Industry 4.0 and digital transformation in higher education through the perspective of smart cites

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Abstract

In this article we present the results of three research projects made by teachers that belong to the Metropolitan Network of Bogotá (RUMBO). The digital maturity model – HEI in Colombia centers its analysis in the adequate planning and implementation of organizations. In a second instance we find the gamified Virtual Environments in the industry, which explain the process of creating a learning environment based on augmented reality and virtual reality (technologies of the industry 4.0), and its design based on constructionism, gamification and serious games. Finally, we have the project "Elements for the design of the interaction and usability in the user experience for accessibility in education in the Smart City". The results showed the importance of educational transformation for the creation of inclusive didactic material, focused on the design of an architecture that facilitates content appropriation.

Keywords

Smart Cities, Industry 4.0, Usability, Digital Maturity

1. Introduction

Smart Cites tend to improve quality of life in people by using the potentialities of technology in the development of the dimensions that arise from the relationship between subjects and their surroundings. Education is a fundamental pillar in the construction of a society that can respond to this new challenge by making an emphasis in training citizens with digital skills and boosting creativity to improve work productivity, while building a dissemination strategy and a consolidation of the Smart Cities concept.

Higher Education Institutions (IES in Spanish) as change agents must tend to issues such as education democratization and renewal of methodologies that try to enhance digital skills based on elements and aspects of Industry 4.0, to be aligned with technological innovations. This revolution permeates documental management, organizational architecture and digital governance posing the challenge for education to be able to design training proposals based on

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an inclusive and accessible education that allow them to face and use the opportunities that the Fourth Industrial Revolution brings.

From the framework of Smart Cities, three research projects were developed, aimed towards the implementation of Industry 4.0 in education. The first one addressed digital transformation in higher education, an issue that has become the chosen path for companies of different economic sectors as it allows to mobilize efficient, productive and competitive processes, strengthened by a digital culture that dynamizes the acquisition and generation of new knowledge. In the second one, there is an explanation of the creation of the gamified environment of an industry in order to be used as a training tool, through user interaction with an immersive virtual and augmented reality system – technologies that contribute to the digital transformation of industrial processes. The third work presents a study on interaction and usability in user experience within virtual higher education to analyze the implementation of accessibility guidelines in two universities and contribute to training in resource and application design, betting on improving user experience.

2. Digital maturity model – HEI in Colombia

2.1. Digital Maturity

Maturity Models are essentially four components or maturity stages, which represent the performance level of an organization [1]. The dimensions categorize the study area [2], described through indicators, properties, activities or measures. Based on this principle we can distinguish a stepped model in which the next level can be achieved when all elements in the previous level have been accomplished [1]: however, the dimensions are not tied to a specific level. Their evaluation serves to establish the initial state of the organizations in their use of TI and their maturity level in Digital Transformation.

Based on the initial diagnosis, the development of maturity models must go through five typical phases: first, problem definition and establishment of objectives; second, it is necessary to create the research area and defined target groups. In the third phase, a bibliographic analysis should be made and compare the existing maturity models, based on which a development strategy will be determined – the options are to make a completely new development or a reconfiguration of the existing models. In the fourth phase, the dimensions and levels are specified, from bottom to top, iteratively. Finally, the model evaluation phase should examine if the model helps to solve the initial problem or not [3].

As a closing remark, maturity indexes are the result of the operationalization of the maturity model implemented in the organization and evaluate its dimensions in a few key numbers in order to determine the behavior of the strategies for descriptive, explanatory or prescriptive purposes [4].

With the purpose of creating a maturity model for HEI in Colombia, the models of the Junta de Andalucia were used [5], as well as the maturity model for universities [6] and finally the arising model that was being generated by the Ministry of Information and Communication Technologies of Colombia MINTIC [7] as an important input in the creation, development and implementation of the proposal that is present in this document.

2.2. Definition of the digital maturity model

The maturity model is presented according to the flow diagram (Figure 1), detailing each step that composes it as well as the processes and procedures of each step which allows us to analyze in detail their importance and their relation to achieve transformation based on the maturity diagnosis until the creation of strategies to achieve goals.

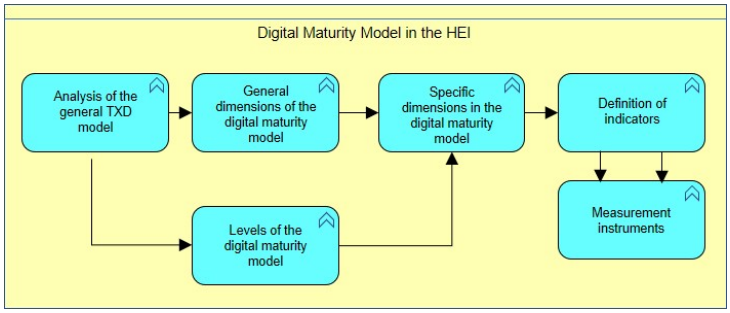

Figure 1: Digital Maturity Model in HEI in Colombia. Source: Own Source.

