FROM A CONCEPTUAL KNOWLEDGE FRAMEWORK TO A DECISION SUPPORTING SYSTEM: ALIGNING SCIENTIFIC AND STARTUP DEVELOPMENT

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Abstract: University-industry cooperation has been recognized as a strategic factor to innovation systems. More recently, universities have been pressured not only to cooperate but also to promote and create startups, combining education and research to promote innovation. In this article, we describe a recent case of the alignment between a PhD research challenge and an innovation and business opportunity. The research challenge was to apply the KBUD (*knowledge based urban development*) framework as the basis to a decision support system, to be used by city managers. The results were fostered into a startup financed by a public innovation call, supported by Ruta-N (Medellin, Colombia). The case of KBUD-DSS system and *Heuristics* startup illustrates an example of how a PhD project can combine research and business development, attending simultaneously both pathways.

Keywords: KBUD; decision-support system; innovation; PhD research; startup.

Resumo: A *cooperação universidade-empresa tem sido reconhecida como fator estratégico para os sistemas de inovação. Recentemente, as universidades têm sido pressionadas a cooperar, a promover e criar startups, combinando sua missão de ensino e pesquisa com promoção de inovação. Neste artigo, descrevemos um caso recente de alinhamento entre um desafio de pesquisa de doutorado e uma oportunidade de inovação e negócios. O desafio da pesquisa foi aplicar o KBUD como base para um sistema de apoio à decisão, a ser usado por gestores da cidade. A oportunidade foi criação de startup financiada por uma chamada pública de inovação, apoiada pela Ruta-N (Medellín, Colômbia). O caso do sistema KBUD-DSS e startup de Heuristics ilustra como um projeto de doutorado pode combinar pesquisa e desenvolvimento de negócios, atendendo simultaneamente os dois caminhos.*

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Palavras-chave: KBUD; Sistema de apoio à decisão; Inovação; Doutorado; startup.

1.   INTRODUCTION

University-industry cooperation generally deals with how the research offered by academic institutions can support industry demands and how business innovation challenges academic research (Sjöö; Hellström, 2019). More recently, however, universities have been challenged to include subjects such as innovation, entrepreneurship, and firm incubation into their educational process. Interdisciplinary research and education have shown new pathways of facing university-industry challenges (Amin, M. et al., 2012). This is especially true in countries with a double-faced challenge: to increase the number of PhDs and to foster innovation.

In this article we describe a recent case of how a PhD project dealt with three dimensional challenges: (i) scientific: to identify an original, relevant and feasible research problem; (ii) R&D: to develop a technological and innovative solution to the scientific problem (named KBUD-DSS); and (iii) innovation: to create a startup (Heuristics), and be acknowledged and financially supported by public authorities.

The KBUD-DSS is a decision support system designed to embed KBUD on daily city decision-making (Carneiro, 2020). In Section 2, we present an overview and the research and development methods applied in KBUD-DSS project. The theoretical grounds in city governance and decision-making, as well as KBUD framework are presented in Section 3. In Section 4 we present KBUD-DSS conceptual and technological architectures. The application of the KBUD-DSS in Medellin/Colombia and its support to decision-making are described in Section 5. Finally, in Section 6, we discuss the key findings to city decision-making when supported by a KBUD-based information system and the potential technical, scientific and innovative evolutions to be further investigated.

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2.   RESEARCH DESIGN

Figure 1 represents a schematic view of all steps that lead the Carneiro's PhD research to the innovation outcomes (Carneiro, 2020). The flow in figure 1 represents the project scientific components adopted to develop the KBUD-DSS as a technological artifact. It started from a general goal of making KBUD an instrument to help city decision makers and went up to a funded innovation project, in Colombia.

Figure 1 – KBUD-DSS Technological Research Design.
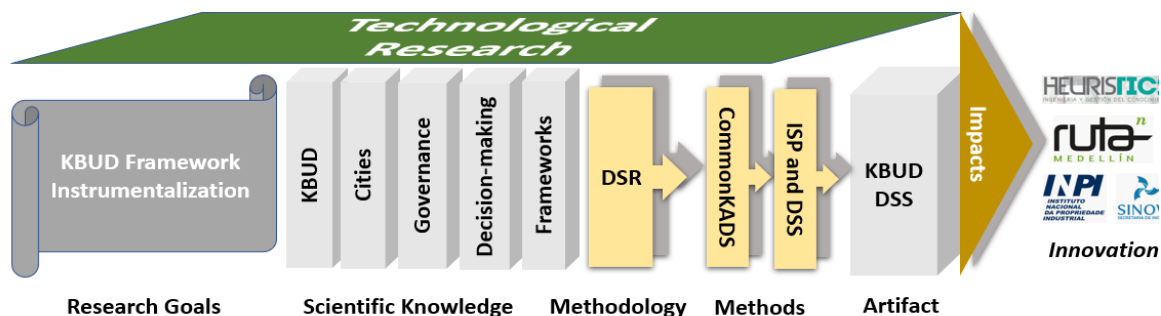
Font: Carneiro (2020)

