Sensing technologies embedding construction workers outcomes/key performance indicators

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Abstract

Construction Industry is and will continue to be crucial for countries' economies. The successful implementation of innovations on the context of the Industry 4.0 demands efforts in technology, processes, and people. The manufacturing industry increases its productivity faster than construction. Labour processes in the manufacturing industry are directly connected to machines. On the other hand, in construction tasks, the workers are the principal dimension of labour productivity, namely during the construction and use stages. The motivation links with the awareness that is necessary to find a balance between technology, people and processes in order to find the best roadmap towards the introduction of innovations, goals achievement and obtain added value from the implementation processes. From this, the workers performance management and potential from the application of sensing technologies to collect data during construction projects was emphasized.

To get the required data, an integrated model must be set aligning construction tasks, sensing technologies for data collection, key performance indicators related to workforce and main constraints in project management. This proposed model must be combined with building information modelling to achieve higher outcomes. The result is the assessment of construction projects performance based in the human resource integration with the current information systems and the new sensing technologies.

The main deliverable is a framework composed by different parts as follows: - basic elements of the construction tasks; equipment, products, workers;

- five major types of sensing technologies;
- twelve KPI's connected to workers in construction;
- seven main construction project management constraints;

Higher industry productivity implies workers monitoring and the identification of ways to improve their performance. Monitoring produces data with big potential for other processes, many of them within the BIM that presently rely on manual processes. From the top project management and governance point of view, this information constitutes relevant data towards smart contracts requirements and assumptions. The role of the worker as builder and as manager of information constitutes the main challenge.

Key words: Construction 4.0, Project management, Productivity, BIM, Smart contracts, Workers, Sensing technologies

1. Introduction

The Construction Industry is essential for the countries' economies and impacts in several dimensions. Multiple global megatrends are shaping the future of construction. These fit on market and customers' requirements, sustainability and resilience targets, political and regulatory aspects and society and workforce role (Forum, 2016). The use/adoption of technology/digitalization is assumed as an "enabler" towards these megatrends. It is found that through technology it will be possible to shape the pace of construction in a route to higher productivity levels (McKinsey, 2017). To measure productivity in construction it will always be necessary to measure fundamental aspects, as the construction products, the equipment's and the human resources. These three dimensions are the base for the materialization of a construction outcome or construction entity that can be further evaluated in terms of cost, time, quality, safety, and environment, among others.

The implementation of innovations in construction on the context of the Industry 4.0 implies Technology, Processes and People (CIB Publication: 373, 2013; Sousa and Magalhães, 2017). The identification of the best technology for each or a group of processes, the refurbishment of these processes towards technology and the identification of the roles, training needs and involvement of the persons/construction agents seems quite an easy equation, but lacks in terms of balance in most strategies of innovation and implementation.

All the above mentioned and the awareness that human resources play an essential role not only for the implementation of innovations but also as a field for the implementation of these innovations, constitute the starting point of the present research. Figure 1 frames on one side the main "traditional" requirements of the construction industry (aspects that constitute a scope for performance measurement) and on the other side the main technological drivers towards the Industry 4.0 vision.