Likewise, the model contributes to the optimal state of the organization in the appropriation of technology as the guiding axis of change management that, based on a rigorous study of general dimensions, will characterize those stages that will generate measurable criteria, which in turn will indicate the percentage of maturity in the company.

2.3. Dimensions of the digital maturity model of HEI in Colombia

For the definition of the dimensions of the Digital Maturity Model in Higher Education Institutions – HEI, it was necessary to evaluate the dimensions present in the selected models, adapting and adjusting them to the characteristics and mission of the HEI that wanted to implement the transformation, as well as to those aspects that contribute in the compliance of Strategic Institutional Plans. As a result, we propose a digital maturity model composed of six dimensions, as shown in Figure 2.

Figure 2: Dimensions of the Maturity Model of the HEI. Source: Own Source.

The dimensions mentioned in the previous figure are aligned with general attributes – Culture, Processes and Technology. The reach of each one is fundamental in the measurement of the maturity level in the organization and therefore, the parameters in which they are based on must be established in order to achieve the strategic goals in the Digital Transformation of the organization.

In Figure 3, the aspects of the previously established dimensions are broken down, which constitute the action and evaluation line of the digital transformation in HEI, all of which are vital for the consolidation of institutional goals.

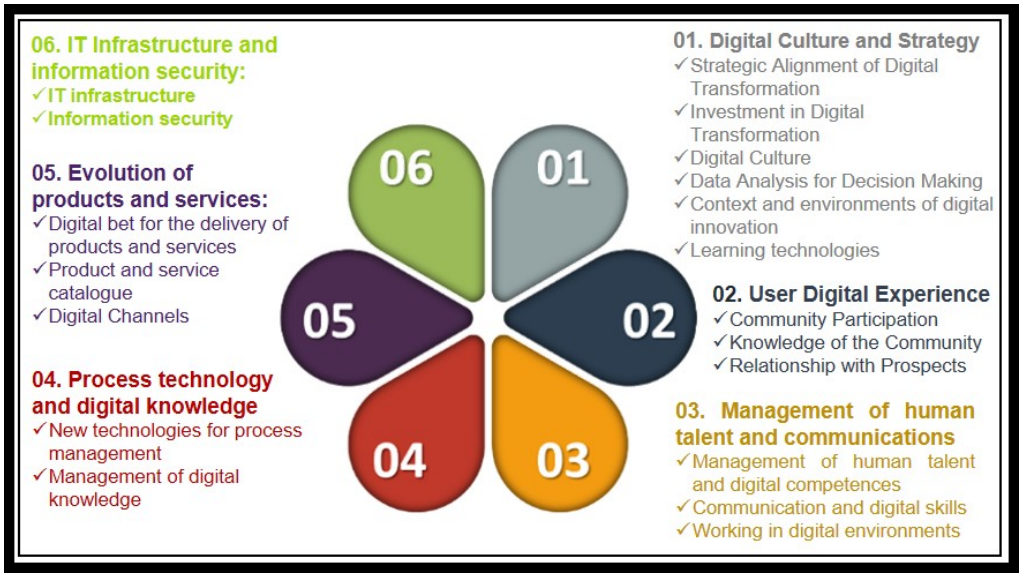

Figure 3: Key aspects of the dimensions of the maturity model in HEI. Source: Own Source.

The intention of classifying the dimensions in aspects consists in covering the elements that involve Digital Transformation and that have been mentioned throughout the document, such as: strategy, planning, organization, administrative and financial operation, digital culture, management of IT providers, leadership, innovation, IT ecosystem, communication, generation of technological capacities and competences, among others.

2.4. Levels of the digital maturity model in HIE – case study

The maturity levels help organizations to measure and scale the operational and technological management system, to reach an optimal performance level. As part of the advantages of level definition, we find: orientation towards fulfillment of strategic goals, early mistake detection, boost of continuous improvement, optimization of performance of all areas involved, focusing on change management, among others. In Figure 4 there are five (5) levels for the categorization of the digital maturity state or grade of the HEI at a determined time: 1. Basic, 2. Initial, 3. Managed, 4. Strategic and 5. Innovative where, transversally, there is an enunciation of digital

culture, strategy and governance, investment, innovation and technology components, with the reach of each one of them.