The research goal came from the aim of taking KBUD framework indicators to city decision makers use on daily basis. Besides the own KBUD, the PhD research had scientific grounds established from literature reviews about cities, governance, decision-making and frameworks.

The thesis goal was to develop a technology, so the methodology chosen was DSR (Design Science Research). CommonKADS, a methodology to design knowledge-based systems, was applied, since the initial hypothesis was that KBUD could be instrumentalized by a knowledge system. Nevertheless, the Organization Model of CommonKADS has shown that the "k" in KBUD is essentially tacit and dependent on KUBD specialist. However, it was also discovered that city halls could also beneficiate from KBUD indicators, if a decision-support system could take place. Hence, in the DSR Development

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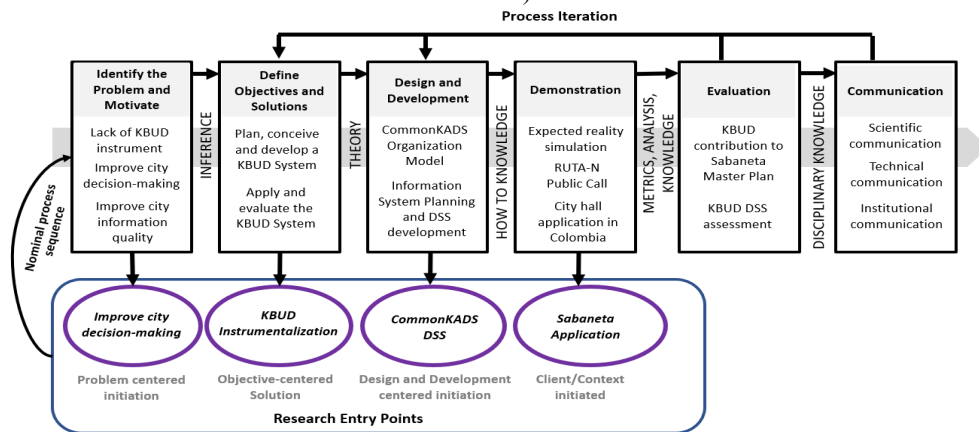
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phase both Information System Planning (ISP) and Decision Support System (DSS) were applied to plan and develop KBUD-DSS.

The project impacts are represented in the last part of figure 1. They are actually innovation achievements. The KBUD-DSS system was first lead to a startup firm, called HEURISTICS and, afterwards it won a public innovation call, conducted by Ruta-N organization, in Colombia, to be applied in Sabaneta, a city in Medellín region, in Colombia. The system was also registered as a joint intellectual property between the university (UFSC), the startup (HEURISTICS) and the authors. So, KBUD-DSS system is a result of both, a scientific PhD and a technological development.

2.1. DESIGN SCIENCE RESEARCH - DSR

As illustrated on Figure 1, the research plan was drawn according to the DSR methodology. DSR is based on design science principles (Simon, 2019) to support technological artifact projects (Hevner; Chatterjee, 2010). It offers a general method with a sequel of activities, including identification, delimitation, motivation, planning, developing, assessment, and communication (Peffers et.al., 2007). In Figure 2 we illustrate how DSR was applied in KBUD-DSS project.

Figure 2 – Design Science Research Application in KBUD-DSS project (Source: Adapted from Carneiro, 2020)

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As it can be seen in Figure 3, DSR establishes an iterative and multidisciplinary set of project activities, from problem identification up to the outcome and impact communication. In KBUD-DSS project we have adopted Iivari's second approach (Iivari, 2015), since the goal was to design a "meta" artifact, in the sense that the system should be suitable to any city management. In this strategy, the artifact is also a prototype (or pilot) rather a final commercial product (Carneiro, 2020). One the strategy was defined, the project followed DSR from problem identification to communication, based on DSR implementation guidelines (Peffers et. al., 2007). As it can be noticed at the bottom of that figure, DSR was a reference method to modelling and developing phases. System modelling was a result of CommonKADS application, taking into consideration the two first DSR phases results. The other four DSR activities were developed by the decision support system methods, as explained in the next sections.