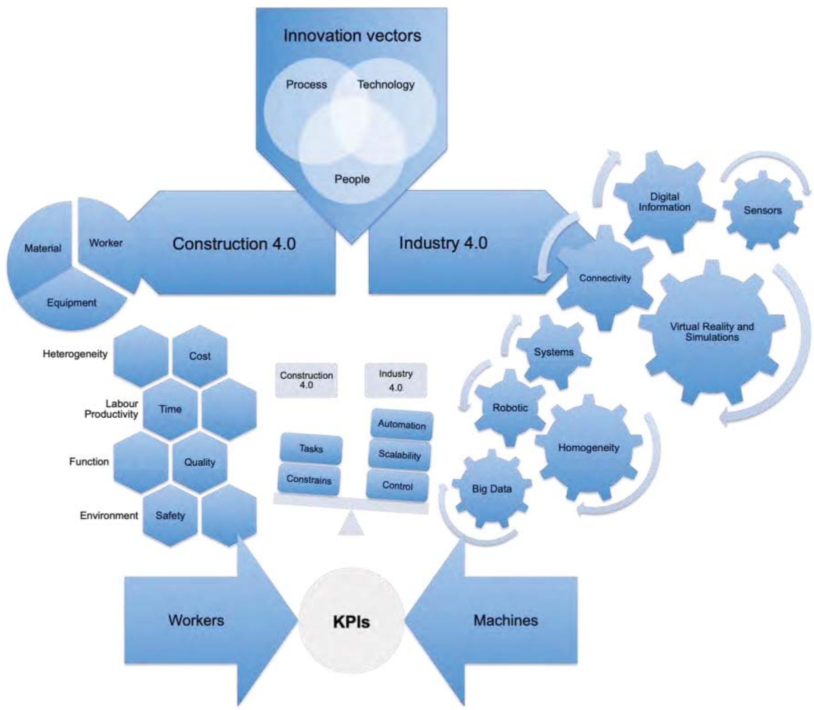

Figure 1: 4.0 approaches to collect KPIs

The effective assessment of productivity in construction is an imperative to improve performance over time, cost and quality. The current technological advances allow the implementation of new electronic performance monitoring processes on workers in the construction industry. Systematic control of constructive operations streamlines specific aspects of the activities under development, highlighting the information requirements for decision-making within an agile management environment (Yang *et al.*, 2015).

2. The assessment of the productive performance of workers

2.1 Initials considerations

Corporations seeking to increase their profits are naturally interested in autonomously monitoring services and workers (Alder, 2001). The ways for implementing operational control methods vary significantly within the framework of construction companies. Work activities involve multiple stakeholders and thousands of physical elements; managing these activities to achieve maximum operational efficiency is extremely complex (Yang *et al.*, 2015). Within a corporate and strategic vision, productivity management should include: the performance of measurement; qualitative and quantitative assessment; and the implementation of actions to control and improve processes (Sink, 1985). The evaluation of the productive performance in the industry is usually based on the methodology of measurement and rationalization of the outputs that are the results of the processes, through the inputs needed to develop the work (Sink, 1985). Performing data collection manually by direct observations is time-consuming and costly, labor-intensive and highly prone to failures. Furthermore, data post-evaluation models are most successfully applied in companies in which the manufacturing process is routinely repeated. In the case of the construction industry, where projects have higher non-repeatability characteristics, post-data evaluation techniques will have limited benefits. (Yang *et al.*, 2015)

Mckinsey (2017) report points out that the use of technology in service fronts has a potential to increase from 14% to 15% the productivity index of the global construction industry. The electronic measurement of performance has the potential to identify the most relevant areas for applying innovation in service fronts and thus, to maximize the effectiveness of the use of other technologies in the works. Electronic devices for data collection in engineering works must meet many criteria: cost-benefit; strength and durability; easy use and training; appropriate dimensions; scalability; reliability; low rates of data transmission and storage; data security (Cheng *et al.*, 2012).

2.2 Construction tasks

It is through the physical and mental effort of direct labour that construction activities are performed. This effort can be replaced or attenuated through the use of equipment, machines or power tools. However, within the current reality of construction, even in activities with a high degree of mechanization the presence of a human operator is still necessary. In fact, human resource performance is the main productive factor in the traditional construction industry.

