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Industrial processes optimization in digital marketplace context: A case study in ornamental stone sector

Agostinho da Silva [a,b,c,d,*], Maria Manuel Gil [e]

[a] CEFAGE, Universidade de Évora, Portugal
[b] MARE - Marine and Environmental Sciences Centre, Polytechnic of Leiria, Portugal
[c] ISG, Instituto Superior de Gestão. Lisboa, Portugal
[d] CIIC, Computer Science, Communication Research Centre, Polytechnic of Leiria, Portugal
[e] MARE - Marine and Environmental Sciences Centre, School of Tourism and Maritime Technology, Polytechnic of Leiria, Portugal

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ABSTRACT

We are witnessing a transition to a digital economy, popularized by academics and practitioners as the Fourth Industrial Era, also designated as Industry 4.0 (I4.0). Among all the available digital technologies and aiming to optimize the Architecture Engineering and Construction (AEC) supply chain, the Building Information Modelling (BIM) is becoming officially mandatory worldwide. Oriented to a zero-waste, zero-ecological footprint and reduced time to execute the constructions, from the BIM, emerges a new procurement model which will affect many sectors integrating this supply chain, especially those more traditional and fragmented ones, such as the Ornamental Stone sector (OS). Addressing this problem through the Service Science perspective, the objective of this research was to conceptualize an Empirical Framework (EF), to evaluate the impact of the Industry4.0 operations on the Time-to-Deliver the products in a digital marketplace context. By applying this EF to a case study related to the Ornamental Stone in Portugal, it was found a positive impact of Industry 4.0 operations on the delivery time in the digital marketplace context.

1. Introduction

Boosted by the integration of Information and Communication Technologies (ICT), we are witnessing a transition to a digital economy, popularized by academics and practitioners as the Industry 4.0 (I4.0).

Among the several I4.0 technologies, with yet unpredictable impacts on the supply chain, the Building Information Modelling (BIM) is becoming mandatory by several governments [2] in the Architecture Engineering and Construction (AEC) which will probably require the shifting in the company's operations in some sectors [3].

In a simple way, we may define BIM as a collaborative technology that combines the virtual simulation with the horizontal and vertical integration in a consistent and interconnected digital Information and Communication system [4], and therefore it may be accepted as one of the I4.0 technologies [5]. Moreover, with the BIM Technology, the AEC market becomes a digital marketplace [6].

Oriented to a zero-waste, zero-ecological footprint and reduced time to execute the constructions, from the BIM, emerges a new procurement model, which will affect all the sectors on AEC supply chain, especially those more traditional and fragmented ones, such as the Ornamental Stone sector (OS) [7].

Traditionally the AEC procurement is made after the building design phase. In the BIM context, the procurement occurs during the building design phase [8]. In a Standard digital format [9] and publicly tendered on the Internet [10], the construction products and materials are pre-designed (standardized) and made available to BIM workstation operators by their providers in the digital web-libraries [11]. In practical terms, the BIM Procurement" anticipates the procurement to the building design phase [12].

Directly employing more than 16.000 people, the Portuguese Ornamental Stone (OS) sector is relevant to the national economy, also because it is one of the main private employer in the interior territories as well as the second sector in the country on value-added per working hour [6]. Although this is a typical traditional and fragmented sector, since 2004 we have witnessed in this activity in Portugal, a trend to employ skills as well as the incorporation of modern and innovative production technologies, which has guaranteed since then, a consolidated growth in exports and value-added [13].

* Corresponding author. CEFAGE, Universidade de Évora, Portugal.
E-mail addresses: a.silva@zipor.com (A. da Silva), maria.m.gil@ipleiria.pt (M.M. Gil).

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The stone is a natural raw material and therefore it has natural defects and heterogenic characteristics. Thus, to finish each piece of stone, it must be processed in a singular way, which slows down the manufacturing process.

In the beginning of the first decade of the XXI century, a prospective study [14] has identified the lack of flexibility and waste reduction as a priority, from which has started a lean and flexible R&D movement inside the Portuguese OS sector, popularized as Leanstone Hornbook (LH) [15], integrating Universities, technology companies and OS companies.

The first wave of digital OS technologies development began in 2006 through the Jetstone Mobilizer Project. From the Jetstone has resulted from several flexible and digital shop-floor floor innovative technologies, which from that time up to now are been incorporated gradually by some OS companies [16].

The second wave of digital technology started in 2010 with Inovstone Mobilizer Project, which had as outputs digital technologies to integrate the shop-floor resources in the operations of the companies.

The third wave of digital technological developments began in 2017 through the Inovstone4.0 Mobilizer Project. From this Project, has resulted in industrial solutions oriented to the co-creation of value in the digital marketplace and with BIM technologies [15].

