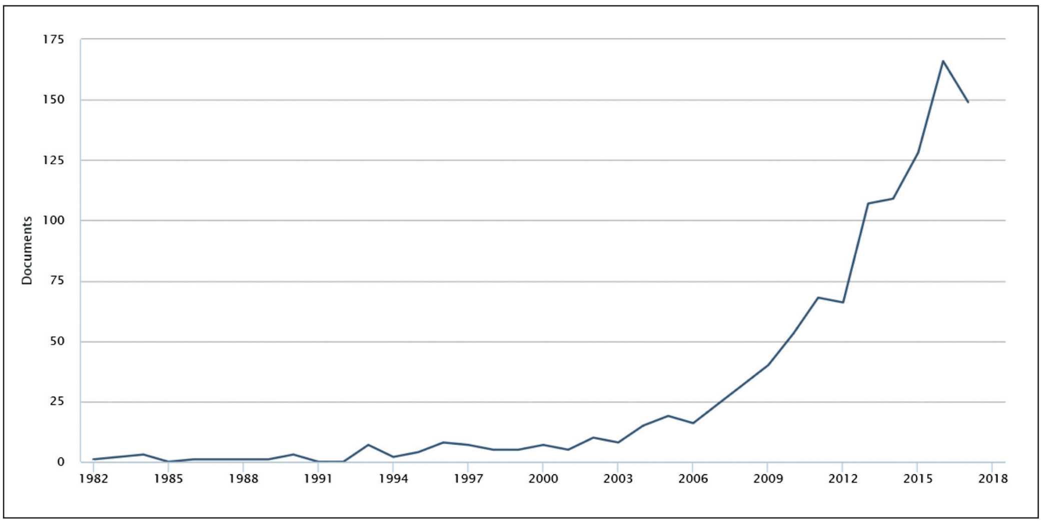


Figure 8. Use of the term "agriculture robot" in research documents over time. Screenshot from SCOPUS.

A search on "agricultural robot" returned 0 results in the anthropological database of Antrosource, whereas the engineering database IEEE Xplore Digital Library returned 55 results, and Agris, an American database for agricultural studies, return with 36 results (*see appendix 1*). In Agris, the first published document referring to the term is from 1984 and is about a Japanese robotic development project of a fruit harvester with the title: "Study on an agricultural robot, 1: Microcomputer-controlled manipulator system for fruit harvesting" (Kawamuru *et al.* 1984). Hence, the idea of robotic developments for the harvest industry is not a new idea but goes back at least 33 years. The words 'harvest AND robot AND greenhouse' were the next search combination in order to narrow down the question: When did the emergence of harvest robots in the greenhouse industry begin? In SCOPUS, this resulted in 41 documents with titles mentioning development projects of greenhouse harvest robots for ripe tomatoes, cherry tomatoes, strawberries, cucumber, eggplant, sweet pepper flowers, roses and sweet peppers. The first document was published in 1993: "This paper represents a state-of-the-art review in the development of autonomous agricultural robots, including guidance systems, greenhouse autonomous systems and fruit-harvesting robots" (Edan 1995: 41). Using this document as a 'historical marker' of the development 23 years ago versus today, the paper states that prototype fruit harvesters have been developed. However, the emphasis on these studies have only been on issues of locating, reaching and picking the fruit and not on autonomous guidance. These 'static point' prototypes has been developed for harvesting tasks in natural environments of citrus (Harrell *et. al* 1990; Harries & Ambler 1981; Juste & Fornes 1990), apples (Kassay 1992; Sevila & Baylou 1991), tomatoes (Kawamuru *et al.* 1986), asparagus (Humburg & Reid 1986), cucumbers (Amaha *et al.* 1989), melons (Benady *et al.* 1991; Edan & Miles 1993), and grapes (Sittichareonchai & Sevila 1989). Only preliminary research has been conducted towards development of a completely autonomous robot agricultural robot, which deals with both automatic vehicle guidance and execution of the agricultural task. Merely one example of a moving agricultural robot exists, for grape-vine pruning (Throop & Ochs 1991), however, this has been achieved only under laboratory conditions (Edan 1995: 42). In Japan, initial research of an autonomous robot with a multipurpose manipulator attached for tomato picking and selective sprayer has occurred (Kawamuru *et al.* 1986). The paper then presents the design of an open filed harvest robot for melon that consists of a robot arm mounted on a mobile platform, which is drawn by a tractor. Today, several operative open field-harvesting robots are on the market, but no greenhouse harvesting robots have yet succeeded in a commercial adoption.

