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Design and Digital Manufacturing: an ergonomic approach for Industry 4.0

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Abstract

The aim of the present paper is to propose innovative methods for ergonomic design of tools, equipment and manual tasks on workplaces of an automotive assembly line, in order to increase worker's welfare and system's performance by improving general safety conditions.

The manufacturing industry is heading to the ever more pushed use of digital technologies in order to achieve very dynamic production environments and to be able to develop continuous process and product innovations to fit into the so called Fourth Industrial Revolution, also identified as Industry 4.0. The main goal of Industry 4.0 is to "re-think" factories through the use of digital, to reconsider the design approach and to monitor the production process in real time.

The research addresses the evolution of industry 4.0 in relation to the discipline of "design", where the management of knowledge in the production process has led to the strengthening and improvement of tangible goods.

Starting by current ergonomic analysis models and innovative approaches to the process design of industrial production line, the manufacturing processes in the virtual environment were defined and optimized with the use of innovative 3D visualization technologies.

The constant interaction among the different disciplines of design, engineering and occupational medicine, enables the creation of advanced systems for simulating production processes based on virtual reality and augmented reality, mainly focused on the needs and requirements of the workers on a production line with the main objective of bringing out the interaction between real and virtual factory (Cyber-Physical System - CBS).

The objective is to define new models of analysis, of development and of testing for the ergonomic configuration of processes, that improve and facilitate the human-machine interaction in a holistic view, in order to protect and enhance human capital, transferring the experiences and knowledge in the factory system, as key factors for the company and for the sustainability of workers welfare levels.

Keywords: *Design, Digital Manufacturing, Ergonomics, Innovation, Virtual.*

1. Introduction

This paper provides innovative methods for improving the design of equipment and manual work stations in industrial environments, with particular focus on the global safety of the worker on the production/assembly line.

Developed activities are subtasks of the research project "DEWO – Design Environment for WorkPlace Optimization", financed by Italian Government at the Second University of Naples. The aim of this project is to identify new methods for optimization of assembly tasks in a virtual environment in terms of overall integration among materials management, working tasks organization and layout, starting from the principles of "WorkPlace Organization" and of the modern theories of "Lean Production".

The research objective concerns the articulation of operational guidelines for the design of manual workstations and tools, for simulation in a virtual environment, for verification of the ergonomic parameters and of the quality of the solutions. This objective will be pursued through the innovative use of virtual reality identified as a "tool" for innovation in automotive manufacturing context.

2. The Evolution of Automotive: from the Handicraft to the Digital Manufacturing

As a matter of fact, the manufacturing industry is heading to the ever more pushed use of digital technologies in order to achieve very dynamic production environments and to be able to develop continuous process and product innovations to fit into the so called Fourth Industrial Revolution, Industry 4.0 (Figure 1). The main goal of Industry 4.0 is to "rethink" factories through the use of digital, to reconsider the design approach and to monitor the production process in real time.

The main application field of this contribution is represented by the manufacturing industry, the major source of wealth and value for a country and for the promotion of economic development. The increase in manufacturing is equivalent to the economic growth of a country, for generating productivity gains, which then go to develop and to spread to other contexts, by creating jobs and, above all, it is the privileged place for research and innovation. For the increasing of this sector, it is essential to guess two aspects, the importance of competitiveness and the constant evolution through innovation.

As part of the manufacturing, the automotive industry plays a leading role. It's one of the main productive, representing a driving force in the economic development. The technical complexity of a car pushes the research in the direction of new productive and efficient product life and process management techniques.

Automotive field was the privileged place of experimentation, technological innovation and implementation of new forms of work organization; in the last decades it has been the field of application of new methodologies to improve the whole process, also from an ergonomic point of view, considering of primary importance the relationship between worker and machine; the human centered approach is one of the main pillar of Industry 4.0, as well as the virtual and digital factory.

In particular, during the assembly of a vehicle, the application of Digital Manufacturing leads to a series of steps forward, especially for the ergonomic aspect in relation to the work areas and equipment used by a worker.

The final assembly area is composed of a variety of sub-assemblies' cells in addition to a main line. The main line has a variety of stations that install and mount suppliers' parts and components into the vehicle shell. The final assembly area is considered a labor-driven process due to the high labor value-added work compared with other stations in the body assembly plant. […] The greater contribution of the labor *input requires further considerations with regard to human-machine interaction in terms of safety, ergonomics, and work standards and time studies* (Omar, 2011).