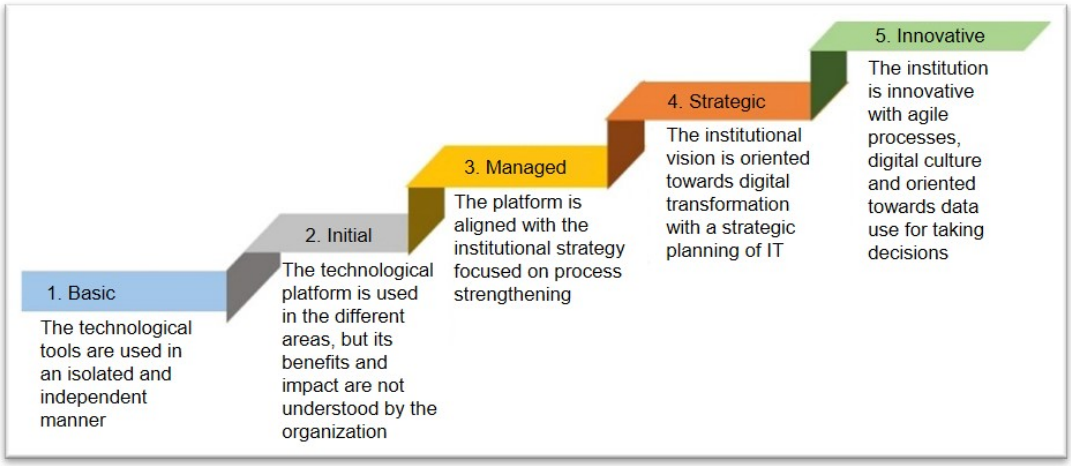

Figure 4: Levels of Digital Maturity. Source: Own Source.

The digital maturity model is the tool that defines and projects digital transformation in the organization. Its certainty requires the alignment between strategic goals and technological tendencies in order to sustain and prepare the organization for an ever more competitive scenario.

In order to make the digital maturity model a functional one, it is necessary to establish: the responsibilities for each area of the organic structure, the strategies for IT implementation and appropriation in each identified dimension and aspect and, essentially, the application of indicators for measurement, creation of improvement plans and their execution.

3. Virtual gamified environments in the industry

From the Computer Technology and Industrial Engineering programs of the Engineering Faculty in the main headquarters of the Minuto de Dios University Corporation – UNIMINUTO, in 2020 the project known as "Training System for Industrial Safety Based on Augmented Reality and Virtual Reality" started. It has the purpose of implementing learning strategies based on some technologies of the 4.0 industry. The prototype design was crafted using modeling and photogrammetry techniques for the creation of 3D objects, avatars and scenarios, and the activities were designed based on the constructionism learning methodology developed by Seymour Papert.

3.1. Constructionism – Gamification – Serious Games

The project was created along with the metal working company TCR Tornometal, dedicated to the creation of automotive and industrial spare parts and contemplates the need to train

employees in industrial safety issues. Based on the occupational accident rates, it was decided to design a simulated virtual environment of the company and of objects present in the surroundings to train the workers in topics related with the manipulation of machinery and risks at work.

The creation of the training system, based on Seymour Papert's constructionism establishes the learning how to learn theory through the use of technological tools that allow the student to be involved in activities that imply object construction or manipulation in order to achieve significant learning [8]. On the other hand, the design of activities is centered on problem solving, challenges and strategies -characteristics of gamification-: according to Borrás [9], these types of learning techniques promote motivation, feedback, generate adequate competences, autonomous learning, competitiveness and user connectivity in virtual spaces.

The design of the training system was established as a videogame, focused on strengthening the teaching-learning process of the participants by integrating avatars, interactive scenarios, animations and 3D objects, all particularities of formative games or serious games. For Chipia [10], the main objective of serious games is the training of the individual through the exploration of microworlds, simulators or video games: in these types of strategies, the participant assumes a role in the virtual or real space, in order to learn.

3.2. Application of metaverses and avatars in educational training

The design of virtual learning objects has evolved from the educational possibilities that Internet offers. The virtual or metaverse worlds that according to Checa [11] are a group of digital locative installations and allow for user interaction – with the object of simulating different real-life situations- have been implemented in the learning-teaching process through contents in different digital formats without barriers of space/time nor language restrictions such as the Second Life application, that incorporates real-life translation systems.

