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Outlining a new Collaborative Business Model as a result of the Green Building Information Modelling Impact in the AEC Supply Chain

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Abstract. BIM (Building Information Modelling) technological push has enabled to integrate the design/construction outcomes of 3D-CAD along the product/service AEC (Architecture, Engineering and Construction) SC (supply chain) through an intelligent DMS (Data Management System) based on standard and interoperable data formats. The proposed end-to-end approach overcomes a typical AEC gap, enables the operationalisation of the sustainable/green building LCA (Life Cycle Assessment) and puts together new collaborative relationships with the owner, among SC stakeholders and with new forms of BIM procurement. The outlined collaborative business model is based on the Quality Control and Assurance framework and provides conceptual consistency to the reintroduction of the owner concerns/satisfaction in the SC, as well as enables consistent and accountable relationships between (smart)materials procurement and building specification. An expert's focus group carried out a preliminary check of the model's interest/applicability, resulting in recommendations for its further detailing and for propositions development into a systematic enquiring process.

Keywords: Collaboration in the AEC Supply Chain; Collaborative Business Model for Green BIM; Green BIM Procurement; Collaborative Customer Relationships, Quality Conformance in Built Assets

1 Introduction

Higher uncertainty in customized products demand, product range broadening, increasing product complexity, higher quality needs, shorter product life cycles, increasing green requirements, decreasing revenue margins, investment in Advanced Manufacturing Technology (AMT) are illustrative of current competitive challenges. These have been introducing requirements for: new organizational structures and, new business models, theories, processes and technologies, which, in turn, should allow companies to create innovative operations paradigms to face them [1].

The proactive adoption of BIM by the AEC Industry has resulted from environmental, social and economic concerns and pressures that also foster the development of sustainable services and manufacturing processes [2,3]. Moreover, Europe is going to adopt BIM for public contracting as promoted by the European Union Public Procurement Directive [4].

On the other hand, the lean paradigm aims also provide a basis for improving sustainability practices. These aims are, as follows: using fewer resources, improving quality and, reducing rework and waste and so, pollution. In turn, reducing rework and waste also supports a variety of lean transformation objectives [5] in a circular way. Moreover, it is possible to reduce waste and energy consumption, and to improve construction quality by using BIM [6]. In fact, BIM might significantly impact the business by promoting a technological push concerning: (i) the functional integration along the supply chain, which is not yet fully explored [7]; (ii) the data standardization that defines the information formats, geometry, behaviour and so, the presentation of BIM smart objects; for instance, the Industry Foundation Class (IFC) format maximizes consistency, efficiency and interoperability across the construction industry [8]; (iii) the data interoperable usability [9]; (iv) the inclusion of Information and Communication Technology (ICT) frameworks and technologies that support stakeholders' collaboration over projects life-cycle [10]; (v) the cloud-based sharing of the lists of products and materials with Building Product Manufacturers [11] and, (vi) a positive impact on materials conformance by assuring the improvement of consistency, quality and compatibility of BIM smart objects. Therefore, the need for consistent and available data, as well as for more precise and reliable procedures to effectively work with BIM is imperative [4]. While for design disciplines, BIM is an extension to CAD, for non-design disciplines, such as contractors and project managers, BIM is more like an intelligent Data Management System (DMS). These data management tools can quickly and directly take off data from CAD packages [12], despite both BIM and these applications are becoming more and more integrated. In fact, BIM objects operate in a Common Data Environment (CDE). Thus, through the use of a common standard, the integration of building and materials information, becomes possible leading to a more effective use of materials [8].

In classical Design-Bid-Build (DBB) project delivery there is a poor understanding between owner and users that together with the used architect milestones both generate large planning periods, lack of proper coordination and no collaboration. This results into late identification of excessive costs, nonconformance, too much reaction in control (no dependability), lead time increase, due date missing and contractual penalties [13,14]. By replacing DBB, the use of BIM to provide data for the *earlier* evaluation of both energy performance and sustainability has been a cornerstone of the Green BIM definition; leading design organizations are adopting this approach to enable integrated design, construction and maintenance towards Net Zero Energy buildings. Green BIM includes Building Energy Modelling (BEM) dealing with project energy performance to identify better options to optimise building energy efficiency during the life cycle [4]. Within a DBB context, the energy analysis packages, when used, provide late feedback to the designers, just regarding how much energy the building will use, what are the anticipated CO_2 emissions and if the built asset will pass performance criteria (such as, LEED or BREEAM). In addition, materials decisions are usually based on cost minimisation and enter in the process too late, missing their critical role in the building envelope, specially the external walls [15]. However, BIM applications for energy analysis (BEM) have been introducing this discussion at earlier stages of the design stage [10]. Thus, shortcomings in materials' decisions could also be eliminated by an integrate project delivery approach [13] that might also change the owner participation role and promote active collaboration among stakeholders.