The ergonomic approach highlights all aspects of the human-machine interaction process, identifies and classifies stages and individually work operations that lead to the assembly of the final product, analyzes postures and movements of the operator in order to check in as much detail as possible his psychophysical wellbeing.

The ergonomics of the assembly processes help the workers to conduct their tasks with ease and within the task time. The main ergonomics concerns in the assembly area are: installing heavy components, the frequent installation di medium to light-weight components, the installation posture, and the human hand utilization. All these aspects should be analyzed while considering that production workers are all different, they have physical and mental limitations, and humans have certain predefined reaction to certain scenarios (Omar, 2011).

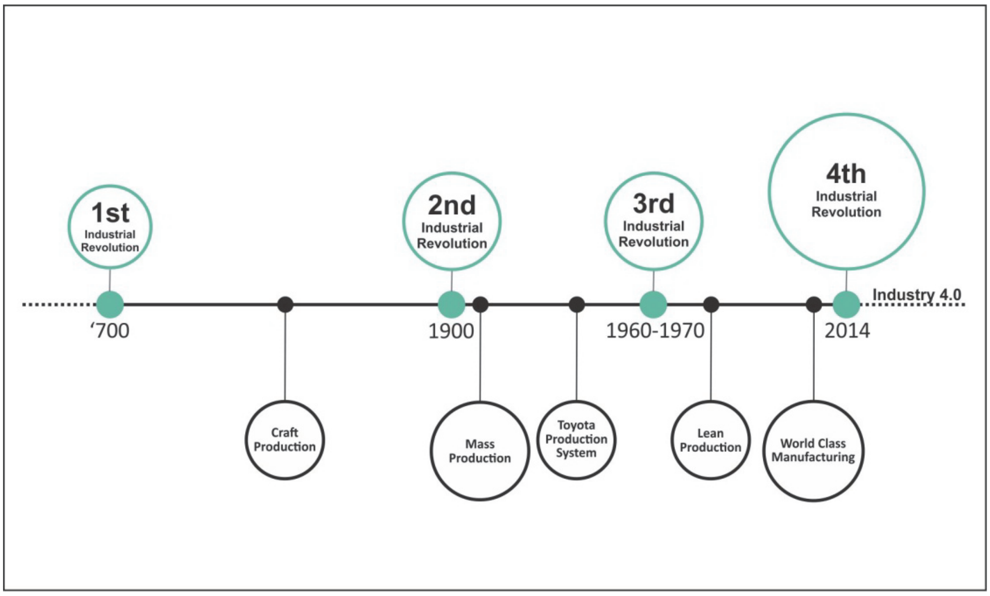

Fig. 1 Process evolution of Automotive in industrial context.

2.1 An ergonomic approach in production chain

This paper is focused on the application of a new ergonomic design approaches of manual workstations on the assembly line, of equipment and tools used by the worker during the development of the different assembly tasks.

Starting by current ergonomic analysis models and by innovative approaches to the assembly line design, the processes in the virtual environment were defined and optimized with the use of innovative 3D fruition technologies (Figure 2).

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (IEA-International Ergonomics Association).

The ergonomic objectives are to improve the quality of the environmental conditions, the working tools and operator performance, to prevent occupational diseases and promote the psychophysical wellbeing of worker. The science of the human factor has as its central subject the human activities in relation to environmental, instrumental and organizational conditions, in which it takes place, in order to adapt these conditions to their needs, protecting life and increasing efficiency and reliability of man-machine systems. In detail, the ergonomics of the work stations has had a strong development thanks to the thrust of the new European regulations and the progress of companies in terms of methodologies and techniques focused on improving of the safety of manufacturing plants.

Un ambiente, un posto di lavoro non debbono essere valutati solo in termini di salvaguardia da condizioni nocive, ma debbono essere giudicati validi nella misura in cui permettono il massimo grado di benessere e le migliori condizioni per l'esplicazione della personalità del lavoratore (Bandini Buti, 2008).

[An environment, a workplace don't be evaluated only in terms of protection from harmful conditions, but be deemed valuable to allow the greatest degree of well-being and the best conditions for the explication of the worker's personality].

For designing a manual workstation, it needs to consider all the possible interference of the physical and not physical aspects for the execution of work tasks, on ergonomic performance of the activity carried out by the operator.

L'ergonomia ha dimostrato di saper sviluppare teorie, sperimentare criteri e metodi finalizzati alla soddisfazione degli utenti al livello di bisogni e di desideri (consci o inconsapevoli) […] Tutti gli approcci per affrontare un problema portano ad orientarsi verso il cliente, che viene in tal modo considerato un'assoluta forza guida (Lupacchini, 2008).