In addition to greenhouse/open field harvest and fruit picking robots, agricultural robots imply categories of technologies such as:

- robots used for other horticultural tasks such as seeds planting, pruning, weeding, weed control, spraying, soil analysis
- driverless tractors, autonomously operating without the presence of a human inside the tractor itself
- livestock robotics such as automatic milking, washing, castrating and sheep shearing robots
- drones (emerging) for cloud seeding (e.g. weather modification) and environmental monitoring

2.8.3 Ongoing studies of agricultural robots

A recent survey of 50 projects in robotic harvesting of horticulture crops (Bac *et al.* 2014) highlighted that over the past 30 years of research, the performance of automated harvesting has not improved substantially despite advances in sensors, computers, and artificial intelligence (Lehnert *et al.* 2017: 872).

This being in spite of an increasing interest in the use of agricultural robots for the harvesting of high-value crops over the past three decades (Lehnert *et al.* 2016: 16). According to an Australian team of roboticists, is the task of autonomously harvesting crops a particularly challenging area for robotics, as it requires integration between numerous subsystems such as, a crop detection system, a dexterous manipulator, a custom end effector harvesting tool, and an intelligent motion planning system (Ibid). In order to harvest sweet peppers, for instance, it is critical to align a custom cutting implement with the crops peduncle, and challenges of perception, motion planning and the hardware design are among the complexities in designing an autonomous sweet pepper harvesting robot ready for the market (Lehnert *et al.* 2017: 873). Interestingly, the Australian roboticists from Queensland University of Technology currently work on building a mobile robotic harvester for sweet pepper. This harvest robot is called Harvey (*see figure 10*), and recent initial field trials (April 2017) in protected cropping environments show a 46% success rate for unmodified crop and 58% for modified crop with this design system (Ibid: 872). In addition, a Japanese roboticist team began in 2005 with the development of a sweet pepper picking robot in greenhouse horticulture (Kitamura & Oka 2005; Kitamura & Oka 2006; Kitamura *et al.* 2008).

A search on *"agricultural robot" AND ethics* resulted in eight hits in SCOPUS,[42] four of which in the subject area of social sciences. Of these documents, one deals with human-robot interaction (HRI) and the increased focus on safety and dependability in the next generation of robots developed (Xing & Marwala), another with future service robots (van Wynsberghe). The last two hits do relate to agriculture, however,

42 Applying the same search combination in IEEE Xplore Digital Library returned no fewer than 3989 hits. However, looking at the titles, the documents did not concern agriculture, but ethics in computer science, medicine and general ethical engineering. Document examples:
"Trust, Ethics and Access: Challenges in Studying the Work of Multi-disciplinary Medical Teams" (Kane & Luz 2017)
"African ethics for enhancing soft skills in young IT professionals in Southern Africa" (Leung 2017)
"Where the "Virtual" Meets the "Real": Free Speech, Community, and Ethics on the Net" (Godwin 2003)

only one of them also with ethics – an interesting book chapter with the title "Satellite farming, food, and human wellbeing" (Addicott 2016) from the book "Changing our Environment, Changing Ourselves: Nature, Labour, Knowledge and Alienation". A passage from this chapter says:

Within the sociological theory, there are deep concerns about the integration of satellite technologies into farming operations. These would include some of Marx's initial predictions about the uneven development of modern agricultural industries and the substitution of agricultural labour by machines and loss of employment in the countryside (Addicott 2016: 171). […] Furthermore, nor can we overlook the organisational powers that satellite-farming systems offer to higher social, political, and corporate powers. It is correct to consider that through 'changing our environment' we change ourselves. However, through reflexively changing ourselves we can also change our environments (Ibid: 174).