All these technologies are today the state of the art and from 2006 are been incorporated gradually by some of the OS companies [5]. Collaboratively integrating these technologies and connecting the factory to the BIM stations, these companies are moving towards the I4.0 Operations [17]. Moreover, the BIM stations used by the building designers, mostly architects and engineers, connected in a co-creative way to these type of stone providers.

Nevertheless, not all the Portuguese OS companies have adopted the Leanstone technologies and therefore still keep their operations in a traditional mode which means no digital production machines in the shop-floor and communications with the market by phone and email only.

One of the official reasons for the mandatory use of BIM in the AEC [2] is its contribution to reduce the time to build, which is assessed through the fourth dimension of the IFC (Industrial Foundation Class) objects [18] as well as the rework reduction [19]. This official reason to make BIM mandatory pushes the procurement towards fast delivery time products [20] becoming a threat to the economic sustainability of the Portuguese OS sector whose competitiveness is based on products customization which slows down the processing time.

As part of the European Program supporting research, development, dissemination, and financing of practices and digital technologies assisted by Cyber-Physical Systems (CPS), and built on the European Parliament document [21,22], the European Union considers that I4.0 operations may reverse the industrial decline seen in Europe in recent years. Being aware of what is happening around them, companies managers and managers are realizing that I4.0 may bring new opportunities regarding the sustainability of their companies [23]. To connect a factory to the Internet and support production through CPS's involves risks, from the investment required to the very maturity of the available digital production technologies [24]. However, representing more than 20% of jobs, equivalent to more than 34 million people and generating over 6400 billion euros annually [25], the European industry cannot risk losing the lead and becoming outdated in this transition stage to the Fourth Industrial Age.

In BIM AEC context, the customers are mostly architects among other BIM operators, who search for building components through digital libraries, on which providers place their products in IFC format [26]. This Marketplace model is oriented to standardized products, which means, that leaves out companies that offer customized products such as the Portuguese OS, thus becoming a threat to their future [15].

Looking at the BIM, it is a digital technology for designing, procuring and managing AEC projects and through its global utilization, the Governments intend to transform the AEC into the transparent and digital marketplace [27]. Booted by EU Initiatives, we are witnessing a trend towards the digital production supported by CPS's, intending to transform the traditional operations to I4.0 operations towards personalized and collaborative manufacturing.

In this context, the following research question arises: What is the impact of I4.0 technologies, on the time-to-deliver the products on the traditional and fragmented sectors in the digital marketplace context?

The Service Science (S|S) is an emerging and multidisciplinary approach for which the value results from the interactions among service systems entities, which compute value given the concerns of multiple stakeholders [28]. Those interactions occur, according to the Service Science perspective, because there are legitimate expectations in each of the stakeholders involved, where part of the co-created value is attributed to it [29]. Addressing this problem through the Service Science perspective, the objective of this research is, therefore, to conceptualize an empirical framework (EF), to evaluate the impact of the I4.0 technologies on the delivery time of the products on traditional and fragmented sectors in a digital marketplace context. The empirical context of this framework will be a case study related to the Portuguese OS sector.

2. Literature review

According to some authors, a scientific discipline is a set of methods and standards, accepted and used by a community, to develop a Body of Knowledge that explains and typifies observable phenomena in the world [30].

Thus, it was necessary to attribute to S|S the conceptual structures, theories, models and laws that could not only be empirically tested but also applied to the benefit of society. Probably with this in mind, the foremost advocates of S|S, considered that S|S must be viewed as a scientific field under construction, for which the Body of Knowledge would emerge slowly but with a challenge to become truly interdisciplinary [31].

This led to the construction of S|S Theory, which could support it as a scientific field, taking into account its interdisciplinarity and considering the Sustainability of the Planet as a transversal concern, in exchanging service and assuming the Service-Dominant Logic (SDL) as its philosophical anchor [32].

The First Service Science Principle has been defined as service system entities dynamically configure four types of resources: people, technologies, organizations, and information (Stephen Vargo & Akaka, 2009), since the purpose of economic relations for the SDL mindset is the exchange of service among entities aiming for a reciprocal benefit [33], that is, for SDL exchange service for service [34].

The Second Service Science Principle has been defined as service system entities compute value given the concerns of multiple stakeholders [28] since the relationships between s|systems are based on value propositions, which from the S|S perspective can be understood as a s|system's request for another s|system to execute an action. Thus, a value proposition seems to be the basic relationship among s|systems, in the form of service exchange or service interactions [28].

The Third Service Science Principle has been defined as the access rights associated with a customer, and provider resources are reconfigured by mutually agreed to value propositions [28] since, in the traditional view (G-D Logic) [35], the producer is the main actor who produces goods and services, and consumers are secondary actors or passive recipients [34]. According to G-D logic, the producer is the source of knowledge and creativity, and therefore also the only source of product innovation [36].