[Ergonomics has demonstrated the ability to develop theories, test criteria and methods for its users satisfaction for their needs and desires (conscious or unconscious) [...] All approaches to address a problem lead to orientate towards the customer, which is thus regarded as an absolute driving force].

For the current competitiveness in industrial realities, the necessary condition is the ability to combine productivity, ergonomics, and operating models that are participative. It is essential to make a distinction of ergonomics not only from the point of view of objectives, but also as regards the different phases of "application". In this regard, we talk about preventive or conception ergonomics in the early stages of a product- process development, which reduces production costs and improves the results in terms of safety and work's quality. Corrective ergonomics, applied in the production phase, consists of an action taken for eliminating the existing not-conformities causes, defects or other undesired situations, in order to prevent its recurrence (Figure 3).

Particularly, *L'intervento ergonomico di concezione è caratterizzato dal fatto che avviene su oggetti, sistemi, ambienti e macchine ancora in fase di definizione o su attrezzature e macchine che devono essere ancora scelte. […] Non esiste alcun ostacolo concettuale affinché il progetto possa essere sviluppato tenendo conto delle prestazioni ergonomiche che si possono ragionevolmente prendere come obiettivo* (Bandini Buti, 2008).

[The conception ergonomic action is characterized by taking place on objects, systems, environments and machines during the definition phase or on equipment and machines that haven't yet been chosen. [...] There isn't a conceptual obstacle so that the project can be developed taking into account the ergonomic benefits that can be reasonably considered a gol].

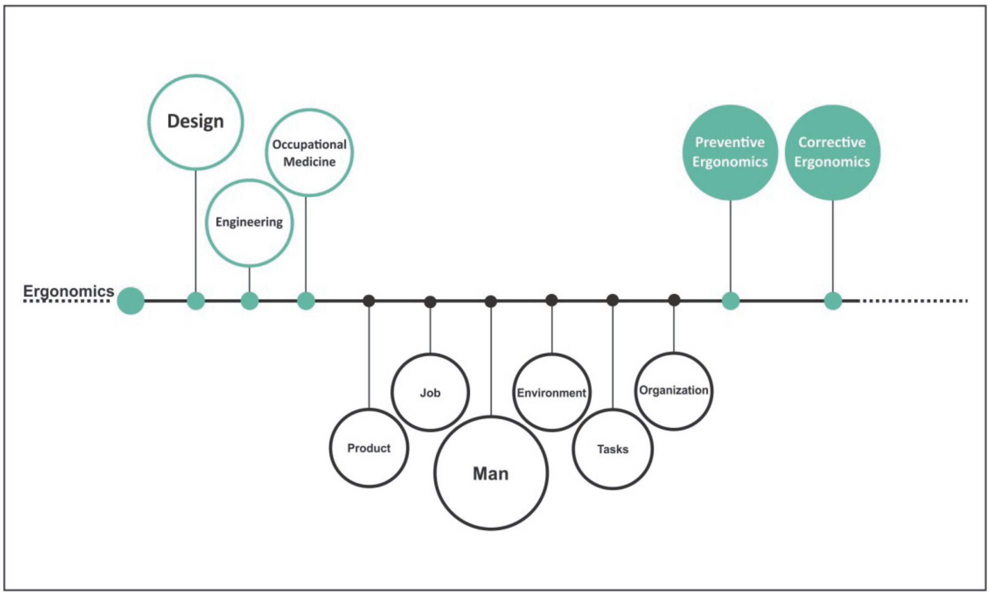

Fig. 2 Ergonomics in product-process development.

3. Industry 4.0 between real and virtual

In un contesto in cui i paradigmi del mercato mutano così radicalmente in tempi molto stretti, le iniziative delle imprese private e pubbliche devono tradursi nella rapida adozione di catene del valore digitali, come elemento strategico di ripresa, crescita e accelerazione. La trasformazione digitale non può rappresentare solo una opzione o un canale accessorio, ma un elemento centrale sui cui puntare, attraverso diffusione delle competenze, investimento nella ricerca e interventi sulle infrastrutture di connettività, data center e accesso alla Rete, evoluzione dei modelli operativi, coerente cultura manageriale e humus imprenditoriale - dalla sperimentazione alle start-up (Poggiani, Tedeschi, 2014).