2.1.   COMMONKADS

CommonKADS Methodology (Schneider et al, 2000) is structured into three layers and six models. It starts by contextualizing the knowledge system in its organizational environment, by checking for potential contributions, risks, feasibility, goals, agents, and tasks the system will interfere or support. These findings are inputs to the second layer, where two models, Knowledge and Communication, represent content and relationships between human and artificial agents. Finally, all elements modeled in the five previous models are inputs to the knowledge system project.

As illustrated in Figure 2, in the KBUD-DSS project, CommonKADS was chosen to conduct the problem-motivation and goals DSR activities. The main assumption was the fact that the KBUD framework itself is a knowledge-based artifact, and also previous studies had pointed out the potential contribution to knowledge-based systems (Yigitcanlar, 2014).

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Figure 2 – CommonKADS Methodology Application in KBUD-DSS project.

Model Suite
Why: KBUD improves city decision-making, but is currently solely expert dependent.
What: to embed KBUD into a system to support city decision.
How: dynamic KBUD indicators integrated to daily city management.

Project Roles
K Mngr.: knowledge strategist
KBUD Expert: knowledge source
K Engineer: model the system
Proj Mngr.: manage project
Developer: build the system
K User: city manager

Org. Context – OM1
City general concept
Managers' **acceptance**
Public funding the idea
Sabaneta city hall needs

Prob. Oport. – OM1
Organization: general city and Sabaneta
Problems: city governance complexity; decision-making miss indicators
Oportunities city DM based on kowledge; transparency. Better governance.
Context: city mission, vision, values. City population (NPS)

Variant Aspects OM2
Structure: plan in city hall
Processes: DM in city governance.
People: city managers
Resources: data and information technologies
Knowledge: public management
Culture and power: public bureaucracy.

Process / KAs - OM3
T1: contextualize the citiy: KBUD analyst (KA1).
T2: collect city data and indicators: data analyst (KA2).
T3: organize city information: data analyst (KA3).
T4: make KBUD analysis: KBUD analyst (KA4).
T5: communicate results: KBUD analyst (KA5).

Know. Assets – OM4
KA1: city KBUD: F-P-T-Q: 4N tacit knowledge
KA2: data mgt: F-P-T-Q: 4 Y/N data quality dependent
KA3: KBUD data structure: F-P-T-Q: 2N+2Y/N; city system dependent
KA4: KBUD city mgt.: 4N; tacit
KA5: KBUD communication: 4N; tacit

Feasib anal. – OM5
Business feasibility: applicable in other cities with urban an governance plan.
Technical feasibility: confirmed in system operation, availabilty, lacking autom. data collection.
Project viability: city process, infrastructure and system.
Proposal: DSS instead of KS

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The most important result in the last CommonKADS analysis was the proposal. Although both kind of systems, knowledge-based and information, are sociotechnical instruments, while the first has domain knowledge embedded, the second offers an organized and structured flow from data to information, leaving the inference process to the user. In the case of KBUD system project, CommonKADS first steps have demonstrated that most of city analysis knowledge is tacit and intrinsically expert-dependent. On the other hand, the organization modeling activity has also confirmed previous literature assumptions about the suitability of an information system to support city manager.