As an emergent discipline whose Body of Knowledge was raised already in the Digital Age, the S|S Theory provides good support to address the digital environments, such as the I4.0 operations [37]. Within the building industry, there has been increasing interest to the building service systems integration, in order to enhance design outcomes, and to detect or even avoid the service systems' clashes and conflicts [38].

3. Research methodology and empirical framework

According to S|S Theory, the impact of innovation on processes must be assessed through the *Innovation Outcomes* (IO) (Stephen Vargo & Akaka, 2009), which results from the evolution of the main stakeholders' concerns. This means we may introduce the concept of Key Concern Indicator (KCI) (Equation 1) as the inverse of Key Performance to evaluate the Concerns evolution of the main stakeholders.

$$KCI = \frac{1}{KPI} \tag{1a}$$

According to some authors [39], an "empirical framework" can be defined as a set of interrelated objectives and fundamentals, where the objectives identify the goals, and the fundamentals are the underlying concepts that help achieve those goals [40]. In social sciences, a research methodology can be qualitative, quantitative, mixed sequential exploratory, explanatory or convergent parallel [41].

From this range of methodological options, in this research, the mixed sequential exploratory method was chosen. Therefore, the research starts with a qualitative data collection and analysis, after which, the results obtained will be confirmed using a quantitative data analysis [42]. This strategy intends to develop better measurements with population-specific samples and confirm if data from some individuals (in the qualitative phase) can be generalized to the quantitative phase [40].

According to some authors, the main benefit of the mixed methodology is the possibility to collect qualitative and quantitative data [42] using constructs, variables and concepts to obtain complementary information leading to greater certainty of results [40]. Thus, following these principles, in this research, the qualitative data will be observed from sources such as interviews, visual observations, documents and records, among others. Similarly, quantitative data will be collected from measuring instruments, observable checklists, numerical records, among others [40].

3.1. The empirical context

The procedure for selecting production orders for follow-up and data collection will be for convenience, as well as the selection of companies.

According to the objectives described above, supported by the Service Science and guided by the pragmatic paradigm, the empirical EF once conceptualized has to be confirmed in practical cases [42], as well as the methodology which will identify the metrics, indicators and outcomes, taking into account the objectives of this research.

In this sense, two groups of Portuguese OS companies were arranged, selected objectively and conveniently. It is intended that each group meets specific criteria, cumulative and, previously specified, based on the comparison of the Innovation Outcomes: (i) G#T - is a group of ten Portuguese OS companies still keep their operations in a traditional mode which means no digital production machines in the shop-floor and communicate with the market by phone and email only, and (ii) G#4.0 - is another group of ten companies that since 2004 have been integrating into their operations the technologies developed from the Mobilizer Projects as described before and therefore, operate collaboratively with BIM operators and the related digital marketplace. For these companies, the production batch procedure, order selection for follow-up and data collection was of convenience.

Focused on the research question and through the Empirical Framework, this research compares the performance of these two groups of Ornamental Stone companies by assessing the IO related to the Time-to-Deliver their products.

Empirical data was collected mainly from observations on the factory floor, written records and through interviews with the support of a script of open questions. With this technique, which always implied a face-to-face situation with the interviewee, a climate of relational approximation was created which favoured the free expression of knowledge, attitudes and intentions by the interviewee, always recommended in Social Sciences [43]. Thus, common perception and knowledge were the basis for the elaboration of a more formalized and general "version of reality" by social scientists [44].

All these selected companies were interviewed, following Morse's (1998) suggestions, namely meeting several criteria of a "good informer" [45]. For this author, these can generically serve as significant basic selection criteria [46].

The names of these companies, at the request of those responsible for them, will not be disclosed in this work. However, by agreement with their managers, there will be no limitations on the entry of academics for observations, if it is for the same purposes of this research.

The EF conceptualized under the support of the Service Science has followed the rules and philosophical principles of this emergent scientific discipline [47], which means that the same rules were followed regardless of whether the companies belong to G#T and therefore with a traditional business mindset or digital-oriented mindset and integrated the G#4.0.

3.2. Qualitative data collection

The qualitative data represents non-quantifiable concerns such as feelings, opinions or responses to an unstructured questionnaire repeated at each one of the 36 steps of the service process Tables, 1,2,3, and 4).

To collect qualitative data related to the four main stakeholders (customer, supplier, competition and authority), has been used: (i) qualitative observations – such as shop floor notes related to the execution of orders, and openly observing the views of respondents; (ii) qualitative interviews – such as questions asked directly to the stakeholders' human resources or by telephone, to obtain the views of respondents; (iii) qualitative documents – such as digital or paper documents, public or private, such as minutes of meetings, reports, letters and e-mails, and finally (iv) audio and visual qualitative material – such as qualitative audio and visual materials, photographs, physical products, websites, e-mails, text messages, among others.

