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Assessing the Innovation Environment of the Research Triangle Region

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RESUMO

The paper studies the Research Triangle Region (RTR), an economic development area in the state of North Carolina, USA. RTR comprises two major technological parks: the Research Triangle Park and the Centennial Campus of North Carolina State University. We applied Amaral's Model for Innovation Environment Management (AMIEM) to the RTR parks and discuss regional development aspects under the prism of innovation management. The research method is descriptive and exploratory. The field research, conducted from 2016 to 2018, involved a literature review, collection of documents, and non-structured interviews. AMIEM is a quantitative-qualitative model with eleven factors to measure the maturity level of the Triple Helix linkages from academia (knowledge producers), the productive sector of goods and services (knowledge producers and users) and government (social and economic regulator). The RTR parks have a high level of maturity. Several successful and overlapping initiatives were found there in the past sixty years which explain the regional development. However, improvements can be made and the new initiatives point in that directions. AMIEM's application is complex due to the number of actors, documents, and initiatives. It is a management tool that recommends actions to improve the effectiveness of innovation environments.

Palavras-Chave: Regional economic development; Research Triangle Region; AMIEM; Triple Helix; Quintuple Helix; RTP; Centennial Campus; Innovation environment.

Avaliando o Ambiente de Inovação da Região do Triângulo da Pesquisa

ABSTRACT

O artigo estuda a Região do Triângulo da Pesquisa (RTR), uma área de desenvolvimento econômico no estado da Carolina do Norte, EUA. O RTR compreende dois parques tecnológicos principais: o Research Triangle Park e o Centennial Campus da Universidade Estadual da Carolina do Norte. Foi aplicado o Modelo Amaral para Gestão de Ambientes de Inovação (AMIEM) aos parques da RTR e foram discutidos aspectos do desenvolvimento regional sob o prisma da gestão da inovação. O método de pesquisa é descritivo e exploratório. A pesquisa de campo, realizada durante entre 2016 e 2018, envolveu revisão de literatura, coleta de documentos e entrevistas semiestruturadas. O AMIEM é um modelo quali-quanti com onze fatores para medir o nível de maturidade das relações do tipo Triple Helix entre atores da academia (produtores de conhecimento), do setor produtivo de bens e serviços (produtores e usuários de conhecimento) e do governo (regulador social e econômico). Os parques da RTR possuem um alto nível de maturidade. Várias iniciativas bem-sucedidas e sobrepostas foram encontradas nos últimos sessenta anos, explicando o desenvolvimento regional. Entretanto, avanços podem ser realizados e as novas iniciativas apontam nessa direção. A aplicação do AMIEM é complexa devido ao número de atores, documentos e iniciativas. Trata-se de uma ferramenta de gestão que recomenda ações para melhorar a eficácia dos ambientes de inovação.

Keywords: Desenvolvimento econômico regional; Região do Triângulo de Pesquisa; AMIEM; Hélice Tripla; Quintuple Helix; RTP; Campus do Centenário; Ambiente de inovação.

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1 Introduction

An innovation environment (IE) is a physical space where a set of relationships between knowledge producers and users (academia-industry or industry-industry) results in the development of new goods, processes, services or business, and has an economic impact. According to Amaral (2015), this definition encompasses business incubators, technological parks, university research parks, technopolises, technology transfer offices, regional economic development initiatives, among other undertakings classified by Etzkowitz (2008) as intermediate organizations or positioned in the hybrid and consensus space, i.e., in the confluence of the Triple Helix (3H) spheres (Etzkowitz and Leydesdorff, 2000).

Amaral's Model for Innovation Environment Management (AMIEM) was developed as a tool to assess business incubators and technology parks. It is a practical tool derived from the 3H approach. The idea behind this quantitative-qualitative tool is to measure the level of maturity of the actors from academia (knowledge producers), the productive sector of goods and services (knowledge producers and users) and government (social and economic regulator). Maturity in this context means not only the presence of actors but the linkages built and the quality of these ties, which can be measured by the results obtained (Amaral, 2015; Leydesdorff, 2008).

Two foci support this study, AMIEM (tool) and the Research Triangle Region (RTR) (subject), a region in the North Carolina state, USA, comprising the cities of Durham, Chapel Hill, and Raleigh, where over the sixty years a successful IE has been developed (RTFNC, 2011). The main objective of this paper is to "apply AMIEM in the RTR and discuss aspects of regional development from the perspective of innovation management." There are also specific objectives derived from the main one: "to verify if the tool is adequate to evaluate a complex IE; and, to verify that the tool covers the Quadruple and Quintuple Helix (4H / 5H) aspects". Conducting the general research question: "what findings can the tool provide on the subject?".