In general, the construction tasks are based on manual work system or worker-machine system without processes based on automated work sub-system. The manual tasks commonly require the use of hand tools (e.g., hammers, saws, trowel) (Groover, 2007) to apply the products. In addition, some equipment (e.g., crane, backhoe, road roller) or portable power tools (e.g., drills, circular saw, routing tools) are operated by human workers as construction aid. The construction products are (framed by function or form or material or any combination of these) intended to be used as a construction resource (ISO 12006-2, 2015). At the construction yards, rarely is seen automated or semi-automated machine processes performed without human assistance. As a result, the worker must be in physical contact with the tools, machines, and products in a specific geolocation on-site to perform the tasks (Navon and Goldschmidt, 2003). Within the service fronts of civil engineering works, mainly in refurbishment interventions, direct labor can be identified as the center of production. The Portuguese legal diploma addressing price revision regime for construction works, determines 40% for the workforce costs within new building construction and 53% for refurbishment operations (Decree-law, 2004). This underlines the added-value that can represent for the sector economy the improvement of workers performance.

2.3 Sensing technologies

When applying electronic devices to monitor tools and machines, it is necessary to look for elements of small dimensions and lightness, once workers will handle them. The same principle is relevant for the monitoring of products and especially when monitoring the workers themselves. In addition, considering that these elements are in great number in construction environments, the low cost per monitored element positively potentiates the application of this type of technology. It worth's mentioning that most of the technologies demands energy for its operation. The autonomy appropriate to the use, size and weight of the supply (encapsulated on the device) and ergonomics are main aspects to be balanced. However, when it is sought to monitor vehicles and equipment there is no need to require miniature devices, and given the reduced number of devices, higher unit costs can be accepted. In all cases the technology must have a wireless concept, it is desired that the device can be contained in a single enclosure and that does not require external elements such as wires or antennas.

Productivity monitoring in construction projects is highly complex, as it involves the evaluation of all elements (products, tools, equipment, workers, etc.) over time, within a context of several interactive processes. With this, different approaches were observed that seek to determine and improve performance in segments of the wide production process. For example, monitoring materials and application elements to assess the times they remain in stock/storage, handling and finally when they are built, constitute extremely relevant information in view of a Lean Construction concept. Moreover, locating and efficiently positioning these elements in real time leads to directly positive results in on-site productivity and enables integrated management of the project schedule and quality, as well as the computerization of the BIM model to obtain 3D/4D.

Most of the studies focus on identifying the areas of occupation and trajectories carried out by workers during their working day. Indeed, based on their occupation are diagnosed the time elapsed within areas considered as production or idle. Also, with the advent of small devices capable of measuring acceleration/speed and wearable technologies, an analysis of the movements and gestures of the workers can be provided. Where within a concept of skeletonization one can even diagnose direct work actions (e.g., hammering, sawing, painting) allowing a detailed modeling of the production processes. Figure 2(a) shows the Electronic Performance Monitoring concept where the workers must use the electronic devices (that have embedded software) during the workday, and these devices must have communication to deliver the data for the interface software. Figure 2(b) highlights the sensing technologies in electronic devices for the electronic monitoring of performance in construction works.

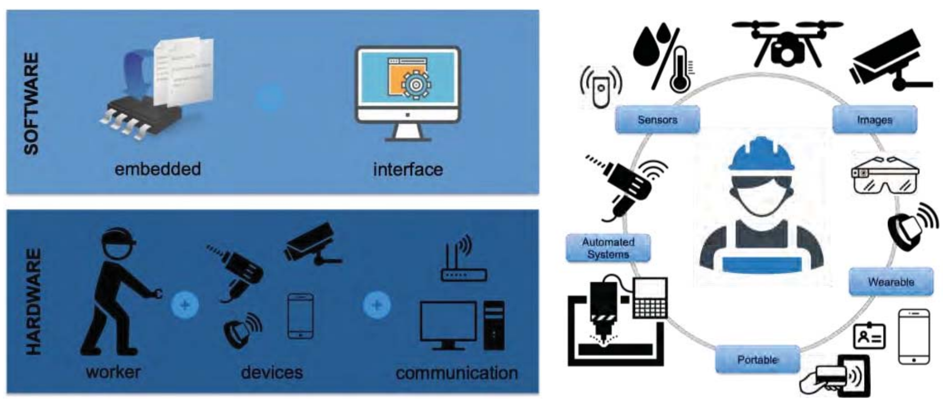

Figure 2:(a) Electronic Performance Monitoring conception, (b) Devices to collect data