Thus, throughout the process of value co-creating, whenever it was found that the qualitative result obtained in a given Step (i), regarding a Concern (j) from a Stakeholder (k), favours the acceptance of the offer discussed, the resulting Qualitative Concern Key Indicator ($KCI_{QUAL\text{-}j\text{-}k\text{-}i}$), was recorded as "U" (Upwards). Conversely, whenever the qualitative outcome seems to go against the acceptance of the proposed bid, the resulting $KCI_{QUAL\text{-}j\text{-}k\text{-}i}$ was recorded as "D" (Down). If at any stage (i) of the service process, the result cannot be evaluated or becomes irrelevant according to the interviewer's interpretation, no data was recorded.

For each one of these four stakeholders, qualitative data maps were recorded and fulfilled throughout the service process. In the (Tables 1–4) was recorded the opinion (feelings) of the interviewer (researcher) based on the concerns of the interviewee (interested party) together with the observations of the shop floor, recorded in terms of two possible results.

To limit the impact of personal "feeling" on the results of the research, the data collection had always the presence of both authors of this research.

3.3. Quantitative data collection

The quantitative information represents the concerns of each stakeholder, related to the numerical data, such as time, energy, number of parts and costs, among others, throughout the 36 steps of the service process [48]. These quantitative data have been collected from direct measurements on production machines, computers, servers and databases, measurements on the shop floor and direct measurements made during site visits to the execution of the order (Tables 5 and 6). Quantitative data maps were prepared for each participant, filled in as the service process takes place, for each order monitored and evaluated.

Table 1
Customer questionnaire-guidelines - qualitative Data.

Customer service process steps	4		8		12		16		20		24		28		32		36	
Customer Qualitative Concerns Questionnaire-Guidelines	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U
What are your concerns regarding the Time to Receive the Product?																		
What are your concerns regarding Flexibility?																		

Table 2
Provider questionnaire-guidelines - qualitative Data.

Provider service process steps	4		8		12		16		20		24		28		32		36	
Provider Qualitative Concerns Questionnaire-Guidelines	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U
What are your concerns regarding the Time to Receive the Product?																		
What are your concerns regarding Flexibility?																		

Table 3
Competitor questionnaire-guidelines - qualitative Data.

Competitor service process steps	4		8		12		16		20		24		28		32		36	
Competitor Qualitative Concerns Questionnaire-Guidelines	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U
What are your concerns regarding Customer Satisfaction?																		
What are your concerns regarding Contract Compliance?																		

Table 4
Authorities questionnaire-guidelines - qualitative Data.

Service process steps	4		8		12		16		20		24		28		32		36	
Authorities Qualitative Concerns Questionnaire-Guidelines	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U
What are the concerns regarding the Taxes & Fines application and execution?																		

3.4. *Customer Key Concern Indicators (KCI_C)*

For the empirical context of this research, stakeholder "Customer" are collective entities that use the BIM to design, manage and monitor the building construction operations, either in private or public sectors. Mostly architects and engineers using a BIM station, these persons represent the "resources with rights" resources of the service system "customer" according to the S|S [49].

The Customer Concerns related to the Delivery-Time are represented as KCI_C and assessed through the Equations 1, 2 and 3 by using the data collected.

KCI_{C1} (Time to receive the product) | this KCI, evaluates qualitatively the customer concerns, indexed to the time between ordering and receiving a product along with the steps (i) of the service process.

Table 5
Customer quantitative Data.

Customer Quantitative Measurements	4		8		12		16		20		24		28		32		36	
Step Process Time (days)																		
Customer Labour Time (hours)																		

Table 6
Provider quantitative Data.

Provider Quantitative Measurements	4		8		12		16		20		24		28		32		36	
Machines Effective Operation Time (hours)																		
Machines Setup Time (hours)																		
Logistic Internal Time (hours)																		
Idle Process Time (days)																		
Labour Time (hours x man)																		
Number of Operations (n)																		

$$TRPC_{QUAL\_C} = \frac{\sum (Dx\ TRPC_{QUAL-C})i}{\sum (Ux\ TRPC_{QUAL-C})i} \tag{1b}$$

KCI_{C2} (Product Flexibility) | this KCI evaluates qualitatively the customer concerns indexed to the provider flexibility to produce the product as required, along with the steps (i) of the service process. Is an indicator associated with the "customization capacity" [23].

$$PFC_{QUAL\_C} = \frac{\sum (Dx\ PFC_{QUAL-C})i}{\sum (Ux\ PFC_{QUAL-C})i} \tag{2}$$

KCI_{C3} (Product Lead Time) | this KCI evaluates quantitatively the customer concerns indexed to the time between steps (i) along the service process

$$PLTC_{QUAN\_C} = \sum (\mathrm{STEP}_{Quant\_Global\_Time\_C})i \tag{3}$$

3.5. Provider Key Concern Indicators

For the empirical context of this research, stakeholder "Provider" are collective entities that manufacture stone products for the construction industry and sell directly to the end-users.