[In a context where the market paradigms change so radically in a very short time, the efforts of private and public enterprices should be set in the rapid adoption of the digital value chains as a strategic element of recovery, growth and acceleration. The digital transformation can not be just an option or a second way, but a central element on which to focus, through dissemination of skills, investment in research and measures concerning the connectivity infrastructure, data center and Internet access, changing operating models, consistent managerial and entrepreneurial culture humus - from testing to start-ups].

As a matter of fact, Industry 4.0 changes the way to think factory, the relationships between suppliers, manufacturers and customers and puts in the foreground the human-machine interaction in a production system.

Oggi è in corso la quarta rivoluzione industriale: dall'inizio del 21˚secolo, stiamo vivendo una trasformazione digitale - cambiamenti associati con l'innovazione nel campo della tecnologia digitale in tutti gli aspetti della società e dell'economia (Potti, 2015).

[Today the Fourth Industrial Revolution is in progress: since the beginning of 21˚Century, we are experiencing a digital transformation - changes associated with innovation in the field of digital technology in all aspects of society and economy].

Industry 4.0 is the consequent evolution of the three already experienced industrial revolutions: the first revolution with the introduction of water power, the use of steam power and the development of machines; the second revolution characterized by electricity and the advent of mass production; the third revolution, more recently, based on the use of electronics and information and the application of automated production.

Lo sviluppo tecnologico e la crescente maturità culturale verso l'utilizzo di dispositivi informatici sta alimentando la trasformazione "digitale" di abitudini e pratiche consolidate sia in ambito privato che aziendale. Anche nel settore manifatturiero l'onda di tale trasformazione sta modificando significativamente il modo di pensare, progettare, realizzare i processi produttivi e di supporto alla produzione. La rilevanza dell'impatto presente e atteso di tali innovazioni in questo ambito ha generato l'opinione sempre più diffusa di trovarsi nel mezzo di una vera e propria nuova rivoluzione industriale (Poli, Martini, Petronio, 2014).

[Technological development and the growing cultural maturity towards the use of computing devices is supplying the digital "transformation" of established habits and practices in both private and business field. Even in manufacturing the wave of this transformation is changing significantly the way we think, design, implement the production process and production support. The significance of the present and expected impact of such innovation in this area has generated the widespread opinion of being in the middle of a real new industrial revolution] (Figure 3).

Industry 4.0 is a social and economic challenge that rethinks the factories through the digital, how to design objects, to create prototypes, monitoring the assembly line in real time. It has the main objective to boost the economy, offering innumerable opportunities to the manufacturing system and a new life and identity to the factories through the connection between the real and the virtual world.

At the center of the great digital revolution there is the "Man" with his needs and requirements. Man and machine work together but the user centrality is the main guideline for digital transformation, demonstrating the superiority of man work on the machine.

Quando si riflette sull'impatto della tecnologia sull'impiego, e sulla perdita di posti di lavoro, è importante cercare una complementarietà fra persone e macchinari, affinché gli individui possano svolgere mansioni che aggiungano valore agli ambienti di lavoro sempre più automatizzati. Molti compiti "non trasformabili in routine", cioè che richiedono creatività, comunicazione sociale, empatia e il trattamento di informazioni nuove e non formalizzate, difficilmente saranno automatizzati nel prossimo futuro (European Schoolnet, Digitaleurope, 2014).

[When we reflect on the technology impact on employment, and the loss of jobs, it is important to seek a complementary relationship between people and machines, so that individuals can perform tasks with add value to the automated workplace. Many tasks "not convertible into routine", that require creativity, social communication, empathy and the treatment of new and not formalized information, are unlikely to be automated in the near future].

Sensors, machines, real operators and IT systems will be connected to each other along the same value chain, giving rise to countless technical and economic benefits. The new "factory" system is characterized by the presence of technologies linked to each other and generate a change of the production paradigm, dictated by the actual technological advances.

Among the different technologies developed in an Industry 4.0, simulation and virtual reality are the main areas in which the contribution fits. To play a production process in a virtual environment is a strong potential for innovation, and even more the opportunity to immerse themselves and experience the virtual world in the most realistic possible way. To live a productive process means reducing time and costs for inspections related to the product itself or the manufacturing process (Figure 4).

The digital revolution is identified as a pure and real innovation that will change the nature of same manufacturing, turning every link in the production chain, taking into account all the stages: from the supply chain to manufacturing operations, from marketing to services. Thanks to new digital technologies, enterprices will be able to put together the physical aspects with "virtual" aspects (Cyber-Physical Systems).