As this case write-up's preliminary analytical findings will show later, similar concerns presented here in the case of agricultural satellite technologies, can be seen in the case of robotic harvest technologies. Qualitative methods are also used in the study of satellite technologies, however, the author James E. Addicott, and the book in general, draw on sociological traditions rather than anthropological like in REELER. In the search of other studies dealing with the effects agricultural robotics have on human beings, the search combination *"Agricultural robot" AND "human effects"* was tried in all four databases. Each search returned with zero results. The same negative results were the case searching on *"Agricultural robot" AND ethnography*. When trying the search combination *Robot* AND harvest AND Ethic** medical journal turned up dealing with artery harvesting and surgical laparoscopy. Likewise, a search on *Robotics* AND agriculture AND ethics** did not give any useful results, but three documents dealing with ethics in nanotechnology, service robots, and subjecting cows to robots were presented.

This review indicates that the amount of research conducted with ethnographic methods in the area of agricultural harvest robotics is very limited - if even existing. Hence, there is a high need for research to address these emerging issues of agricultural robots effects on humans and society to provide input to policy decisions (see Roos 2017: xii).

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2.9 Cleaning – SPECTRUS

2.9.1 Cleaning robots

Service robots are still a relatively new and minor portion of the worldwide robot market, but are on the rise. Europe is especially active in the service robot sector. According to the International Federation of Robotics, there were roughly 60 thousand service robots sold in 2016, with 5 times as many industrial robots sold in the same period.[43] Industrial robots, however, were the first robots produced for the market.

The history of robots is two-pronged. On the one hand, there is the exploration of man in the machine, derived from fiction and built primarily for artistic and entertainment purposes.

43 https://ifr.org/downloads/press/Executive_Summary_WR_2017_Industrial_Robots.pdf
https://ifr.org/downloads/press/Executive_Summary_WR_Service_Robots_2017_1.pdf

On the other hand, is the evolution of working robots derived from increasingly complex machinery. Although a very small portion of service robots are beginning to blend these origins (adding humanoid features and functions to industrial robot technologies), robots are still firmly rooted in industry.

The evolution of standards shows that service robots, even while meant to fulfil certain human roles, are built on industrial robot technologies and are primarily meant to augment work. Industrial robots, machines created for labour purposes, were the first type of robots to be built and sold, beginning in the 1960s. The ISO standards for industrial robots, for example, are found in ICS 25.040.30 which translates to *Manufacturing Engineering/Industrial automation systems/Industrial robots. Manipulators.* This standard shows the evolution of the robot from industrial work machines. The standards for service robots (and the standards for collaborative robots) fall under the same umbrella of *Industrial robots. Manipulators,* which at first glance seems odd given that service robots are specifically defined as non-industrial robots:

"**service robot:** *a robot that performs useful tasks for humans or equipment excluding industrial automation applications... [such as] manufacturing, inspection, packaging, and assembly."* (ISO 8373:2012)

The reason for including service robots under the industrial robots classification is that the distinction between the two is contextual rather than technical:

"The classification of robot into **industrial robot** *or* **service robot** *is done according to its intended application...While* **articulated robots** *[i.e., robot arms] used in production lines are* **industrial robots***, similar articulated robots used for serving food are* **service robots***."* (ISO 8373:2012)

Service robots are thus not technologically distinct from industrial robots, but are industrial robot technologies applied in non-industrial settings or doing non-industrial tasks. The two robots studied in this particular case are first and foremost mobile robots, which are specified for cleaning and disinfecting. It is their application in hospitals and hotels that marks them as service robots.

There are many other types of service robots being tested and employed in hospitals and hotels. In these settings, robots are primarily used to perform: a) logistics tasks such as the transport of linens, food, or medications, b) care and hospitality tasks providing reception, socialization, comfort, or information services, and c) cleaning tasks such as vacuuming, surface cleaning, or disinfection. This case covers only the two lattermost tasks and two robots which might perform them, with an emphasis on the disinfection robot.