The Provider Concerns related to the Delivery-Time are represented as KCI_P and assessed through Equations (4)–(10), by using the data collected.

KCI_{P1} (Time to receive the product) | this KCI evaluates qualitatively the provider concerns related to the time as it was promised to the customer, along with the steps (i) of the service process.

$$TRPC_{QUAL\_P} = \frac{\sum (Dx\ TRPC_{QUAL-P})i}{\sum (Ux\ TRPC_{QUAL-P})i} \tag{4}$$

KCI_{P2} (Product Flexibility) | this KCI evaluates qualitatively the provider concerns related to the required flexibility to manufacture the product as expected by the customer, along with the steps (i) of the service process.

$$PFC_{QUAL\_P} = \frac{\sum (Dx\ PFC_{QUAL-P})i}{\sum (Ux\ PFC_{QUAL-P})i} \tag{5}$$

KCI_{P3} (Market Interfacing Time) | this KCI evaluates quantitatively the provider concerns related to the time of all the necessary operations, either productive or non-productive and including the setup time at every step (i) of the service process.

$$MITC_{QUAN\_P} = \sum (M\_E\_O\_Time\_P)i + \sum (M\_S\_Time\_P)i + \sum (L\_I\_Time\_P)i + \sum (I\_P\_Time - P)i \tag{6}$$

KCI_{P4} (Product Cycle Time KCI) | this KCI evaluates quantitatively the provider concerns indexed to the production, setup and logistics time on each step (i) of the service process.

$$PCTC_{QUAL\_P} = \sum (M\_E\_O\_Time\_P)i + \sum (M\_S\_Time\_P)i + \sum (L\_I\_Time\_P)i \tag{7}$$

KCI_{P5} (*Production Occupation Time)* | this KCI evaluates quantitatively the provider concerns indexed to the equipment occupancy rate. This indicator measures the time in all the steps (i) of productive machines including their setup time.

$$POTC_{QUAL-P} = \sum (M\_E\_O\_Time\_P)i + \sum (M\_S\_Time\_P)i \tag{8}$$

KCI_{P6} (Production Layout Balance) | this KCI evaluates quantitatively the provider concerns indexed to the waiting times between two steps (i) (balancing) along the service process.

$$PLBC_{QUAL-P} = + \sum (I\_P\_Time\_P)i \tag{9}$$

KCI_{P7} (Logistics Capability) | this KCI evaluates quantitatively the provider concerns indexed to the effectiveness of internal logistics along the service process.

$$LCC_{QUAL-P} = \sum (L\_I\_Time\_P)i \tag{10}$$

3.6. Competitors Key Concern Indicators

For the empirical context of this research, the stakeholder "Competitor" are collective entities that manufacture that compete directly or indirectly with providers, either in terms of products or market geography.

The Competitor Concerns related to the Delivery-Time are represented as KCI_{CP} and assessed through Equations (11) and (12) and by using the data collected.

KCI_{CP1} (Customer Satisfaction Concerns) | this KCI evaluates qualitatively the competitor concerns about how happy the customer is with the current provider.

$$CSC_{QUAL\_Cp} = \frac{\sum (Dx\ CSC_{QUAL-Cp})i}{\sum (Ux\ CSC_{QUAL-Cp})i} \tag{11}$$

KCI_{CP1} (Contract Compliance) | this KCI evaluates qualitatively the competitor concerns indexed to the compliance and good faith of the provider.

$$CCC_{QUAL\_Cp} = \frac{\sum(Dx\ \ CCC_{QUAL-Cp})i}{\sum(Ux\ CCC_{QUAL-Cp})i} \tag{12}$$

3.7. Authority Key Concern Indicators

For the empirical context of this research, the stakeholder “Authority” are official entities that represent the governments and laws either in the provider and in the customer country.

The Authority Concerns related to the Delivery-Time are represented as KCI_A and assessed through Equation (13) by using the data collected.