L'impatto delle tecnologie emergenti (informatica, telecomunicazione, bioingegnerie, robotica e tecnologia dei materiali avanzati) porterebbe a un progressivo assottigliarsi della materialita del mondo, ad una dematerializzazione della nostra realtà nel suo complesso. In altre parole, si sarebbe ormai avviata una contrazione dell'universo degli oggetti materiali, oggetti che verrebbero sostituiti da processi e da servizi sempre più immateriali (Maldonado, 1992).

[The impact of emerging technologies (IT, telecommunications, bioengineers, robotics and advanced materials technology) would lead to a progressive narrowing of the world materiality, a dematerialisation of our reality overall. In other words, it would now start an universe contraction of material objects, objects that would be replaced by processes and increasingly intangible services].

Industry 4.0 considers the virtual reality as an innovative tool to manage and optimize a production process, taking into account every aspect. The enjoyment of a virtual environment has the purpose to increase the productivity of a production plant.

Da un punto di vista puramente tecnologico la VR è costituita da una serie di strumenti in grado di acquisire informazioni (strumenti di input) attraverso i quali l'utente diviene in grado di fornire al computer molteplici dati in ingresso, che verranno integrati e modificati in tempo reale dal calcolatore in modo da fornire una immagine 3D in movimento. Queste saranno restituite all'utente attraverso più o meno sofisticati strumenti di fruizione dell'informazione (strumenti di output) (Morganti, Riva, 2006).

[Since a purely technological point of view, the VR consists of a set of tools able to acquire information (input devices) through which the user becomes able to provide the multiple incoming data computer, which will be integrated and modified in real-time by the computer so as to provide a 3D moving image. These will be returned to the user through more or less sophisticated information access tools (output devices)].

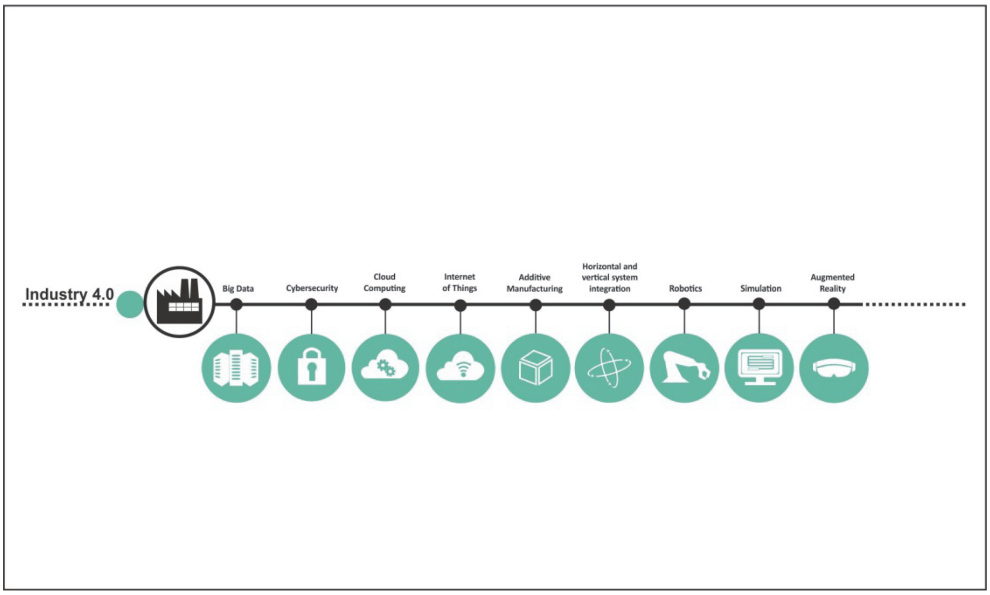

Fig. 3 Digital technologies in Industry 4.