Therefore, in the following section of this paper, it is reported a unique conceptual merge between technical and management knowledge that will address a relevant gap that has been a missing link of building sustainability. In fact, there is an emerging need for a conformance correlation between the customer/owner dynamic priorities or expectations and the built asset. The use of conforming materials operationalised within the conceptual positioning on an end-to-end collaborative green model supported by BIM procurement was identified as a possible way to address the problem-situation. Reddy and Jagadish [16] confirm the interest of this gap concluding that material selection greatly contributes to the reduction of operational energy and emissions, in a separated way from the effects on embodied energy consumption. Moreover, Hardin and McCool [17] also position material selection and use among the three main areas of sustainable design that have a direct relationship to BIM.

So, in Section 2, a new innovative conceptual model focusing on the energy used by buildings during its operation will be deductively outlined from an in-depth literature review. Section 3 explains the adopted methodology. In Section 4, the empirical findings coming from a focus group of three experts are communicated and discussed to prepare this preliminary proposal for future adjustments and confirmation. Finally, in the conclusions section, the paper is closed over the research question, by considering the empirical findings. Recommendations for further developing the outlined conceptual model towards a process of enquiry are also made.

2 Outlining a Conceptual Model

Buildings account for a substantial proportion of global energy consumption [18]. The building sector is responsible for about 40% of the energy demand worldwide, 32% of CO_2 emissions, and about 24% of raw materials extraction [19,20], which makes the AEC sector a major target for environmental improvement [21]. So, Bynum et al. [22] consider that global warming threats puts pressure on the construction industry to address more seriously the need for energy efficient buildings. Therefore, sustainability, in general, and energy efficiency, in particular, have become a key measure of building performance [10]. In fact, the main objective of sustainable design is to create buildings in sustainable cities that are livable, comfortable and safe. On the other hand, BIM does have the potential to aid designers to select the right type of materials during the early design stage and to make vital decisions that have great impacts on the life cycle of sustainable buildings [23].

This investigation is only going to focus on the energy used by buildings during its operation, which has been a major research trend [24] in green buildings. In fact, the operational stage consumes a bigger proportion of energy than all the other stages, over the lifecycle of buildings. These stages have been described as raw materials extraction and materials manufacturing (*initial embodied energy*, as defined by Yohanis and Norton [25]), construction and maintenance (*recurring embodied energy* as defined by Cole and Kernan [26] and, Ibn-Mohammed et al. [27]) and end of life (demolition and disposal) [28].

In fact, embodied energy can represent approximately 10 to 20% of the life cycle energy of a conventional building [29], which might be considered negligible. However, in some low-energy buildings, embodied energy contributes to more than 60% of life cycle energy [30,31]. During the construction and demolition of the buildings, transportation is responsible for about 10 to 40% of the embodied energy demand and nearly 2% of the embodied carbon emissions [32,33,34]. Recent studies reveal that energy use for on-site construction makes only a marginal contribution to the building life cycle energy and emissions, which is made up of about 6.5% of embodied energy, 8% of embodied SO_2, 12% of embodied NO_x and 8% of embodied CO_2 [35,36]. Therefore, in some studies energy use and emissions during on-site construction were also excluded from modelling and measurements [33,37].

So, the energy performance of the building envelope and its components (external walls, roofs, windows etc.) can be critical in determining how much energy is required internally [38]. Popovic and Arnold [39] also consider that a properly designed and constructed envelope should be considered in the construction of a building façade. In addition to aesthetics, façades have an important role in affecting energy savings. However, façade failures are also originated by deficiencies caused by lack of quality control and supervision in design, construction, and maintenance [40]. Hence, this research is going to focus on the role of the external walls in the thermal balance of the building during its operation. So, the materials to be addressed concern the ones required to build adequate façades/external walls in thermal terms.