KCI_{A1} (Taxes & Fines Concern) | this KCI evaluates qualitatively the Authorities Concerns regarding the taxes, fees and fines.

$$T\&FC_{QUAL\_A} = \frac{\sum(Dx\ T\&FC_{QUAL-A})i}{\sum(Ux\ T\&FC_{QUAL-A})i} \tag{13}$$

3.8. Innovation Outcomes (IO's)

As observed in the literature, for S|S, when the interaction between two service systems evolves the mode of its operation, it generates as outputs the Innovation Outcomes [29]. Therefore, the $IO_{qual\text{-}k}$ and $IO_{quan\text{-}k}$ (Equations (14) and (15)), represent the variation observed in the $KCI_{qual\text{-}k}$ and $KCI_{quan\text{-}k}$ indicators, resulting from the innovations along the service process [50]. For the EF, stakeholders' concerns will be qualified and quantified based on the right metrics for each of the KCI_{QUAL} and KCI_{QUAN}, and so, it is possible to assess each result before and after the innovation.

$$IOqual_{IJK} = \frac{[KCIqual\_jki(Current\_State)\ -\ KCIqual\_jki(Future\_State)]}{KCIqual_{jki}(Current\_State)} \tag{14}$$

$$IOquan_{IJK} = \frac{[KCIquan\_jki(Current\_State)\ -\ KCIquan\_jki(Future\_State)]}{KCIquan\_jki(Current\_State)} \tag{15}$$

If $IO_{jki} > 0$, (i) it means the innovation impact tends to favour acceptance of the value proposition; (ii) if $IO_{jki} < 0$, it means the innovation impact goes against acceptance of the value proposition and; (iii) if $IO_{jki} = 0$, it means the innovation did not have any impact on the acceptance of the value proposition.

As a key assumption of the mixed methodological approach, qualitative data and quantitative data must provide results that lead to similar conclusions. In other words, by using the mixed methodology, if the results of the IO_{QUAL} combined with the IO_{QUAN} results are in the same direction, they will be robust enough to conclude about the impact of I4.0 operations, on delivery times.

4. Confirmative study | framework empirical application

The qualitative and quantitative data were collected and recorded in every step of the service process, either for the ten G#T companies and for the ten G#4.0 companies monitored.

Following the methodological procedures, the data collected has been used to compute either the indicators $KCI_{qual\text{-}K,}$ $KCI_{quan\text{-}K}$ and the outcomes $IO_{qual\text{-}K}$ $IO_{quan\text{-}K}$ for each one of the main stakeholder (k), (Customers, Suppliers, Competitors and Authorities), followed by their discussion and evolution interpretation.

4.1. Customer qualitative KCI's and IO's

The customer concerns are represented by a set of data along every step of the service process. From these data, the $KCI_{qual\text{-}C}$ have been computed either for the G#T and the G#4.0 group of companies.

By using the Equations 1 and 2, we found that the $KCI_{qual\text{-}C}$, have are been reduced considerably, resulting in a positive $IO_{qual\text{-}C}$ (Equation (13)), when the operations changes from G#T to the G#4.0.

4.2. Analysing in detail the $IO_{qual\text{-}C}$ related to customer concerns, we found that the

KCI indexed to the “Time to Receive the Product” contributes to the main impact on the delivery time (Table 7). This major gains in terms of concerns reduction may be justified by the fact that in I4.0 mode (G#4.0 group of companies) the transparency and production efficiency tend to increase when digital operations are used. Moreover, the permanent collaboration of the customer during the whole service process in I4.0 mode of operations, puts pushes the provider to become more efficient.

Paradoxically, we found that from the customer perspective, I4.0 does not increase the flexibility, which at first glance is counter-intuitive since one of the challenges of I4.0 is to provide production flexibility. The justification for this result may be related to the fact that all G#T companies, despite manually or traditionally manufacturing but they provide products customized, which is, in fact, one of their main competitive advantages currently. Moreover, what the G#4.0 companies are expecting from the digital operations is to keep their current flexibility and additionally reduce the delivery time among other benefits.

4.3. Provider qualitative KCI's and IOs

The provider concerns are represented by a set of data along every step of the service process. From these data, the $KCI_{qual\text{-}P}$ has been computed either for the G#T and the G#4.0 group of companies.

By using the Equations (4) and (5), we found that the $KCI_{qual\text{-}P}$, have are been reduced considerably (Table 8), resulting in a positive $IO_{qual\text{-}P}$ (Equation (13)) when the operations change from G#T to the G#4.0.

4.4. Competitor qualitative KCI's and IO's

The Competitor concerns are represented by a set of data along every step of the service process. From these data, the $KCI_{qual\text{-}CP}$ have been computed either for the G#T and the G#4.0 group of companies.

By using the Equations (11) and (12), we found that the $KCI_{qual\text{-}CP}$, have are been reduced considerably (Table 9), resulting in a positive $IO_{qual\text{-}CP}$ when the operations changes from G#T to the G#4.0 (see Table 10).