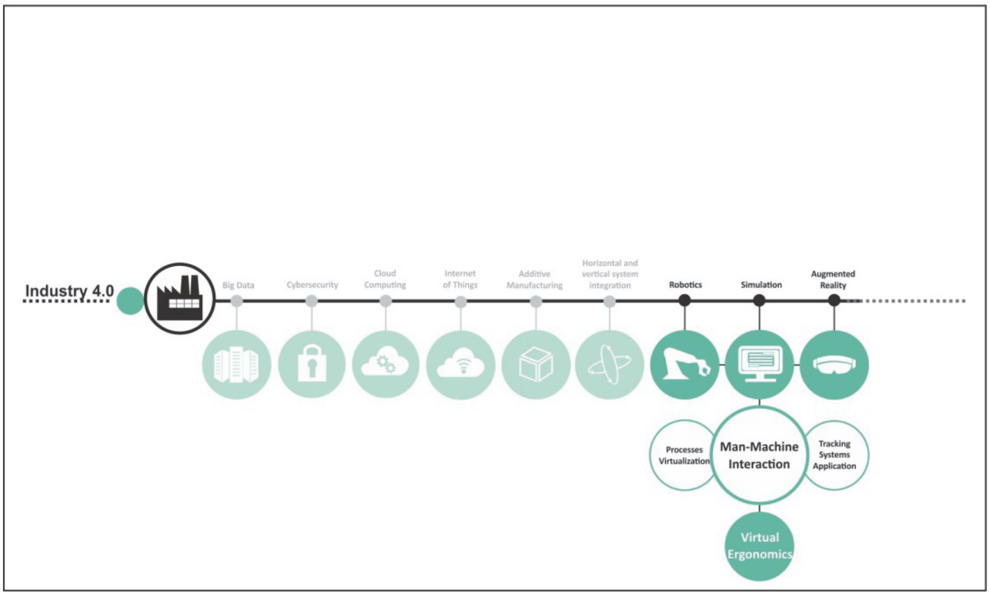

Fig. 4 Simulation and virtual reality in Industry 4.0.

3.1 Immersive Reality for Design

The constant interaction among the different disciplines of design, engineering and occupational medicine, enables the creation of advanced systems for simulating production processes based on virtual reality and augmented reality, mainly focused on the needs and requirements of the workers on a production line where it is possible to bring out the interaction between real and virtual factory (Cyber-Physical System).

The manufacturing landscape will evolve and create huge value through constant interconnection between the different expertises from various professional fields in a expressly collaborative vision.

Interdisciplinary use of advanced digital models is indispensable competences to approach the innovation of the product / process design.

I modelli di simulazione possono essere ricavati velocemente , altrettanto rapidamente, essere osservati da ogni angolo e all'occorrenza modificati. È significativa, perciò, la positiva incidenza sul miglioramento di un prodotto, tant'è che, grazie alla biomeccanica, designer, ingegneri e altri specialisti sono in grado di condurre uno studio particolarmente approfondito di ogni singolo aspetto del progetto nelle sue capacità e potenzialità. La biomeccanica dunque è una delle componenti dell'ergonomia ed è intimamente connessa al fattore umano del design; mentre il comun denominatore delle tre discipline può essere rinvenuto nella tecnologia (Lupacchini, 2006).

[Simulation models can be quickly obtained - be viewed from every angle, and modified if necessary. It is significant, therefore, the positive impact on the product improvement and thanks to the biomechanics theories, the designers, the engineers and other specialists are able to develop a deep study of every aspect of the project in his abilities and potentiality. Biomechanics theory is one of the components of ergonomics and is intimately related to the human factor design; the common denominator of the three disciplines can be found inadvanced technologies].

The research addresses the evolution of innovation within Industry 4.0 in relation to the discipline of design, where the management of knowledge in the production process has led to the strengthening and improvement of tangible products. The discipline of design takes on a fundamental role in the definition and design of tools and manual workstations through a highly ergonomic and innovative approach.

Design è un'attività creativa il cui scopo è di definire le molteplici qualità degli oggetti, dei processi, dei servizi e dei loro sistemi nell'intero ciclo di vita. Il design è quindi il fattore centrale per l'uma-nizzazione innovativa delle tecnologie e il fattore cruciale per gli scambi culturali ed economici (Verganti, 2008).

[Design is a creative activity whose aim is to define the multiple qualities of objects, processes, services and systems during the entire life cycle. Design is therefore the main factor for innovative human-harmonization of technologies and the crucial factor for the cultural and economic exchanges].

Therefore, as part of the research, new models of analysis, of development and testing were classified for configuration of ergonomic processes, that improve and facilitate the human-machine interaction in a holistic view, in order to protect and enhance human capital, transferring the experiences and knowledge in the factory system, key factors for the company and for the sustainability of workers welfare levels.

In order to identify these models, during the initial phase of the research, it was carried out a "virtual scenario" of a work place with the presence of 3D models related to equipment and a virtual anthropomorphic dummy that interacts with the environment (Figure 6). The virtual dummy can be manipulated according to the required needs, customized and changed for the posture to be taken in certain work activities, generating as much as possible realistic behaviors. The virtualization process determines preventively the possible discomfort associated with selected positions and eventually proceed to improve them in terms of re-design of a particular work tasks or of tools and equipment.