Given the proposal of a KBUD-DSS rather than a knowledge system, the next CommonKADS modeling tasks became no longer needed. Tasks, agents, knowledge, and communication requirements became factors to be analyzed in the next project step.
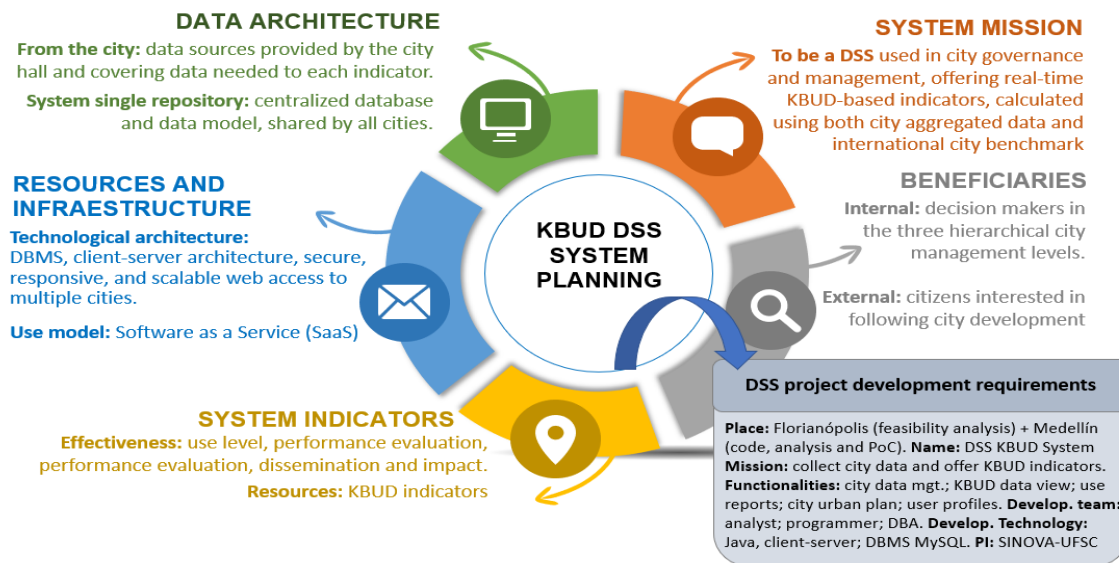
2.2.   DECISION SUPPORT SYSTEM

As illustrated previously in Figure 1, once the application of CommonKADS methodology has indicated a KBUD-DSS to support city governance, the project proceeded

with DSR Design & Development, Assessment and Communication phases, following information system planning guidelines (Amaral & Varajão, 2000).

The first DSS project phase was to define the system project and planning. Although some system planning factors were already revealed in CommonKADS organization model, they were now revisited according to a DSS system approach.

In Figure 5 we have shown the steps and results from DSS system planning. The first landmark is the system mission (i.e., to be a DSS used to support city governance by offering KBUD indicators based on online city data and international benchmarks). It was also indicated both internal and external system beneficiaries, including city hall managers and citizens, respectively. To verify how well the KBUD-DSS accomplish its mission and reach all beneficiaries, it was defined a set of performance indicators, regarding use, performance, and impact.

Figure 3 – Information system project and planning results.

DATA ARCHITECTURE
From the city: data sources provided by the city hall and covering data needed to each indicator.
System single repository: centralized database and data model, shared by all cities.

SYSTEM MISSION
To be a DSS used in city governance and management, offering real-time KBUD-based indicators, calculated using both city aggregated data and international city benchmark

RESOURCES AND INFRAESTRUCTURE
Technological architecture: DBMS, client-server architecture, secure, responsive, and scalable web access to multiple cities.
Use model: Software as a Service (SaaS)

BENEFICIARIES
Internal: decision makers in the three hierarchical city management levels.
External: citizens interested in following city development

KBUD DSS SYSTEM PLANNING

SYSTEM INDICATORS
Effectiveness: use level, performance evaluation, performance evaluation, dissemination and impact.
Resources: KBUD indicators

DSS project development requirements
Place: Florianópolis (feasibility analysis) + Medellín (code, analysis and PoC). Name: DSS KBUD System Mission: collect city data and offer KBUD indicators. Functionalities: city data mgt.; KBUD data view; use reports; city urban plan; user profiles. Develop. team: analyst; programmer; DBA. Develop. Technology: Java, client-server; DBMS MySQL. PI: SINOVA-UFSC

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Regarding DSS technological architecture, the planning activity defined parameters to resources, infrastructure, and data management. In this phase, all technical details regarding database, scalable web access, and service modeling (i.e., SaaS) were detailed.

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This has also included the city and KBUD data model and sources, and the single data repository to be shared by different cities (to facilitate benchmark analysis).
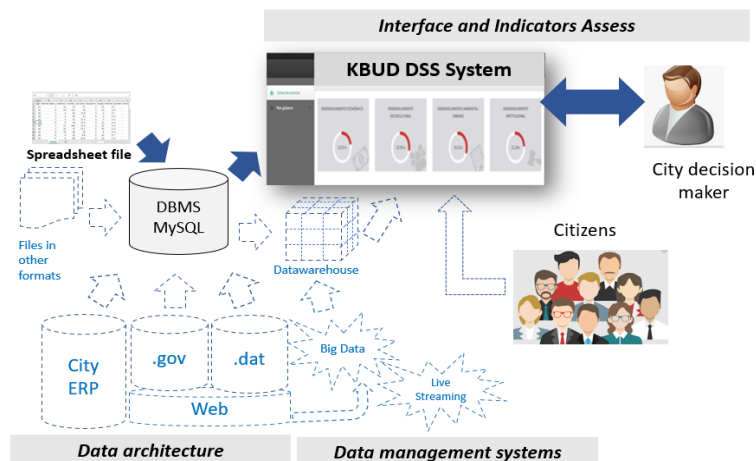
The KBUD-DSS planning has also concluded the DSR Design activity. As indicated previously in Figure 3, next DSR step is the artifact development. As it can be seen in the frame at Figure 4, the KBUD-DSS development inputs created in the planning phase were based on presentation sections with city managers from Florianópolis city (as described in CommonKADS activity - Worksheet OM-1, first part in Figure 4). These requirements were revaluated in Medellín, first to the write the project funding proposal and afterwards to KBUD-DSS development. The other system planning outputs were about functionalities, technical team, technology, and intellectual property requirements to KBUD-DSS project.