4.5. Authority qualitative KCI's and IO's

The Authority concerns are represented by a set of data along every step of the service process. From these data, the $KCI_{qual\text{-}A}$ have been computed either for the G#T and the G#4.0 group of companies.

By using Equation (13), we found that the $KCI_{qual\text{-}A}$, have are been reduced (Table 9), resulting in a positive $IO_{qual\text{-}A}$ when the operations changes from G#T to the G#4.0.

4.6. Quantitative Innovation Outcomes | computing and discussion

As detailed in the methodology, the key assumption of the

Table 7
Customer $KCI_{qual\text{-}C}$ e $IO_{qual\text{-}C}$ | Evolution results from G#T to the G#4.0

Customer Qualitative Concerns	KCI-QUAL-C (G#T)	KCI-QUAL-C (G#I4.0)	IO-QUAL-C
$TRPC_{qual\_C}$	1,54	0,16	90%
PFC_{qual_C}	0,29	0,29	0%
Average Qualitative Customer IO			45%

Table 8
Provider KCI_{QUAL-P} e IO_{QUAL-P} | Evolution results from G#T to the G#I4.0

Provider Qualitative Concerns	KCI-QUAL-P (G#T)	KCI-QUAL-P (G#4.0)	IO-QUAL-P
$TRPC_{QUAL\_P}$	2,14	0,40	81%
PFC_{QUAL_P}	2,00	0,67	67%
Average Qualitative Provider IO			74%

Table 9
Competitors $KCI_{QUAL-Cp}$ e $IO_{QUAL-Cp}$ | Evolution results from G#T to the G#I4.0

Competitors Qualitative Concerns	KCI-QUAL-Cp (G#T)	KCI-QUAL-Cp (G#4.0)	IO-QUAL-Cp
CSC_{qual_Cp}	1,06	0,33	69%
CCC_{qual_Cp}	0,80	0,21	73%
Average Qualitative Competitor IO			71%

Table 10
Authorities KCI_{QUAL-A} e IO_{QUAL-A} | Evolution results from G#T to the G#I4.0

Authorities Qualitative Concerns	KCI-QUAL-A (G#T)	KCI-QUAL-A (G#4.0)	IO-QUAL-A
$T\&FC_{QUAL\_A}$	0,38	0,14	62%

exploratory mixed methodological approach is that qualitative data and quantitative data, while providing different types of information, taken together must confirm the results, this being the main advantage of mixed methodology.

Observing the IO_{quan-C}, related to the Customer evolution of the KCI_{quan-C} (Table 11), we found a quantitative gain of 58% in the $PLTC_{QUAN-C}$, confirming the qualitative gains of 45% computed on the previous section.

Observing the IO_{quan-P} related to the Customer evolution of the KCI_{quan-P} (Table 12), we found that the most significant gains (1,05 h/m2) occurred during the first phase of the service process (Marketing Interface Concerns), which appeared to happen as the result of easy and integrated collaborative operations between the I4.0 provider and the BIM operator.

Moreover, we also found gains of 0,40 h/m^2 in the “Production Cycle Time Concerns”, of 0,33 h/m^2 in the “Production Occupation Concerns”, 0,29 h/m^2 in the “Production Layout Balance Concerns”, and 0,07 h/m2 in the “Logistics Capability Concerns”. These average quantitative gains of 0,44h/m2, confirm the qualitative average gains of 74% found in the previous section, according to the provider perspective (Chart 1).

5. Conclusions

Supported by the Service Science Body of Knowledge, in this research we have found a possible answer about the impact of I4.0 operations, on the time to deliver the products, of the traditional and fragmented sectors in Digital Marketplace context.

For this assessment propose, an empirical framework (EF) was conceptualized under the Service Science perspective and applied to a case study related to the Portuguese Ornamental Stone sector. The case study has involved twenty stone companies split into two groups of ten, all of them, directly involved in the negotiation, production and delivery of the orders monitored during this empirical research: (i) ten companies operating traditionally, here designated as G#T operations context and, (ii) ten other companies are using digital technologies since 2005 in their operations and collaboratively work today with the BIM marketplace, here designated as G#4.0 operations. During the empirical research, orders' follow-up, qualitative and quantitative data were collected, and the normative nature of the ornamental stone was also observed in all

Table 11
Customer KCI_{QUAN-C} e IO_{QUAN-C} | Evolution results from G#T to the G#I4.0

Customer Quantitative Concerns regarding the Time-Deliver	$KCI_{quan-C-(G\#T)}$	$KCI_{quan-C-(G\#I4.0)}$	IO_{quan-C}	units
$PLTC_{QUAN\_C}$	0,52	0,22	58%	hours/m2

Table 12
Provider KCI_{quan-P} e IO_{quan-P} | Evolution results from G#T to the G#I4.0