2.10 Logistics – WAREHOUSE

2.10.1 The evolution of logistics robots

The origins of logistics robotics date back to the early 20th century. This was the moment when the automobile and aviation industry have emerged, which led Henry Ford to start pioneering the use of conveyors for mass production of cars in an assembly line system. Over decades, different technologies and approaches have been developed with regards to how to handle, store and manage the goods at warehouses. The development of entire warehouse industry was always interrelated with other changes and developments taking place in the market production, supply chains, organisation of human labour, policies etc. Such a process has eventually led to the development of advanced warehouse management systems and robotic systems that address the requirements of e-commerce. The main goal of warehouse automation is to simplify the distribution and handling of product from manufacturer to stores and increase efficiency and productivity.[44]

In general, warehouses and distribution centres constitute a vital part of logistic systems. After producing different products, they are moved from the production facilities to the warehouses where the products are stored until they get ordered and sold. In order to successfully manage a variety of products, products are identified and sorted across warehouses by type and number (Kellett 2011). The moment a given product is ordered, it can be identified, picked and packed, and eventually moved to a shipping point. In other words, '[o]n a product level, the basic functions of warehousing thus include receiving, identification and sorting, dispatching to storage, placing in storage, retrieval from storage, order picking, packing, shipping and record keeping' (Kellett 2011). The main tasks for robots in this context is to pick and transport products. On the one hand, the use of robots in warehouses continues to pose serious technical challenges, for example, in terms of grasping soft items or objects of irregular shapes (e.g. grocery). One way to deal with this issue is to use mobile platforms that transport the entire shelves rather than pick single objects (compare images in Fig. 1) (these two types of robotic systems have sometimes been called 'stationary piece picking robots' and 'mobile piece picking robots' (Robotics in Logistics, 2016)). Also, it is important to note that in order to be functional, warehouse robots often require warehouse environments to be modified, for example, in terms of warehouse software and management as well as physical space. Thus, due to the cost and complexity of warehouse robotics as well as different technical challenges, automated / robotized warehouses are still a minority (note that automatic systems are not necessarily robotic systems). According to some sources, 80% of current warehouses are still only manually operated (Robotics in Logistics, 2016).

On the other hand, it seems that robotics technology has reached a sufficient degree of maturity to allow significantly

44 Source: http://www.symbotic.com/2012/11/20/evolution-robotics-warehouse-automation/

increasing the degree of automation in the warehouse industry (Correll 2016). In fact, there is a number of companies that have already been offering warehouse robotic solutions. The leading players in the global market include ABB Ltd. (Switzerland), Fanuc Corp. (Japan), Kuka AG (Germany), Yaskawa Electric Corp. (Japan), and Amazon.com, Inc. (U.S.). The leading countries in the European warehouse industry are Germany and the UK (Warehouse Robotics Market Research Report, 2018). It is also interesting to note that most of the companies in the EU warehouse industry classify as large companies (see Fig. 2 below). In addition to robots, other technologies used in the warehouse industry may include for example barcode scanning devices or recently also voice picking headsets (later in the course of fieldwork a warehouse worker said that as far as robot design is concerned *"Voice-activated would be brilliant"* because *"It seems easier than pressing buttons"*). In any case, from both the technical and business perspective, the expectations towards warehouse robotics are certainly high.

2.10.2 References

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2.11 Construction – WIPER

2.11.1 Evolution of construction robots

According to Rohana Mahbub (2008), construction robots have generally been described as ingenious machines that use intelligent control, designed to increase speed and improve accuracy of construction field operations (Mahbub 2008: 27; cf Aris & Iqbal 2006: 125-126). Although there is no consensus on a clear definition of construction robots (Aris & Iqbal 2006: 126; Gann & Senker 1993:3), a review by Mahbub (2008) concludes that construction robots are generally defined as:

The use of self-governing mechanical and electronic devices that utilises intelligent control to carry out construction tasks and operations automatically. The construction work tasks and operations are regulated through programmable controls and sensors; set up as a series of individual computer-controlled or robotic equipment with electro-mechanical links (Mahbub 2008: 29).