Within this context, and by following Garvin [41] guidance, a non-defective built asset, as regards operational energy performance, must conform with its Thermal Specification, which is a Design Outcome. In addition, the Design Outcome should conform with the Product Requirements Document, i.e. the Customer Expectations Outcomes (Figure 1a). This approach eliminates a major gap pointed out by Naoum and Egbu [42], which concerns the separation of design from construction. Furthermore, the explicit inclusion of the customer (owner) priorities and expectations in the business process, also enables to overcome another gap concerning the lack of dynamic adjustments, by formally introducing them (also Naoum and Egbu, [42]). This is in line with the findings of Grilo et al. [43] that suggest that the role of the building owner is changing. They also identified requirements for a more open collaborative network, where specialised and integrated agents increase end-user interactions with users, flexibility and iterative facilities design. This organizational design is required to satisfy the social behaviour adequate to the operationalisation of the outlined model. In addition, a non-defective built asset must use materials with characteristics conforming the required building thermal specification. Thus, the materials SPEC should match its required thermal performance defined by their thermal requirements previously expressed in the Building Thermal Specification (Figure 1b). This is the way that this descriptive conceptual model operationalises the material fitness for use as defined by Juran and Gryna [44].

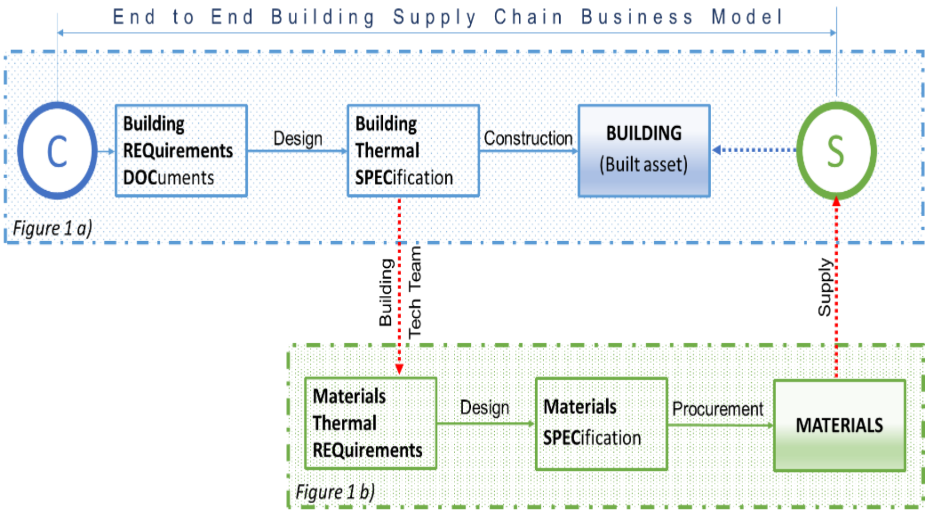

Fig. 1. Root definitions of a collaborative end-to-end business model to guarantee materials conforming to the building owner expectations

A collaborative end to end business model guided by the Quality Control and Assurance (QCA) principles is outlined, in Figure 1. It is expected that it might guarantee that the chosen materials are adequate to the customer expectations for the building. Quality control and quality assurance are two terms that are often used interchangeably. Quality has been defined as fitness for use, conformance to requirements, and the pursuit of excellence [45]. The use of the QCA body of knowledge enabled the establishment of a direct link between the materials employed and the fulfilment of the building owner expectations by using a relevant objective criteria, i.e. the expected building energy performance. It might be argued that the quality control process might support a different customer requirements (CR) reasoning and a different type of procurement, i.e. BIM procurement (Figure 1). In fact, QCA together with 3D CAD enables the energy analysis modules (BEM) to be run at early stages of the specification, on the top of the virtual building generated by BIM. So, the owner might be involved in the technical decision making process required to adjust the SPEC to the energy requirements of a green building taking visual advantage of a powerful Graphic Unit Interface (GUI). Moreover, using smart objects from electronic databases means the powerful ability to automatically adjust the building specification, if the material definition parameters are changed, e.g. to cope with changed owner requirements.