3.   KBUD-DSS CONCEPTUAL ARCHITECTURE

In this section we present the architecture, modules, requirements, and features of the KBUD-DSS developed.

A conceptual information system architecture is a frame of reference (Ahlemann, 2009) for system modelling and development. The KBUDD DSS conceptual architecture is presented in Figure 6.

Figure 6 – KBUD-DSS system conceptual architectural (Source: Carneiro, 2020)

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At bottom of Figure 6 there are the data architecture and data management systems expected designed to collect, transform and storage analytical data. The sources include city hall, other governmental databases, and worldwide web. The first set of data is generally available in ERP systems, covering all socioeconomic city data. Also, other national or state agencies can own city data (.gov) accessible by interoperability of integration information services. Finally, city data can also be available in information services offered by research organizations (.dat) or accessible on the internet.

All these data can be accessed by systems such as data crawlers or automatic (robot) search systems and treated by bigdata features to make data compatible, integrated and suitable to allow city comparison or benchmarks.

At the upper left side of Figure 6, it is represented the data flow coming from files (spreadsheet and other formats). City data coming from all sources go to a main relational database (DBMS). From this relational repository, city data are managed to be imported into a datawarehouse, from where KBUD indicators are calculated (by means of a Java code program), and presented in KBUD-DSS interface, to be accessed by city decisionmaker or by citizens (upper right side in Figure 6).

3.1.   KBUD-DSS FEATURES

All KBUD-DSS features are accessible by a main control panel, where the information services are available, including the access to each KBUD dimension indicator and (Figure 8).

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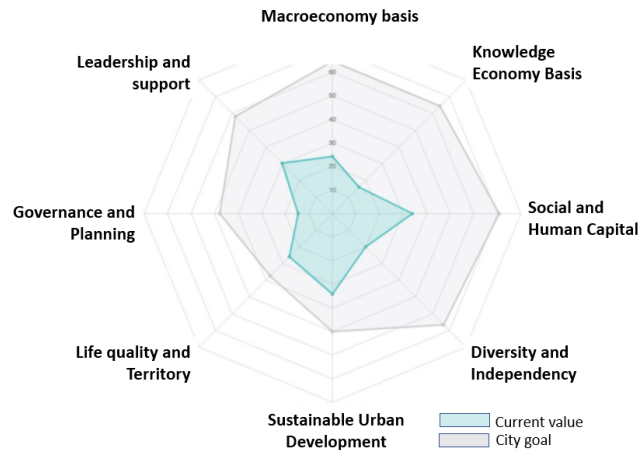Figure 8 – KBUD-DSS Control Panel

Font: Carneiro, 2020

Each graph in the center of Control Panel presents a dashboard, a synthesis of the city situation on that correspondent KBUD dimension. At the left side the panel offers other services designed to KBUD-DSS, including city master plan (to check for particular urban plan goals of the city), citizen participation (to check for society use of the system), and city reports (to access previous textual reports about the city).

When the user chooses one of the KBUD graphs, the system opens another screen with city indicators in the correspondent dimension (Figure 9). For each KBUD indicator the system presents the city current value and the goals to be achieved, according to city master plan. If the use clicks on Economic Development, the indicators are Macroeconomic basis, Leadership and support, Governance and planning, Life quality and territory, Sustainable Urban Development, Diversity and independency, Social and Human Capital, and Knowledge Economy Basis.

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Figure 4 – KBUD-DSS City indicators

Font: Carneiro (2020)

4.   CASE APPLICATION

Following the DSR methodology, the Demonstration and Evaluation phases were developed in Sabaneta, a city in Medellín region, in Colombia. In this section we present the steps and results of the KBUD-DSS Sabaneta application.