Construction robots are designed to increase the speed and improve the accuracy of construction work. Furthermore, they are considered to be "helpful because the activities they undertake are dirty and dangerous" (Aris & Iqbal 2006: 126). Numerous efforts have been made to automate parts of the construction process in order to improve its speed and efficiency (Mahbub 2008: 29). According to Thomas Bock and Tetsuji Yoshida (2016), the story of construction robots began in the 1970s in Japan where the first ideas appeared. Due to a lack of skilled labour force, low productivity, quality problems of construction work, numerous accidents, and high construction demands, some of the first prototypes of construction robots were developed towards the end of the 1970s (see also Mahbub 2008: 56). Adapting ideas from automobile manufacturing, shipbuilding, and the chemicals industry, the construction industry saw the introduction of robots on building sites where they carried out specialized tasks such as spraying, smoothing concrete, distributing materials, fitting equipment to ceilings, assembling form-work, installing facades, painting, and so forth (Bock 2016: 116). In the late 1970s, masonry robots capable of laying regular bricks and blocks were also being developed, and the late 1980s in Japan marked the increasing popularity of construction robots (Mahbub 2008: 29). Since then, Bock and Yoshida (2016) argue, the development of on-site robots in the 1980s peaked with the development of integrated automated building construction sites in the 1990s. These automated construction sites used robots for logistics and assembly (Bock 2016: 116). According to Thomas Bock, most of the construction robots developed today are stand-alone devices designed to perform narrowly defined tasks without the need to communicate or cooperate with other machines (ibid: 39). Examples of these construction robots include wall and façade climbing robots for inspection and maintenance, concrete power floating machines, concrete floor surface finishing robots, construction steel frame welding robots, wall panel bricklaying robots, robotic excavators, and automated cranes for the assembly of modular construction elements (Lee et al 2011: 446; for a review of robots developed for the construction industry, see also Bock 2016 and Mahbub 2008 for an overview based on countries).

As illustrated above, the construction industry uses different kinds of robots. Generally, in the manufacturing industry, robots are stationary and the product moves along the assembly line, whereas construction robots move around the site to perform different tasks in different conditions and environments (Aris & Iqbal 2006: 126). Furthermore, construction robots often handle large loads with components of variable sizes, and they are required to function under adverse weather conditions (ibid). As mentioned previously, a review by Jackson concludes that four generic families can be identified among the construction robots developed: 1) Assembly robots, 2) Interior Finishing Robots, 3) Floor Finishing Robots, and 4) Exterior Wall Finishing Robot (Jackson 1990: 76-84). With reference to the International Association of Automation and Robotics in Construction (IAARC), Rohana Mahbub (2008) similarly suggests that construction robots generally fall into three categories: 1) Enhancements to existing construction

plant and equipment (Mahbub 2008: 41), 2) Task-specific, dedicated robots (ibid: 42), and 3) Intelligent machines (ibid). Enhancements to existing construction plant and equipment can be realised through the attachment of sensors and navigational aids in order to provide feedback to the operator (ibid: 41). An existing crane can, for example, be conversed into a semi-automatic robot with an enhanced control system. Another example is a prototype earthmoving grader developed at Lancaster University (2005) called LUCIE (ibid: 42). As Mahbub describes, once the machine is placed in front of its work area, digging and placing of soil can be done automatically through adding sensors and controls that enables program controlled operation (ibid). Thus, entirely manually controlled methods can be improved through the use of supplementary aids, sensors and advanced control systems.

According to Mahbub, task-specific, dedicated robots are characterized as performing a specific, well-defined task, and they come in a variety of examples that can be categorised further into 1) robots for structural work, such as concrete placing and steelwork lifting and positioning, 2) robots for finishing or completion work, such as exterior wall spraying, wall and ceiling panel handling, positioning, and installation, 3) robots for inspection works, such as external wall inspection, and 4) robots for maintenance work as, for example, window and floor cleaning (ibid 42). These robots are usually used within a specific task of the construction process. Concrete examples include mobile robots developed to compact and control the thickness of concrete, or the range of painting robots in the area of interior assembly developed at the Technion Israel Institute of Technology (ibid: 43).

The final category of construction robots includes intelligent machines supported by a high degree of autonomy and knowledge-base with which the range of construction work tasks problems on-site are resolved (ibid: 44). According to Mahbub, the development of these robots is the most technologically challenging, and developments within this category are more prevalent in other industries compared to construction. Although adaptations of robots from these industries may be possible, Mahbub speculates that, in reality, construction environments need to be more structured and controlled before they can really start to take over (ibid). Mahbub comments that although these robots cannot adapt to other tasks than the one they are programmed to perform, they have nevertheless been "shown to produce productivity savings of a worthwhile order" (ibid).