BIM includes a technical, an organisational and a social dimension. In this context, Singh et al. [12] consider that should include a concern with collaboration because AEC projects are mostly multi-organizational and multi-disciplinary. Thus, the success of BIM depends on its collective adoption by the professional users that are expected to participate in the collaboration activities. Moreover, the collaboration requirements would vary from project to project, and, hence, collaboration should be an integral part of the BIM development to better facilitate the adoption of the new technologies, leading to more intelligent automation in the AEC Industry. This collaborative social behaviour is the *glue* required to operationalise an integrated end to end approach to the AEC Supply Chain (AEC SC), i.e. from the building owner to the constructor, if a built asset that fits the use is expected to be delivered. Accordingly, cloud computing – i.e., an innovative way to access information in real time [46] and share it via internet – is identified as a relevant ICT missing link that is required to enable *seamless* data interchange across the end-to-end AEC SC in a *quasi*-integrated data approach [47].

To sum up, the outline of the conceptual model is made up of three parts. Firstly, the graphical representation of the idea was depicted. Secondly, a supported explanation of the assumptions, models and concepts is provided and, then, a supported description of the main elements and relationships of model draft is made. Finally, a research question is formulated, as follows:

Which type of collaborative relationships might arise along the AEC supply chain powered by BIM procurement within the green building scope?

3 Methodology

When approaching a problem-situation we may take several types of world views – *Weltanschauung* [48]. While the specialists' one favours the detail, others might broaden the scope by enabling fresh insights from the chosen areas of knowledge. The latter also increases the complexity, but brings in a richer picture of the problem-situation, which is useful when the social component is relevant, in addition to the technical one [49]. Our choice was to include, in the root definitions of the problem [50], recognised knowledge such as Quality, Supply Chain Management, Sustainability, Collaborative Relationships and IS/IT in response to the repeated claims of the authors in the area. These were pointing out the same flaws for several years without a sufficient reaction from the specialists. So, the generic knowledge of these areas was first considered in the outline of a model to reposition the problem-situation and to structure it after an interdisciplinary approach. This aims at merging the views from technical, social and organizational backgrounds by offering the potential to structure the problem-situation in a different way that includes several relevant points of view, in addition to the specialists' one, i.e. Design-Bid-Build, BIM, BEM and BIM procurement, usually the ones strictly considered in the AEC Industry.

As this is an innovative approach, it was decided to run an exploratory qualitative research, which was conducted by putting together a focus group of specialists that were carefully chosen and so, by asking about their perceptions, opinions, beliefs, and attitudes towards the presented ideas. Three engineers were participating. They were chosen because of their technical, social and organizational competencies, as follows: i) in AEC Industry and BIM (2 out of 3); ii) in IS/IT and Customer Requirements (1); iii) in CAD (3); ii) in Collaborative Operations, Supply Chain, Procurement, Quality and Change Intervention Programmes (1); iv) in Energy Balances and Sustainability (1). Topics were defined as clear and precise as possible, in an iterative way. There was a focus on enabling and taking notes about the outcomes of the interactive discussions between participants. The participants had both interest and characteristics related to the topics being discussed and they were encouraged to share their points of view without any pressure to reach a consensus.

These discussions were run several times, for 2 hours each time, with similar participants. The group met on a regular weekly basis to discuss on going progress, during 4 months (February-May). Progress and adjustments were always emerging from the focus group meetings, in terms of the clarification of topics relevance, theories, concepts and their relationships. The results were also analysed together with the INOVSTONE® 4.0 Project Chief, in three occasions within this 5 month time horizon, to collect some feedback, guidance and validation. Data were treated and processed according to adequate techniques that are usually used to process text (i.e. the focus group notes) in qualitative analysis, i.e. contents analysis [51].

Moreover, issues to be discussed were generated from the literature review, which configures a hypothetical-deductive approach. The kick off question concerned the impact on the owners' role of new customer requirements arising from BIM procurement and green concerns in the AEC; then, a collaborative customer-centric view was developed; papers from a specialist background providing a clear picture of the status of the art in the AEC Industry were further read and discussed (main outcomes: need for quality procedures, unifying a split SC, green building and energy issues); so, the topic of Green Building related to lifecycle analysis and the identification of the building operation energy as critical, have showed up as the next tip to be followed; then, the impact of BIM in the project delivery and the comparison with the DBB approach brought in the BEM issue were the topics on demand; finally, the idea was to put together generic established knowledge like Quality, end-to-end Supply Chain, and Collaboration with the BIM integrated project delivery, in the scope of a relevant energy analysis considering the building LCA. The outline of the conceptual model (Figure 1) was the resulting summary of all the relationships found.