According to national Colombian policy, Sabaneta has a municipal urban plan, a starting point to each government period. The city master plan is called "Plan de Desarrollo Municipal" (PDM-2016-2019 – "Sabaneta for all"), a plan developed by the planning city unit and signed by the mayor. It is also a state instrument to continuing city evolution, even when facing political changes in city elections.

Sabaneta PDM makes explicit the city commitments with transparency, effective management, quality life improvement, sustainability, and territory occupation protecting natural resources. It is also concerned with social factors such as gender equality, poverty reduction, security, and community services. Sabaneta PDM was also based on surveys to have opinions from urban residents, constructors, traders, politicians, religion leaders, among other public opinion leaders.

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Once national standard, city commitments and citizens visions were established, Sabaneta city hall developed a program based on five dimensions. As presented in Table 2, the dimensions goals led to 26 programs – with their correspondent KBUD dimensions – and one hundred subprograms, with specific goals and indicators to measure city performance.

Table 2 – Sabaneta PDM, City Programs 2016-2019 and correspondent KBUD dimensions.

Dimension	Emphasis	Goals	City Programs		KBUD	
Living conditions	Education	Quality education: combine education and innovation ensuring quality and promoting pedagogical excellence.	1. 2. 3. 4. 5. 6.	Education for all Health for all Nutrition for sports and recreation for all Decent housing for all Public services for all Drinking water and sanitation for all	1. 2. 3. 4. 5. 6.	SD SD SD UED UED UED
Standard of living	Job	Promotion of science, technology and innovation, encouraging entrepreneurship, generating job opportunities, taking advantage of tourism potential and working articulately university, company and state.	1. 2. 3. 4. 5. 6.	SCT for all Job for everyone Entrepreneurship for all Agricultural development for all Competitiveness and development for all Tourism for all	1. 2. 3. 4. 5. 6.	ED ED ED ED ED ED
Way of life	Public space	Effective urban development control, with mechanisms to environment protection, use of public space by all citizens, and infrastructure and facilities to ensure access and mobility in all city territory.	1. 2. 3. 4. 5.	Public space and equipment for all Environmental Urban development for all Infrastructure for all Transport and mobility for all	1. 2. 3. 4. 5.	UED UED UED UED UED
Life relationships	Understanding	Embrace understanding of citizenship needs, with local planning systems, effective and reliable public management, and coexistence and active participation values for all citizens.	1. 2. 3. 4. 5.	Coexistence for all Culture for all Citizen participation of all Institutional strengthening and governance for all Municipal tax and finances for all	1. 2. 3. 4. 5.	SD SD ID ID ID
Life protection	Justice, equity and peace	Equality for all groups of the population, with strategies for security and justice, contributing to peace.	1. 2. 3. 4.	Justice and security for all Heritage for all population groups Life-long equity for all Peace and post-agreements	1. 2. 3. 4.	UED UED UED UED

KBUD Dimensions: **SD** – Social Development; **UED** – Urban and Environmental Development; **ED** – Economic Development; **ID** – Institutional Development. Source: adapted from Carneiro, 2020.
Font: Carneiro (2020)

The KBUD-DSS configuration is a step intrinsically dependent on city masterplan dimensions and goals. The city masterplan indicators must be mapped into KBUD indicators, as in the last column of Table 2. Each city masterplan program (and subprogram) has a set of indicators. KBUD-DSS combines this indicator set with the original masterplan city, allowing decisionmakers not only follow city evolution, but compare it with other cities, in all KBUD dimensions.

5.   CONCLUSIONS

The combination between scientific research and technological innovation has been a challenge to university-industry relationship. From academic perspective, there is a risk

of reducing complexity and lowering R&D educational quality, while industry fears raising time and costs in innovation process.

In this article we described a case where research and innovation were combined and aligned since the PhD research question to the creation and support of a startup. To Heuristics startup, innovation was not only an organization process, but its own driving force mechanism. On the academic side, the fear for lower quality has showed the opposite: by fixing a research question connected to technological achievements, the PhD has brought competences not only to make or lead research, but also to look for impact and fostering entrepreneurship.

In this process of combining research and innovation during a PhD project, multidisciplinarity, teamwork and hybrid methodologies have shown to be decisive factors. By establishing an aligned view from research question to innovation, the KBUD-DSS project has illustrated that PhD programs have the potential not only to deliver scientific research and PhD human capital, but also connect these outcomes to startup creation and innovation fostering.

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