These objectives are a result of gaps identified in the literature. First, there are few articles about the IE assessment. In the private business sector, there is a spreading culture of evaluation, which is not the same in public organizations or IEs. The second gap is the number of studies available about RTR. The region is part of a triad of successful world-class regional economic development experiences in the USA based on technology and innovation (with Silicon Valley and Route 66). Despite dozens of studies investigating the success and looking for a pattern in the experiences in California and Massachusetts (Etzkowitz, 2002, 2013; Henton and Held, 2013; Lee, 2000; Saxenian, 1994), few studies have focused on North Carolina's realizations (Link, 1995, 2002; Link and Scott, 2003; Meszaros, 2004; Rohe, 2011). The last gap is the adequacy and evolution of the assessment tool. AMIEM has been applied and improved over the years to map/understand/assess university-industry-government linkages (Amaral, 2015). However, the model originally did not include the actors from new spheres of the Quadruple Helix (4H) and 5H approaches. The challenge is to verify the adequacy of the eleven factors to these new approaches (Carayannis *et al.*, 2014, 2012; Carayannis and Campbell, 2010).

We assume that AMIEM is a 5H tool applicable to the RTR and allows a useful analysis of the IE. The case study was the method chosen, based on the literature review and

field immersion in the environments. This document has five parts: introduction, literature review, research procedures, case study, and discussion.

2. Conceptual foundations of IE

Knowledge is generated through creativity, combinations, and production processes in so-called knowledge/innovation models and thus becomes available to society. The modes of knowledge production have evolved over the years. Mode 1 of knowledge production focuses on the traditional role of the research university as part of a "linear innovation model" (Gibbons *et al*., 1994; Bush, 1945). As an evolution, Mode 2 emphasizes knowledge application and knowledge-based problem solving (Carayannis *et al.*, 2016). It is a nonlinear model of innovation.

The 3H thesis emerged as a confluence from Henry Etzkowitz's interest in the study of university-industry relations and Loet Leydesdorff's research in an evolutionary model to generate a next-order hyper-cycle or an overlay of communications (Leydesdorff, 2013). Proposed in 1994, the 3H metaphor of university-industry-government linkages asserts a basic core model for knowledge production and innovation. The three blades intertwine creating an innovation system (statist, laissez-faire, or hybrid and consensus space) (Carayannis and Campbell, 2014:12; Etzkowitz and Leydesdorff, 2000). It differs from previous approaches by giving the university the same relevance as the other spheres. More than that, in a knowledge-based society, the university leads the process of knowledge generation, essential for the development of new, multidisciplinary, and complex products/services (Leydesdorff, 2013).

The Etzkowitz-Leydesdorff approach is a network or trilateral system (economy, science, and politics) and hybrid organizations coordinating the creation and exchange of knowledge between these systems (Carayannis *et al.,* 2012). Through several interactions between the actors, four kinds of activities occur (Etzkowitz, 2008):

- Many internal transformations in every sphere.
- The influence of organizations from one helix in organizations from other spheres.
- The creation of new structures due to the resulting overlap.
- A recurring effect between the three propellers.

In the last decade, Mode 3 of knowledge creation was proposed, with emphasis on the coexistence/coevolution of different knowledge/innovation modes. The hypothesis is the competitiveness and superiority of a knowledge system that is determined by its adaptive capacity to combine/integrate different knowledge and innovation modes (coevolution, co-specialization, and co-opetition knowledge stock and flow dynamics) (Carayannis *et al.*, 2016).

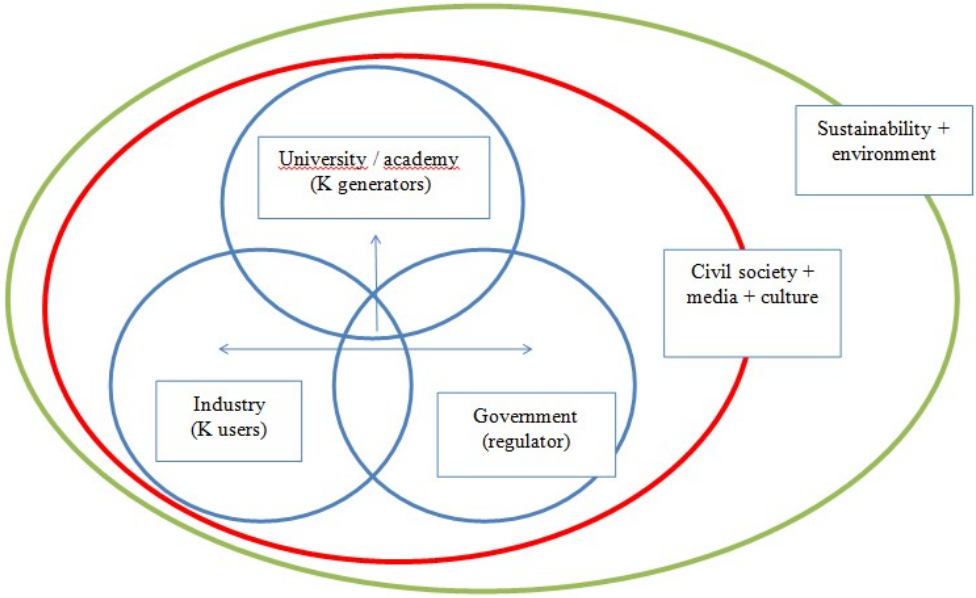
In this way, Carayannis and Campbell (2014) proposed the 4H approach, adding the "public" as the new helix. They defined this sphere like the influence of the media and culture in the so-called community or civil society. The 4H concept is not yet well established and widely used in innovation research. This new sphere associates media, creative industries, values, lifestyle, culture and art, and the notion of the creative class, in sum, many aspects of contemporary society. It is the perspective of the dimension/context of democracy for the production of knowledge/innovation. The 3H can exist without democracy (as in the statist configuration); while there cannot be a 4H innovation system without that context.