To sum up, this exploratory assignment collected feedback from experts aiming at progressing towards a detailed conceptual model [52], in the future. Then, the emerging propositions will support the definition of questions for fine tuning a questionnaire to support semi-structured interviews taking place as further work.

4 Empirical Findings and Discussion

This section will report the preliminary findings coming from the focus group and run a first cross check with what some fellow researchers and authors in the addressed domains are saying from the same topics.

4.1 Conceptual Model positioning after Quality Control & Assurance guidance

The experts considered that the use of the quality Body of Knowledge (BoK) [e.g. 45], a well-established domain in the scientific community, provides a robust embedding for the descriptive model of the problem-situation (Figure 1). The Quality BoK has being been sharply developed since the 1970s, when The British standard BS 5750 was first published, in 1979, despite many isolated but important occurrences might be traced back to earlier times [53]. In fact, by setting a credible, well-defined, relevant, clear and supported relationship between the building owner requirements and the physical materials to be procured and incorporated in construction appears to be an attractive idea, given the AEC problems. This would merge several knowledge areas under the umbrella of quality. Garvin [41] is very clear on identifying several definitions and a multi-dimension model to define and position quality. So, in the proposed conceptual model (Figure 1), the following dimensions were used: (i) *product-based*, since a precise way to assess and link procured materials to building specification was outlined; (ii) *user-based*, since the building owner expectations/requirements were reintroduced in the end-to-end SC approach that supported the conceptual operationalisation of the QCA framework; this also satisfies a concern from the Service Science domain [54], which brings in services to the outlined model equation, in addition to the built asset as the physical product; (iii) *manufacturing-based* approach, since the concerns of manufacturing and procurement sides are included in the outlined model (Figure 1); (iv) *value-based*, since value is about tangible and intangible benefits for the stakeholders and so, both the effort done to achieve them and the inclusion of owner view brings in to the equation the redefinition of the customer/owner requirements within a holistic context; BIM procurement is also addressed as a collaborative and empowered approach to the traditionally fragmented AEC SC; moreover, by the use of digital technologies all the AEC SC will be leveraged, from customer to materials suppliers. In this way, it is argued that the outlined model enables the conceptual design of an interdisciplinary rich picture (as defined *in* Silva, [55]) of the AEC SC. Still according with the specialists, this contextualization fits very well the needs of a holistic end-to-end approach to the supply chain that copes with many pointed out structural problems [e.g. 42, 56], in an innovative but supported way.

4.2 Impact of Building Information Modelling

Secondary data [51] coming from checking a practitioner' site [11] confirmed the experts' opinion that BIM as an intelligent cloud based collaborative Data Management System (DMS) is a *sine qua non* condition to create and share design, bill of materials, tenders, bids and direct orders seamlessly and so, overcome the AEC weakness concerning the split between design and construction [e.g. 42,56]. In fact, allowing the automation of several procurement processes, diminishing the probability of errors and processes duration are expected direct results of the BIM procurement DMS component [57]. Moreover, data interoperability and standardization are required to do a comparison of the products supplied by different suppliers [58] and so, increase visibility, transparency and fairness through BIM procurement. In addition, collaborative processes in procurement arise primarily from buying requirements through the specification development process, using real-time communication and exchange of information [59], which confirms the DMS need *ab initio*. Therefore, a collaborative environment is possible to develop in BIM procurement, instead of confrontational attitudes between client, contractors and consultants under the traditional procurement arrangement [42].

The specialists went further on by considering that the requirements for Digital Technologies have to match the DMS base together with the reinforced CAD functionalities of modern BIM to support different functional or simulation systems and, massive real world data gathering and communication, which is corroborated by the findings of buildingSMART® [60]. According to them, BIM implementation should be done before any requirements or expectations concerning further processing by many other different systems (e.g. Digital Business Platforms, e-procurement, engineering packages, etc.), information/data broadcasting, sensory systems to collect real world data, big data analytics, augmented/virtual reality technologies, cyber physical systems, etc. For instance, an improved coordination among appliances to optimize the usage of room allocated to maintenance accesses or, the ~~use~~ utilisation of augmented reality to follow/detect pipes embodied in the walls are just two examples of innovative functionalities enabled by BIM reinforced CAD functionalities that were mentioned by the experts. Many examples supporting more types of new functionalities coming from 4D CAD are also mentioned in the literature. For instance, the combination of 3D CAD and 4D animations can dramatically improve communication, coordination, and planning of construction projects, while reducing risks and costs [13].