In the developed virtual environment, the operator assumes the main role and the trainer a content facilitator. The exploration of the virtual environment is done through the incorporation of an avatar that represents the worker: for Sánchez [12] the avatar is the unfolding of the subject through visual architectures and ways of being through the image. The user, through his representation, feels part of the virtual world and accesses knowledge in spaces designed for his interaction with the designed objects.

3.3. The use of 3D surroundings in education

The technological advances make it possible to develop immersive 3D surroundings, oriented towards gamification. In the creation of these environments, sensors are used, which allow knowing the location and movements developed by the user represented by the avatar who, in real time, simulates actions that favor learning through his experience in the virtual world. In addition, the design of a gamified environment requires an adequate planning, which is in tune with learning objectives, while maintain the interest and motivation of the participant.

In the training system for industrial safety, immersive virtual reality is used, which is a relevant technology for the issue at hand. In the industrial sector, there are safe procedures which workers have to know about and practice through a first-person experience, an experience

that is possible through the interaction in digital spaces created and incorporating 3D models that simulate the premises of metalworking industry. With this, [13] assure that educational platforms based on immersive experiences boost individual knowledge construction. In this sense, the immersive experience makes it possible for workers to achieve significative learning and at the same time eliminating the risk of accidents.

3.4. Development of a 3D learning environment based on a videogame for industrial safety training

For the development of the industrial safety training system, the TCR Tornometal was modeled in 3D: the machines, the objects present in the physical space and an avatar that incorporates a system of movements and interactions with the elements of the environment. These designs are based on photogrammetry: according to Caro [14], photogrammetry enables the obtention of volumes and measurements of 3D objects based on photographs. The system has two entertainment activities related to industrial safety, based on the concepts of gamification and serious games. We now explain the purpose of each exercise.

3.5. Activity: Personal protection objects

The challenge of this first activity is to collect three personal protection elements (helmet, vest and boots), which can be found in random spots in the first level of the videogame: in order to find them, the worker walks around the environment looking for clues that will guide him along the way. Based on gamification theory, each object has feedback associated to work safety, and this information becomes active once the object is found. In Figure 5, we can see the boots located on a shelf, ready to be picked up by the avatar.

Figure 5: Personal Protection Objects in the workplace. Source: Own source.

3.6. Activity: machine manipulation

In the second activity, workers access the area where machines and tools are located, as long as the avatar has the safety elements with him. In this second stage, the worker can only activate the machine mechanism if he has completed previous training mentioned in the information posters associated to each object. Figure 6 shows the avatar with the safety elements at Level 2 of the videogame.

Figure 6: Level 2 of the videogame – machine manipulation. Source: Own source.

The training system proposes education alternatives to explain study issues that can be boring or hard to understand, based on topics of the 4.0 industry. The established activities try to strengthen training processes of the workers in the TCR Tornometal company, which seek to reduce the risks of work-related accidents, based on constructionism, gamification and serious games.

4. Elements for the design for interaction and usability in user experience for education accessibility in Smart Cities

In the search for implementation of studies that allow more inclusiveness of educational spaces to contribute to digital education and the experience of Smart Cities, the research project PG 14-2017-2020 was developed, called "Analysis of guideline implementation on accessibility of virtual learning in UNAD – Colombia and UNSL – Argentina" and the work with the group Smart Cities of the RUMBO network was also used in the construction of the master's program in User Experience Design of the UNAD in Colombia and the Lleida University in Spain. The main objective of the project was to analyze the implementation of guidelines regarding accessibility

in virtual education in the National Open and at Distance University (UNAD) in Colombia and in the San Luis National University in Argentina, due to their relation with the RUMBO network. The focus that was used in the research was holistic and a mixed model as it used quantitative and qualitative techniques for information collection and analysis. The research design was done in stages, starting with the exploration stage by identifying the needs regarding accessibility of the different groups of people in the cities where the UNAD and UNSL are located. In the descriptive stage there was a structuring process of theoretical foundations of accessibility, usability and human-computer interactions, and then accessibility guidelines were established, from which some elements are taken in the present article. Then the implementation of the guidelines was carried out by training teachers, course development, resources and necessary adjustments for implementing accessibility in the human-computer interaction on the website of each institution. Later, an evaluation was made using the survey technique and interviews were applied to the participants of the implementation such as students, teachers, course designers and web designers. After the completion of the project, some of its results served for integrating UNAD systems and as input in course construction for the Master's program in User Experience Design, for example: accessibility of digital information and design of accessible interfaces.

Smart Cities have the challenge of implementing services for all groups of people that are its citizens according to their characteristics with accessible websites and for this, both technological design and training are required, with a strategy of inclusive higher education which means education for all so that it can benefit those who need it: those with disabilities and those who are marginal for whatever cultural, social, economic, physical and other reason.