2.11.2 Technical complexities

In his comparison between robots in the manufacturing and construction industry, Thomas Bock (2016) argues that the difficulties encountered in the development of construction robots are mainly due to the complexity of construction tasks. Bock suggests, for example, that the products of construction are much more complex and ill-structured, and in contrast to the repetitive products that flow down production lines, the design of the construction product and the process of building it are individually adapted in each case. Thus, while the manufacturing process is highly repetitive once production starts, that in construction is always changing (ibid: 38), consequently posing a series of technical challenges to be overcome (cf. Mahbub 2008: 69; Jackson 1990). Furthermore, the physical environment of construction is often much more hostile to machines as well as people. In regard to the design of machines, this means that they must be made sturdy and robust in order to withstand extreme weather, dust, and unexpected forces (Bock 2016; cf. Jackson 1990, Mahbub 2008: 69).

These considerations are in line with Rohana Mahbub (2008) who agrees that the development of construction robots is technologically difficult (Mahbub 2008: 68). The construction industry, so it is argued, is a diverse industry that has to cope with an almost unique set of circumstances on each site and project, consequently creating noteworthy barriers to the use of robots that must be robust, flexible, and with high mobility and versatility. Since every construction product is unique and involving complex and non-repetitive work processes generally peculiar to a specific site, robots are difficult to put into use (ibid: 68). Furthermore, the cost of owning and using these technologies on-site means that it is difficult to find contractors willing to invest in these technologies (ibid: 66; see also Jackson 1990).

Other studies address the question of technical barriers towards the use of robots in the construction industry by agreeing that the physical dexterity and flexibility of the human work that is required when working in construction sites cannot be duplicated by a robot (Jackson 1990). Jackson argues, for example, that the adaptability, creativity, and flexibility of the human worker in the working environment cannot be overstated and that designers tend to take these factors for granted:

A designer may state on the plans to "field verify door dimensions and construct to fit"; if the door opening is too large, the carpenter will use shims in fitting the door to the opening. Artificial intelligence is required to perform this function, but that technology is still in its infancy (Jackson 1990: 67).

In a comparison between the development of construction robots in Britain and Japan, David Gann & Peter Senker (1993) make a similar point. They conclude that the tendency to develop complex robots in an attempt to "improve quality and consistency by removing human judgement and control" is rarely successful (Gann & senker 1993: 7). Thus, the technological approach to finding solutions to problems of skill shortage often fails, Gann & Senker argue, because it does not take account of the role played by the skills that workers acquire through their experience on construction sites. The attempt to develop robots which themselves are capable of embracing the tasks acquired by skilled workers is "extraordinarily difficult," resulting in the development of highly complex and expensive robots (ibid: 7). Gann & Senker conclude that unmanned handling devices have minimal chances of success, whilst manned handling devices designed as an aid

for skilled operatives have a considerable chance of success (ibid).

2.11.3 Work environment and safety conditions

In his master's thesis on construction robots, Rune Elfving (2011) argues that the implementation of construction robots can be considered ethical if they improve the work conditions and environment for the construction workers (Elfving 2011: 17). According to Elfving, the primary purpose of introducing robots in the construction industry is thus to help workers by reducing strenuous, unpleasant and dangerous tasks. The issue of improving the work environment and safety conditions with construction robots is taken up by a number of studies (Jackson 1990; Warszawski 1985; Mahbub 2008). In his analysis of construction robots in the United States, Jackson (1990) argues, for example, that the most important factors when considering the development and use of robots in construction are related to issues of safety and work environment (Jackson 1990: 72; cf. Elfving 2009: 18). The construction industry, he argues, is generally characterized by a high amount of fatalities and disabling injuries among workers, caused from falls, materials falling on workers, crane and material handling accidents, and the collapse of trenches and excavations (Jackson 1990: 72). In comparison with the manufacturing industry, construction accounts for seven times as many fatalities per worker and twice as many disabling injuries (ibid; cf. Warszawski 1985). The implementation of robots, Jackson argues, will reduce these fatalities and disabling injuries (ibid: 73).