Nonetheless, the current technological advances allow the automation of some manual data collection processes. As well, it allows the development of new ways of measuring the performance of workers. It can streamline current methods of checking and controlling access at locations through badges and readers and/or filming. Machinery and equipment used in construction tasks may inform their time of use and/or quantity of product applied. Also, external sensors can measure environmental conditions at service fronts, such as temperature and humidity. New analysis processes focus on the geographical mapping of the location and trajectory of the workers, in order to quantify the time spent in specific areas and in motion. Several studies look for the detailed analysis of the movements and gestures of the workers through the method of skeletonization.

2.4 Outcomes/key performance indicators

It is based on the analysis of historical data of the projects that are determined the Key Performance Indicators (KPI), and also, are classified the best benchmarking (Groover, 2007). In this context, project data on the tasks, inputs, time and human resources expended are analyzed. Depending on the process of each company, these records may be contained in physical documents, or already in digital format. The main process for obtaining this data in the field is through human appropriation. Still, it is through human observation that process modeling and time studies are performed. Directly related to the analysis of the performance of the workers and teams stand out the scientific models in the study of the time and in the measurement of the work done. (Adrian, 2004; Groover, 2007)

Following are presented 12 KPIs for standardization of performance metrics for construction workers based on data collected by electronic devices. To begin with the classic approach to measuring the productivity through the ratio of the input per output (Sink, 1985). Furthermore, the performance indicators classified as quantitative and qualitative (Cox, Issa and Ahrens, 2003). At the same time, the KPIs classified as objective measures and subjective measures (Chan and Chan, 2004). Also, some aspects of the work of Adrian (2004) and the safety accidents measure approach of ConocoPhillips corporation (Freibott, 2013) are connected to the presented KPIs .

Units per Man-Hours (input per output): The quantitative analysis of the Man-Hour spends in work to performer a unit task is the measure approach most applied in the construction industry. (Sink, 1985; Cox, Issa and Ahrens, 2003)

Value associated per Units (input per output): Another input per output quantitative method is related to the measure of the unit of complete work per the monetary value associated (e.g. Dollar and Euro). (Sink, 1985; Cox, Issa and Ahrens, 2003)

On-time completion and time variation: Based on the schedule of the construction project it identifies the finish estimated of the tasks. By measure, the completion of tasks and the achievement of milestones it is possible determines the schedule performance. It allows the on-time completion analysis and the overview of the time variation in the estimated project. (Cox, Issa and Ahrens, 2003; Chan and Chan, 2004)

Human resource management: The measurement of the HR spent in the construction projects is extremely important for assessment time and cost. It allows the determination of the Man-Hours expected against the Man-Hours real performed. (Sink, 1985; Cox, Issa and Ahrens, 2003)

Quality control and rework: The quality of a construction project is related to the scope specification and features. Quality failure account in 6% to 12% of the overall expenditure Man-Hours. The rework increase the Man-Hour needed and greatly increase the overall time and cost of the projects. (Cox, Issa and Ahrens, 2003; Chan and Chan, 2004)

Percent complete and speed of construction: The percent complete and speed of construction are the actual status of the project in determinate date. Consequently, is a partly of the on-time completion and time variation. It method is widely used in measuring the monthly performed, and allows a perception of the speed of the construction. (Cox, Issa and Ahrens, 2003; Chan and Chan, 2004)

Earned Man-Hours and values: The earned value and the earned Man-hours are connected to the completed work in place. It provides an indicator of job productivity based on the estimated Man-hours and values against that real performed. (Cox, Issa and Ahrens, 2003; Chan and Chan, 2004)