As Higher Education Institutions, there is the challenge to make virtual education accessible, because it is a true alternative for students belonging to groups with real and diverse needs: however, this implies assuming transformations that allow the creation of a web that is truly accessible and that the courses have accessible designs and resources for all. This also means with designs that have been oriented from universal design, where there is an implementation of interaction and communication means from an intercultural perspective for empowerment and overcoming social gaps.

Population and Sample: As part of the project, the sample group was determined to be the teachers, course designers and students of the UNAD and UNSL universities, taking into account that Chavez [15] says that a sample is a representative proportion of the population that allows making a generalization on its results. The people were classified as units within a subgroup whose main purpose was to build observations and answers where the information was taken out from: these information units were composed by an incidental or causal sample as defined by Tamayo and Tamayo [16] as the process in which the researchers selected directly the subjects of the population that complied with the characteristic of having participated in the implementation of accessibility guidelines from their role as virtual course designers, teacher and student of the courses both on the web platform and with the resources where said guidelines were applied.

4.1. Design in the human-computer interaction as part of the User Experience

One of the core findings is the need to design resources, devices and applications in the transdisciplinary framework of the human-computer interaction (HCI) where there are several sources as mentioned by Soegaard and Dam [17], which are: artificial intelligence, facial recognition technologies, psychology, haptic technologies and the user experience (UX) that becomes a "simply how people feel when they use a product or service, and in some cases could be a technology service or product".

In this sense, the user experience is a design process of products that induce significative experiences: it is not reduced to interaction, as the idea is to implement design guidelines that enable the creation of products which are useful, efficient, pleasurable and that can satisfy needs in the specific context where the person uses the product. Thus, the design of the interaction implies the creation of multimodal interfaces and systems as mentioned by Chhabria, Dharaskar and Thankare [18] where other issues must be taken into account such as human behavior, emotion recognition and human gestures with information systems, with the necessary sensors that incorporate receptive capacities, which in turn implies both physical and computational complexity on quality metrics, based on mode fusion techniques.

4.2. Accessibility in education to setup a Smart City

This is how, when facing the challenge of proposing scenarios for the development of the citizens, the organizations that propose this participation must have as part of their website guidelines human-computer interaction based on user experience with accessibility. This accessibility is, in the words of Ferrer [19], the possibility of subjects to have at their disposal goods and services of the knowledge society, overcoming barriers that may arise. In the same sense, Acevedo [20] states that accessibility is the overcoming of obstacles and barriers of technology appropriation and use in all virtual and physical surroundings.

4.3. Usability in the user experience in education for Smart Cities

Usability is configured in the effectiveness achieved in a site or device in terms of how is it comprehensive and efficient for the user, so that errors are reduced making it possible to respond to user needs for a specific objective, with efficiency and satisfaction in a context of particular use. In this sense, the ISO standard [21], presents six sub-characteristics in which the maturity degree of the usability model of each product can be assessed. These subcategories are: learning capacity (learnability), operability (operability), protection against user errors (user error protection), appropriateness recognizability, user interface aesthetics and accessibility.

Therefore, some necessary elements are the application of web accessibility on the virtual platform with the development of operability, which must contain interaction and navigation elements that can be handled by people with different characteristics and disability conditions, which means that the contents have to be legible and understandable, according to Hilera [22]. It is also required to implement web accessibility on the virtual platform with an understandability development, which implies "ensuring that the information and the relations implicit in the visual or auditory format are maintained when the presentation format changes. For example,

the format of the presentation changes when a screen reader reads the content or when the style sheet provided by the author is replaced", according to Benavidez [23].

5. Conclusions

Digital transformation in all organizations is a process that depends on an adequate planning and implementation of a digital maturity model, and its effectiveness lies in the generation and strengthening of a governance model that involves all levels of the organization (strategic, tactical and operational), and that is formalized through rules, policies, guidelines and strategic plans.

Regarding the training system, it was possible to create the virtual 3D environment of the TCR Tornometal with a high realism level, which contains the elements that compose the factory and the objects for work safety. The immersive surroundings allow the user to interact with the machines present in the virtual space, thanks to the incorporation of physics that recreate the reactions of artifacts when being handled by the worker.

In the framework of Smart Cities, educational transformation implies the generation and publication of didactic material, guaranteeing the accessibility to all citizens, eliminating barriers of space and time. Said material must have technological aids and elements, in order to facilitate content appropriation. Therefore, there is the need for an architecture that responds to the design of user experience, where there is coherent information, in a website that complies with usability sub-categories.

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