The main benefits gained from the simulation of the manual tasks during a work activity are the reduction of accidents risks, the improved communication of the problems identified in the process, an increase of the quality of a process and the reduction of times for assembly processes planning and validation (Figure 5).

I modelli informatici possono offrire alla ricerca scientifica e alla progettazione in tutti i campi possibilità mai avute nel passato. Al posto del tradizionale modo di affrontare i problemi percorrendo un lungo e defatigante itinerario di prove ed errori, subentra ora un metodo nel quale prove ed errori richiedono un investimento di tempo e risorse sostanzialmente ridotto (Maldonado, 1992).

[The IT models can provide the scientific research and design in all possible fields. Instead of the traditional way of dealing with problems along an exhausting itinerary of trial and error, now a method takes over in which trial and error require an investment of substantially reduced time and resources].

Afterwards the virtual context was explored from the "immersive" point of view through the use of tracking systems with digital dedicated software which allows to relate the virtual and physical world (Figure 6). A tracking device enables to capture in real-time the user movements that moves in front of system, turning them into gestures and actions into virtual environments (Figure 7). The realism of the captured movements by a tracking device produces an immersive experience of user, originated from the use of innovative technologies of Industry 4.0.

Il fatto che, per esempio, mettendoci una cuffia oculare (eye-phon), infilandoci un guanto intelligente(data-glove) e indossando una tuta intelligente (data-suit), siamo in grado di entrare in una realtà illusoria e viverla come se fosse reale (o quasi), è un passo evidente in questo senso. Ora siamo in condizione di perlustrare dall'interno una realtà che è la controfigura della nostra. Il che sarebbe, in pratica, come proiettarsi dentro un videogame. E ciò senza rischio alcuno per noi stessi, in quanto la nostra azione in tale spazio si combinerebbe solo con la vicaria complicità di un nostro sosia, di un alter ego digitale (Maldonado, 1992).

[The fact that, for example, putting an ocular element (eye-phon), inserting a smart glove (data-glove) and wearing a smart suit (data-suit), we are able to get in an illusory reality and live it as if was real (or almost), is an obvious step in this direction. We are now able to reconnoiter from inside a reality that is the stunt of our reality. Which would, in practice, as projected in a videogame. And this without any risk to ourselves, because our action in this area will only combine with the vicarious complicity of our double, a digital alter ego].

Through immersive reality, the real user is synchronized with the virtual dummy. The user can move in real space and his movements are recorded by the tracking device and transferred to the virtual dummy that moves, creates paths and navigates into the virtual scene. In addition to a primarily visual aspect, the ability to look at a 3D scene, the interaction has the main purpose to identify methods and procedures to perform ergonomic analysis in an innovative way and in less time.