Lost time accounting and identification: The impact factors of unproductivity are response for lost of time in the construction tasks. It is extremely important identify each factor and measure their impact. Most important is assessment productivity to determine qualitatively and quantitatively what are the factors that cause the most impact, both in productive activities and in the events that generate workers' idleness, which will allow the development of effective actions to modify the behaviour of a productive process. (Cox, Issa and Ahrens, 2003; Adrian, 2004)

Punch list and Extra time: Usually, the punch list approach occurs at the end of any task, phase or project. The extra time required for the workforce is another specific situation that has to be analyzed. As a result, quantifying that amount of Man-Hours will allow the best understanding of resource spent during a construction project. (Cox, Issa and Ahrens, 2003)

Safety (accident and hazard rates): Nowadays safety should be a major concern in construction projects. The quantification of the work injures accidents started with the work A. W. Heinrich (1931), passing per Frank E. Bird Jr. (1969) to in 2003 a study by ConocoPhillips Marine. Based on the ConocoPhillips Model it is connected the number of unsafe actions on-site in the way to diagnosis the potential workers' recordable injuries, lost workdays and, death fatality. (Cox, Issa and Ahrens, 2003; Freibott, 2013)

Absenteeism: A worker out of service is a Man-Hour lost. The number of lost Man-Hours due to absenteeism over the duration of the construction project should be measured to provide historical data. (Cox, Issa and Ahrens, 2003)

Motivation: The understatement of the workers' motivation is very important to achieve productivity. At the same time, it is a complex and difficult assessment. A motivated worker will present the best attitude towards the tasks and the environment created on the job site. (Cox, Issa and Ahrens, 2003)

2.5 Main constraints in project management

Constraints are assumed as limiting factors that affect the execution/performance of a project or process. Project success (or part of it) should be measured based on pre-established terms of completing the project within the constraints of scope, time, cost, quality, resources and risk. It is the main role of the project manager to "manage" these constraints. (PMI, 2017)

Besides these overall well-known constraints (Cost, Time, Quality and Scope/Function), construction projects are directly affected by others as safety, environment and labour productivity. Nowadays, it is mandatory in construction yards to increase the occupational safety and health performances. The International Organization for Standardization through ISO 45001:2018 established the requirements that should be implemented in projects (ISO 450001, 2018). Aspects related to climate change and environmental protection agreements have placed the environmental theme in evidence. As result, it can be considered as another dimension of performance assessment in engineering projects (Gangolells *et al.*, 2009). Finally, the labour productivity as a fundamental engine of the construction projects drives the relationship among these other factors, in order that any poor performance in labour productivity is likely to affect the others and/or cause constraints.

3. The framework for standardization of the KPIs

Based on the above explanation about the data collected by electronic devices and workers' performance in the context of the standards of metrics and benchmarking, Figure 3 presents the framework for standardization of the electronic performance metrics.

All the concept of collecting Man-hours is based on workers' personal identification, position, geolocation, trajectory, movements (gesture). In addition, the integration of information from automated tools and equipment also allows the collection of unit quantity executed. Each worker must have one device attached or be filmed and identified. This will measure the hours on duty, the movements (gesture) and, the occupancy zones. At the same time, automated tools or equipment can provide the identification of the work process being executed. Further, the data obtained by sensors allows the measurement of external factors (e.g. temperature, and humidity). Based on the position, on the field of the item or element, it is possible to identify the work completion. Additionally, through image analysis is possible to interpret the work completion.

The electronic monitoring of construction workers can contribute for the assessment at the bottom of the ConocoPhillips Model. The At-risk behaviors and the Near Misses are the most difficult safety measurement approach as they depend of the human-observation notes usually conducted in a safety audit. Based on the location, trajectory, velocity and use of Personal protective equipment (PPE) At-risk behaviors might be measured. Also with the monitoring of the equipment and vehicles, it is possible to measure the Near Misses. For sure, the IT integration allows the information about the Recordable Injuries, Working Days Lost and Fatalities. The percentage of time inside the production zone could indicate more endeavors. The amount of time handling tools and equipment could indicate more effort. The interpretation of feelings by brain activity could indicate more motivation.