An early technical and economic analysis by Miroslaw Skibniewski & Chris Hendrickson (1988) similarly concludes that robots for surface finishing can reduce health hazards among construction workers. Referring to medical and statistical studies supporting the claim that surface finishing processes pose a substantial health hazard related to lung silicosis, Skibniewski & Hendrickson estimate that replacing human labour with an autonomous robot will eliminate such a hazard (Skibniewski & Hendrickson 1988: 55). Other benefits, they add, may be increased work productivity and labour cost savings, by reduction of human labour through a robotic replacement (ibid: 55-56). Another study by Seungyeol Lee et al. (2011) evaluates the use of a glazing robot developed to overcome the risk of musculoskeletal disorders and accidents among construction workers (Lee et al. 2011: 445). Given that inappropriate working postures have been considered one of the major causes of musculoskeletal disorders, stress, accidents and discomfort during work in construction sites and given that material handling, which constitutes almost half of all construction work, causes problems for workers because the materials and equipment used for construction are heavy and bulky (ibid: 446), the study compares existing installation methods (i.e. manpower) of heavy glaze at a construction site to the method of installing such glaze with a robot. Lee et al. conclude that the application of the robot reduced the labour burdens and accident elements for the workers by minimizing posture discomfort and, thereby, the risk of developing musculoskeletal disorders (ibid: 453). Similarly, Aris et al. (2005) demonstrate how painting robots "solve the problem of working in an upright position, which is very troublesome, boring, unhealthy and harmful to a human being if the working period is long" (Aris et al. 2005: 47; cf. Ni et al. 2011; Jannadi 1996; Aris et al. 2005). Furthermore, Ni et al. (2011) conclude in an experiment with a remote-controlled teleoperated construction robot that such robots can accomplish the task effectively with better safety and reduction of stress among the construction workers who operate it (Ni et al. 2011: 494).

On the other hand, other studies argue that technical devices must do more than only improve work and safety conditions by handling and transporting heavy materials, in order for them to be put into use among construction workers (Leeson 2017). As an anthropological study among Danish construction workers demonstrates robots and technical devices more generally need also to prove their effectiveness on the workers' productivity. In a work environment characterized by piece rates (akkordlønninger), this means that even if robots and other technical devices are welcomed because they may improve the work environment and safety conditions (Leeson 2017: 27-28), they are nevertheless often disregarded and neglected if they delay and slow down the workers' work (ibid). Hence, the study concludes that the development of construction robots must, therefore, take into consideration that if such robots are to be accepted and used among construction workers, they must be capable of improving the work environment and safety conditions while simultaneously supporting, and ideally improving, workers' productivity. Another anthropological study on safety and work environment among Danish carpenters similarly demonstrates that technical devices are often experienced as slowing down work procedures and are therefore not always put into use (Grytnes 2013: 81, 186). Even if they might prevent dangerous work or accidents, they are abandoned because they take too much time to use (ibid, see also Baarts 2004).

Assuming that the use of construction robots improve the work environment and safety conditions, several other benefits can be highlighted. One benefit of construction robots which work to improve the work conditions is the positive effect on quality and workmanship (Warszawski 1985; Aris et al. 2005: 29; Jannadi 1996; Ni et al. 2011; Mahbub 2008; Leeson 2017). According to Jackson a problem that has been generally noted in the construction industry is the variation in the quality of construction projects. Although the quality may meet minimum standards, no two projects, even if performed by the same contractor, will possess the same level of quality (Jackson 1990: 71). The same point is made by Aris & Iqbal (2006) in their discussion of the design and development of a robotic system capable of painting houses. Thus, Aris & Iqbal argue that low-quality work is often produced because the worker has to look upward for a long time, which can cause neck pain and injury to the body. For this reason, the worker cannot concentrate on the job and will produce low-quality work (Aris & Iqbal 2006: 127; cf. Kangari & Halpin 1990:92). In this context, one of the advantages of using robots is repeatability which ensures that high-quality standards are attained and maintained, providing higher and uniform quality

over several construction projects (Jackson 1990: 71). Other studies show that, for the workers involved, the improvement of quality with robots may further professional pride (Leeson 2017: 31). As expressed by a construction worker in the study:

It was so smart with the welding robot (svejserobot) and the product you produce, well, it looks really good. Because the welding is uniform and you can easily see that there are no uneven spots at all. When you weld normally, it is easy to see that it is done by hand because sometimes your arm hits something and then it jumps a bit. But such thing doesn't happen with the robot. It just welds and everything is completely the same. That is impossible to do as a human being. Well well, yes, it may be possible but not eight hours in a row. But the robot doesn't care. It just welds as long as there is power (Leeson 2017:31).