4.3 Sustainable Collaborative Supply Chain

The focus group participants also agreed that the expected supply chain view is not always pursued in practice [e.g. 42,56] and, also, that it should be expanded to include not only the design/built asset relationship, but also the customer/building owner expectations/requirements, as well [44]. This is a holistic end-to-end SC approach that is also required by LCA, which is a core concept in green building [28]. The general feeling is that addressing the whole supply chain from the building-owner to the materials supplier, under a collaborative approach supported by a BIM platform using interoperable data, promotes more transparent and fairer design and construction processes with an expected improvement in terms of product conformance, timings and costs [e.g. 60]. Moreover, the experts are quite confident that involving the owner/customer with the building specification and construction, by assuring a more reliable, participative and objective collaborative partnership, should generate visibility, transparency, full traceability and higher fulfilment of its expectations. In some way, this will soften the ownership of many technical decisions that used to be exclusively made by the building technical team, by co-creation with the customer [54]. One of the participants even commented that this is a similar process of the one supporting the House of Quality technique [61], where the technical decisions are related to the customer (in this context, the owner) requirements (customer-centric). Therefore, the decisions might be more humanized, perhaps more driven towards a broader sustainable interest and not focusing exclusively on short term costs [23], as many times happens, accordingly to the experts' opinion. Still, according to them, the current stricter unidimensional focus was advanced as one major reason why the last part of the LCA concerning maintenance and demolition is ignored, exactly as suggested by Vigovskaya et al. [62].

5 Conclusions

Revisiting both the formulated research question and the experts' opinions, one might conclude that there are relevant positive correlations and synergies among the involvement of the built assets owner (i.e. a customer-centric approach), internal collaborative works (including all the involved professionals) and the BIM procurement process. In fact, evolving information technologies applied to innovative integrated project delivery approaches have shown up as powerful drivers to outline a new conceptual business model for the AEC SC context. So, the implementation of a new information paradigm for the AEC sector (BIM) is expected to leverage the whole supply chain performance under a quality umbrella that links the owner expectations to the procurement of smart materials. Guided by BEM, sustainable operations are pushed towards LCA, which is a core concept for green building ratings. Therefore, the expected resulting reduction in energy consumption during the total operational life of the building represents a relevant positive impact on the environment, which is an important contribution to the practice and society in general [*vide* 63]. In addition, the outlined model enables the practitioner to benefit from the possibility to specify and procure materials for the external walls that are in conformance with the built asset thermal specification. So, there appears to be a relevant research contribution of this business model concept that enables a different decision making support to materials procurement, when compared with the consultants prescriptions based on their unsupported and many times biased opinion. At last, it is argued for the outlined conceptual model as being innovative because it adds value to the AEC sector by working on the boundaries of several areas of knowledge, promoting their merge towards a relevant collaborative proposal for the construction industry.

However, a research limitation was recognized as regards the empirical part of the exploratory study, which was purposefully designed to preliminarily check the feasibility and interest of the presented approach. In order to overcome it, in the sequence of this paper, our research line has been cross-investigating if the BIM authoring tools are complying with the generic expectations that were introduced by the outlined model. So, the innovative contribution to theory is the operationalisation of a richer picture of the problem-situation by expanding its root definitions, during the structuring of the real world situation (unstructured). This includes knowledge areas that could provide a more complete response to the recurrent criticism of the authors from an AEC background. This is neither the best, nor the unique answer, but a relevant innovative one, because it is unique and supported on knowledge accepted by the scientific community.

As a recommendation for future work, the grounded knowledge generated by the preliminary empirical discussion of this model might support an extension to the in depth literature review towards establishing robust innovative propositions that further detail it. These propositions would generate questions for a process of inquiry [55] to be operationalised by semi-structured interviews that would gather the empirical data required to a more robust confirmation of the model. Moreover, the introduced customer centric approach leading to co-design and co-creation should be further discussed under the umbrella of adequate management theories that concern how well the representing actors (agents) match the ones that are being represented (principals).

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