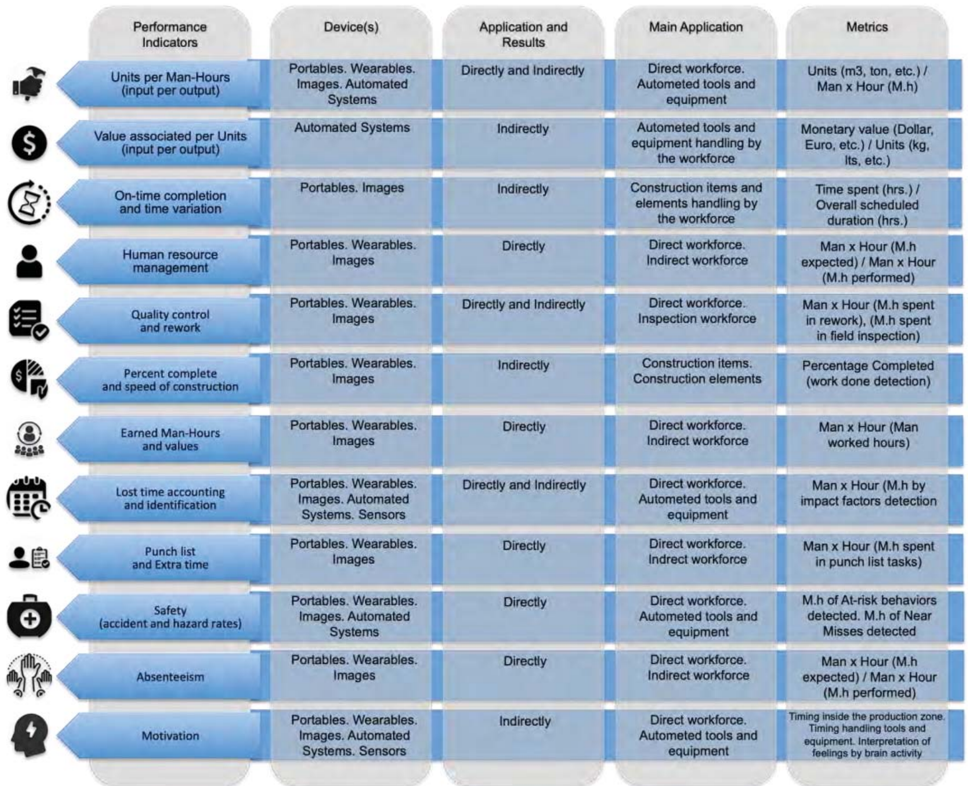

Figure 3: General Framework

4. Construction 4.0 based on Workers dimension

4.1 Integrated management KPIs model

The KPIs (worker-centered) detected by sensing technologies above presented are in an interactive way connected to the main constraints of project management. Project managers by controlling the construction projects based on these KPIs will be able, in early stages, to best-detected impacts in the project constraints, Figure 4. The type of building and its function drives the needed features and it delimits the project scope. As so, the tasks are connected with the function and have influence on the specifications, allowing the determination of the environmental impact of the construction. The environment negative impact is directly connected with the duration of the construction stage in terms of pollutants, as CO2 emissions, wastewater, dust and noise. Consequently, a more productive project is less aggressive to the environment. Labour productivity also drives the projects' time and cost. In this sense, all the KPIs that measure Man-Hours are connected with the above-cited constraints. In addition, quality defects and rework will drain project resources and increase its cost and time. Most important, a safe workplace mitigates accidents and consequent absenteeism, fostering workers' motivation.