Furthermore, according to Warszawaski and Rosenfeld's (1994) economic analysis of the performance of an interior-finishing robot, it can be concluded that the use of such robots has considerable potential for productivity improvement and economic savings on the building site (cf. Warszawski 1985; Bradley & Seward 1990; Mahbub 2008). Thus, the average productivity of a robot is not only assumed to be higher by 50 % than that of a worker (Warszawski 1985: 80), not least because robots are capable of working 24 hours a day (Elfving 2011: 18). It is also assumed that the replacement of labour by robots in hazardous tasks will decrease the incidence of accidents and thereby also the economic costs involved in such accidents (Waszawski 1985: 77). Thus, as Mahbub sums up the potential capability of construction robots, "the construction site could, theoretically, be contained in a safer environment, with more efficient execution of the work, greater consistency of the outcome and higher level of control over the production process" (Mahbub 2008: 1).

2.11.4 Replacement and retraining

As illustrated above, construction robots need to prove their positive effects on the work environment and safety conditions among workers in order to be considered ethical to use (Elfving 2011). Construction robots must not harm their users, whether that is by hurting them, killing them, or by displacing them (ibid: 17, 41-44). But how does one ensure that no one is harmed in the collaboration between workers and construction robots? In their study on the effects of a glazing robot on the work environment in the construction industry, Lee et al. (2011) delegate the question of safe robot behaviour to robot engineers when arguing that realization of safe use depends on an appropriate design that does not cause new types of accidents (Lee et al. 2011: 446). Similarly, Gann & Senker (1993) suggest that if construction robots are to be implemented effectively, robotic researchers need better understanding of construction site work and of the skills exercised by construction workers. According to Gann & Senker, this involves, also, that the interaction between robotic researchers and contractors need to form as a basis for developing the training programmes necessary to ensure that robots can be operated and maintained safely and effectively on-site (Gann & Senker 1993: 9).

Another suggestion for ensuring that robots do not harm people comes from Jackson who considers the ways in which construction robots may potentially displace workers in the industry. Since the implementation of robots in any organization, Jackson argues, is done to improve production efficiency and quality, thereby reducing costs, the threat of impending and potentially widespread unemployment is of greatest concern to the workforce and the unions (Jackson 1990: 37). Consequently, with the development and implementation of robots, Jackson argues, the job security of the workers targeted for replacement should be of primary concern. This involves transferring displaced workers to another job within the same company or retraining them for the new "robot-related work", which now involves programming, repairing, and supervising the robots (ibid: 38-39). In an environment characterized by concerns for unemployment, Jackson therefore concludes, the key to successful use of robots is communication and education. On the one hand, managers must state why robots are necessary, and how robots will reduce costs, making the firm more competitive. In addition, management must present its plan for accommodating the worker who will be displaced by robots. On the other hand, adequate education will help guide people away from manual jobs, which are prime targets for robotization, towards more technical jobs (Jackson 1990: 42-43): "In essence, this is a form of proactive management, as the workers of tomorrow are trained for the skills that will be needed and guided away from potential areas of robotization" (ibid: 43).[45]

Although this line of thinking is in line with Mahbub who agrees with Jackson on the fact that for robots to become commonplace in the construction industry, "a new breed of workers is needed; who has a strong academic background with special training in areas of robotics engineering and control" (Mahbub 2008: 69), Mahbub also argues that some workers might not necessarily be interested in, or capable of, learning the new skills required to handle sophisticated equipment. A similar point is made by Vest-Arler (2014) in their study of the introduction of iPads among construction workers in Denmark in which several workers refused to learn how to use the new technological tools (Vest-Arler 2014: 24). This issue, the authors argue, is particularly related to the fact that the benefits of using the new technology seemed unclear. Hence, workers did not experience that the technology improved their work and they were therefore sceptical towards using it (ibid). Thus, as robots not only take time to set up and need to be constantly monitored by skilled workers while also relying on an adequate supply of appropriately skilled operators who can and will operate the sophisticated machinery, they might at the same time exclude those people from work

45 For a discussion on the issue of retraining and education in relation to the implementation of robots in the construction industry in Denmark see for example Mandag Morgen 2016.

who are not willing to, or capable of, receiving the necessary retraining (Mahbub 2008: 70).

2.11.5 References

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