Provider Quantitative Concerns regarding the Time-Deliver	$KCI_{quan-P-(G\#T)}$	$KCI_{quan-P-(G\#I4.0)}$	IO_{quan-P}	units
$MITC_{QUAN\_P}$	1,29	0,24	1,05	h/m2
$PCTC_{QUAN\_P}$	1,29	0,89	0,40	h/m2
$POTC_{QUAN\_P}$	1,05	0,72	0,33	h/m2
$PLBC_{QUAN\_P}$	0,48	0,19	0,29	h/m2
LCC_{QUAN_P}	0,24	0,17	0,07	h/m2

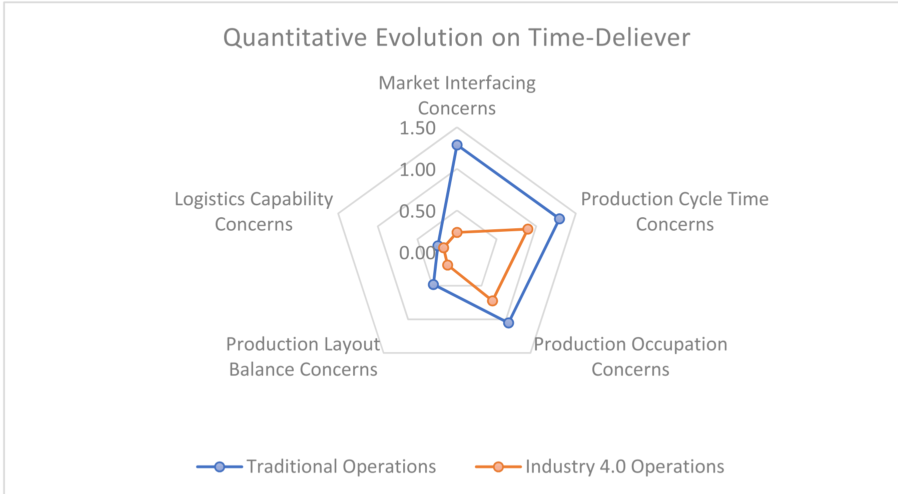
steps of the service process.

For Service Science perspective, each stakeholder expects and makes a different assessment of the value of the proposals. Thus, for the EF conceptualized, the concerns for stakeholders were defined in terms of Key Concern Indicators (KCI) with which it was possible to measure the concerns qualitatively and quantitatively and their evolution in the shifting context, through qualitative and quantitative Innovation Outcomes (IO), as defined by Service Science.

- From the Customers' perspective, we found an average qualitative customers' concerns relief of 45%, confirmed by a quantitative average relief of 58%.
- From the Competitors' perspective, we found an average qualitative gain of 71%.
- From the Authorities perspective, we found an average qualitative gain of 62%.
- From the Providers' perspective, we found an average qualitative gain of 74%, confirmed by a quantitative average relief of 0,44h/m2.

From these results, we may conclude that for the traditional and fragmented sectors in the digital marketplace context, may reduce the time to deliver their products if they shift the operations to Industry 4.0. Without considering the important investment component required to purchase these technologies, since the impact of the I4.0 on their response to the threats arising from the digital procurement is technically positive, it is recommendable to the traditional and fragmented companies to integrate these technologies on their operations. We may also conclude that the empirical framework, conceptualized according to Service Science Theory was appropriate for the research problem addressed in this research, allowing the combination of qualitative and quantitative data in an exploratory way, and enabling robust conclusions to be drawn about the response of stone companies in different operational contexts, resulting in a research contribution of this work to practice.

Although the proposed objectives have been broadly achieved, there were several difficulties to overcome during this research, which led to some limitations. Monitoring the entire sequence of events from the discussion of orders to delivery of the products to customers was another difficulty found in this research since a great amount of data occurred simultaneously and in different geographical locations. The difficulty in identifying competitors who were “competing” for the same orders was perhaps the most difficult task during the data collection process since directly asking potential competitors if they were competing for the



Graphic: 1. Provider Quantitative Gains (h/m^2) regarding the Time to Deliver) | Evolution results from G#T to the G#I4.0.

orders monitored would mean passing on information from the providers with whom the researcher was committed to confidentiality. Ornamental Stones are natural raw materials and therefore their natural variability cannot be avoided. To minimize this unavoidable situation, orders using the same stone type were selected, but even so, the physical-chemical characteristics may not have been the same in all the orders monitored, resulting in limited reliability of some of the data collected. Finally, another limitation is related to the state-of-the-art BIM software releases available in the market [51].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Agostinho da Silva: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Funding acquisition. **Maria Manuel Gil:** Methodology, Formal analysis, Investigation, Writing - review & editing, Visualization, Supervision, Funding acquisition.

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