4.2 BIM integration concept

Linking extra 'dimensions' of data to information models has the potential to provide a richer understanding of a construction project (Richard McPartland, 2017). BIM dimensions have been studied and developed in a way that the range of this methodology can fit the construction life-cycle (Wong and Zhou, 2015). The use of BIM during the construction stage as been most related with scheduling and supervision, dimensions closely related with the project constrains (Jang and Lee, 2018; Schwabe, Teizer and König, 2019).The aspects related with safety and risk also relate with project constrains and are being argued if they are part of the 4D or if constitute a new dimension (GhaffarianHoseini *et al.*, 2017). For the purpose of this work and in respect to BIM, the workers monitoring finds links with tasks/job, schedule and safety dimensions, a part of being considered or not the same. Following ongoing research related with product information to be set during construction (Mêda, Moreira and Sousa, 2019) and information strategies towards asset information management (Munir, Kiviniemi and Jones, 2019), COBie has been explored as the structure to support and manage all the non-graphical data. Due to this, the storage and management of relevant workers data to perform the KPI's, is being envisaged using COBie Job spreadsheet combined with activities. This will constitute an interesting framework towards the integration of workers monitoring on BIM (Borrmann *et al.*, 2018). Considering the open discussion related with the dimensions this can be found to be "WD" (workers dimension).

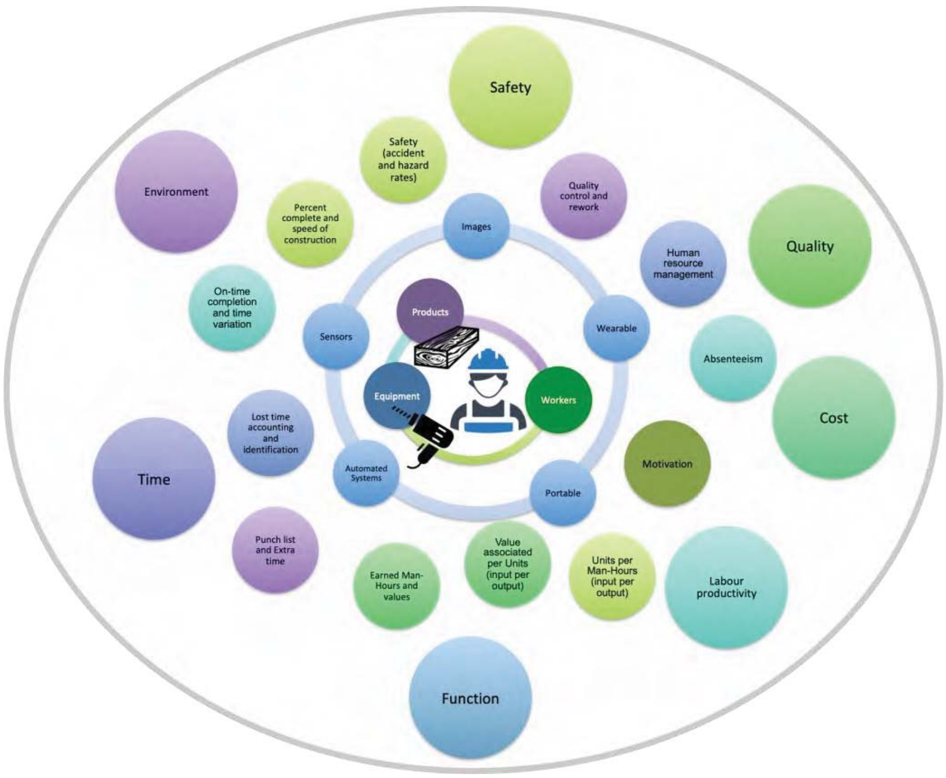

Figure 4: Integrated model

4.3 Smart contract integration concept

Finally, a construction smart contract centered on the workforce on duty is presented. The real-time workers-KPIs monitoring fosters an automatized and transparent contract administration. In addition, the whole process becomes more effective due to the automation of project updates (task order), service measurement and, payments (ICE, 2018). A collaborative project ecosystem is possible with the distributed information ledger between the distinguish stakeholders (e.g., client, contractor, subcontractor, vendors, suppliers, designers, consultants, certifiers, authorities, insurance, bank).