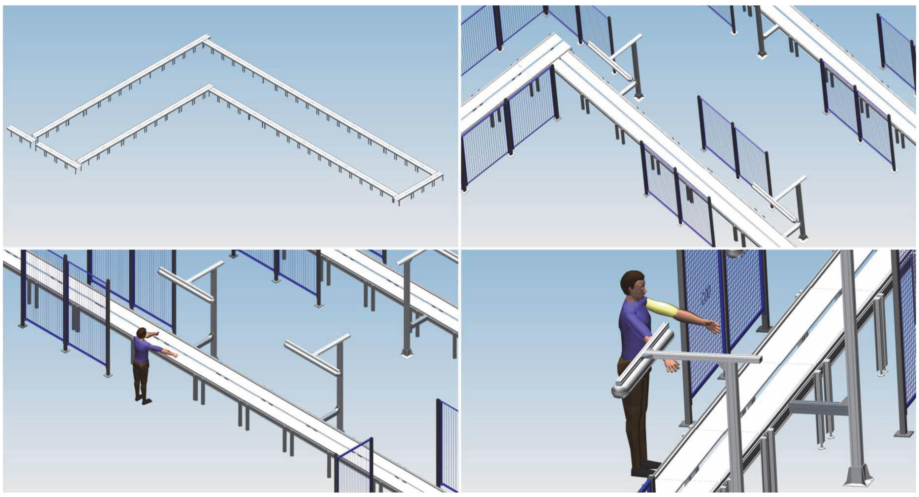

Fig. 5 Virtual Environment creation with Digital Software

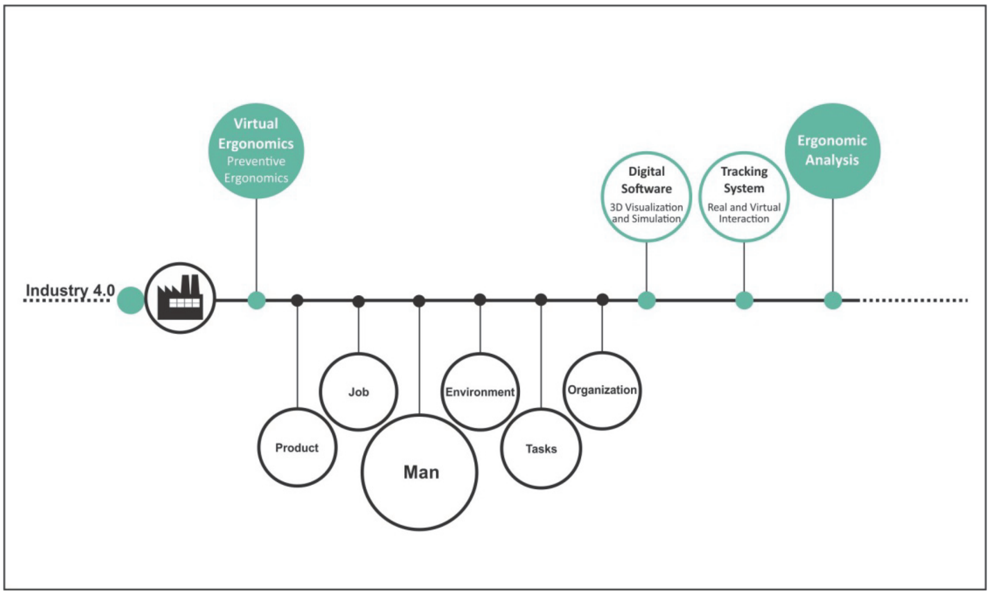

Fig. 6 Virtual Ergonomics in Industry 4.0

Fig.7 Interaction interface between Real and Virtual World

4. Conclusions

Within manufacturing applications, the use of virtual reality is an innovative and intuitive tool that facilitates the global design process. This new approach is validated through the continuous interaction between real and virtual. Its main ability is the easy and fast detection of ergonomic indexes and their management in order to solve expected and unexpected criticities on the production line.

Through the use of tracking systems, it was possible to bring out a number of advanced features and to improve current ergonomic standards. With the aid of such devices, the real user allows virtual dummy the quick and flexible navigation of the virtual scene; time reduction for placement in a particular work area and a more realistic setting of postures in order to perform a particular task is also allowed. At the end, the reachability of a working point or of a tool, dynamically acquiring ergonomic measures in relation to different movements of the dummy is possible (Figure 8).

The quickness of the ergonomic analysis allows the identification of innovative methods and procedures to design general equipments which a production operator uses. The procedure for ergonomic checks will bring an increase and a radical innovation in the production process of Automotive. Through technology transfer, this procedure can be applied to different production sectors to implement the general manufacturing environment.

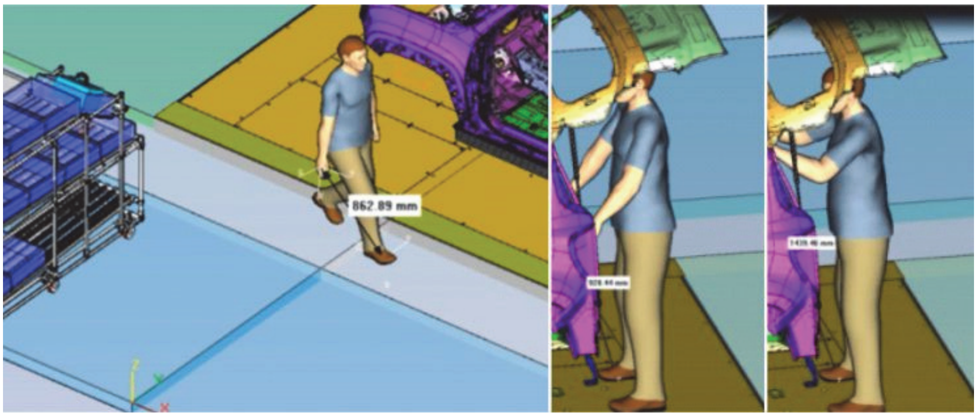

Fig. 8 Virtual dummy navigation and dynamic measurements detection with Tracking Systems

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