Figure 5 presents the concept that underlies the construction smart contract process. First, the data collected from the workforce on daily duties is processed by means of information technologies and techniques, being integrated into the BIM (WD-Workers Dimension). The Blockchain system, in a private network, makes the processing and validation of this information. Subsequently, the pre-defined contract rules are automatic played, the information is shared and specific routines are developed. Most importantly, the right information will be provided for the pre-establish stakeholder without the needed of accessing the BIM tools.

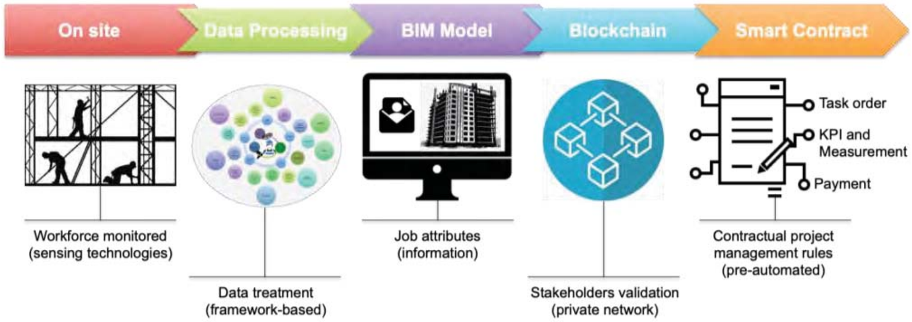

Figure 5: Smart Contract (WD - Workers Dimension)

Problems as unsolved claims and fast tracking during the execution of contracts affect the finance margin of contractors. At the same time SME cannot support late payments (ICE, 2018). Due the traceability of the most valuable information about the workforce, types of incentive fee contracts should be easier to structure. It is expected a lower risk of delays and over budgets. Furthermore, no more filtered information about poor safety conditions in the yards will be possible. Also, the BIM integration at the level of tagged build elements will allow a total quality assurance of the buildings.

As a result, all the construction production chain will earn more compliance and accuracy. Complex projects, principal de EPC (engineering, procurement and, construction) ones will take advances on the smart contracts application.

5. Conclusion

The construction industry is being pushed towards the adoption of innovations and new technologies. All aim to improve the performance of the outcomes and increase the productivity. The implementation of the presented megatrends will only succeed if there is a balanced approach between technology, processes and people. In what concerns the construction stage, the workers are main drivers towards innovation once they will handle and apply the new technologies on the construction processes. In addition, they constitute themselves a field for innovation through the use of devices that can measure performance in different dimensions. The Worker 4.0® (Calvetti, 2019) is the concept that aims to materialize the main principles and behavior of workers in a Construction 4.0 scenario.

The work developed led to the systematization of a framework to standardize electronic productivity metrics. Through this framework is becomes possible a streamlined selection and definition of Performance indicators based on the main applications, metrics and type of devices. This has direct implication with the characteristics of the works to be developed, the yard conditions, as well as the type of organization and willing of the workers. The integration of workforce-related data on BIM and the implementation of Smart contracts foster traceability, collaboration, and transparency, enhancing projects efficiency.

Empirical studies have been conducted in the CONSTRUCT/Gequaltec (Faculty of Engineering University of Porto) in order to develop and test methodologies of workforce electronic performance monitoring. The added-value of this work for the construction industry can be improved through the integration of other factors. These, in addition to the improved support for the selection of Performance indicators, may allow, among others, the integration with other technologies for processes not related with workers performance as well as guidelines and awareness for the training of workers.

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