The 5H approach adds as the new helix/sphere the "natural environment." It is a transdisciplinary/interdisciplinary framework of analysis for sustainable development and

social ecology. It is a model in theory and practice to understand the link between knowledge/innovation to promote sustainable development. It combines knowledge, experience/know-how, and nature/environment systems (Carayannis *et al.*, 2012).

The basis of the 3H metaphor to understand innovation focuses on the knowledge economy. The 4H innovation model proposes coevolution of the economy and the knowledge society. The 5H emphasizes the socio-ecological perspective of the natural environments of society. It presents the mutual interaction and exchange of knowledge in a nation-state through five subsystems or propellers (or spheres or helix), as shown in Figure 1 (Carayannis and Campbell, 2010).

Figure 1: Visual conception of innovation models' evolution



Source: Developed based on Carayannis and Campbell (2014).

2.1. The IE concept

The IE can be defined as the "place" or "space" where technology transfer happens. It can be a business incubator (Amaral, 2015; ANPROTEC, 2012), a research park and its spinoffs (Lubik *et al.*, 2013; Luger and Goldstein, 1991), a technopolis (Longhi, 1999; Mello and Rocha, 2004), a science and technological park (Cabral and Dahab, 1998; Collarino and Torkomian, 2015; Martinez-Cañas and Ruiz-Palomina, 2011; Schmidt and Balestrin, 2015; Vedovello, 1997), a regional economic development project (Etzkowitz, 2002; Jacoski *et al.*, 2015) or an innovation network (Agostini and Caviggioli, 2015; Mineiro *et al.*, 2016), among other institutional arrangements (Leunga and Wub, 1995; Svobodova and Coupek, 2013; Varisa and Littunena, 2012). What defines the kind of environment for innovation is the presence of players that create and use knowledge. Due to this, an IE is a "place" where a bilateral university-industry (or industry-industry) relationship occurs, or a multilateral 3H of university-industry-government linkages reaches its hybrid and consensus space. This consensus space allows knowledge flow and promotes innovation and economic development

(Amaral, 2015; Etzkowitz, 2008; Etzkowitz and Leydersdorf, 2000). An IE can also be understood as a "space" where the boundaries of different players are not clearly defined, and a "pollination" process happens. This exchange of information flows enhances learning and accumulation capabilities. New stock of knowledge is created and allows firms to produce goods, enhance processes, offer services, and reconfigure business models and industries. This information and knowledge flow are the essential idea of technology transfer (Bradley *et al*., 2013).

Within the literature, there are a number concepts similar to IE, such as areas of innovation (Nikina and Piqué, 2016), innovation habitat(s) (Figlioli and Porto, 2012; Henton and Held, 2013), habitats for innovation (Lee, 2000), innovative millieux (innovative agglomeration) (Hernández, 2015) or innovation districts (Katz and Wagner, 2014). The concepts of innovation ecosystem (Ikenami *et al.*, 2016) and innovation system in their national, regional or local approaches (Freeman, 1995; Mineiro *et al.*, 2016; Wanga e*t al.*, 2015) are broader and involve more players and layers. Some of these concepts can overlap. A set of 4H relations in a technological park can be simultaneously a regional economic development project, an IE, and a part or the whole of a regional innovation system. The IE concept should not be mistaken with agglomeration concepts, as industrial clusters, districts, or agglomerations (Becattini 2002, Porter, 1998), or local productive arrangements (Lastres and Cassiolato, 2005). Within these concepts, there are knowledge flows, but the focus is on the dissemination of existing knowledge, not the creation of new knowledge.

2.2. The IE assessment

In the innovation literature, it is possible to find some models/tools for IE assessment, briefly described here:

- Cabral-Dahab model: Ten recommendations for access to qualified research and development (R&D) personnel for management vision, planning, and skills, passing through market access, services to companies, and patents. (Cabral and Dahab, 1998).
- Estrategigram: Proposed to formulate park strategies. It has seven axes (location, technology source, place/attraction, kind of business, market focus, networking, and governance). Each one is scored from 10 (positive) to −10 (negative), composing an index and a route to managers` action for improvements (Sanz, 2006, cited in Amaral, 2015).
- CERNE: A set of best practices with 62 processes, organized in a three-level system (venture support, operational processes, and incubator management) and four levels of maturity. It is implemented in 123 incubators in Brazil as a certification tool (ANPROTEC, 2012).

In this context, AMIEM is an answer to fill the assessment gap in the literature and management practice. The original version was developed in 2008 after twelve case studies in Brazil, Uruguay, Italy, and France (Da Poian, 2008, cited in Amaral, 2015). The current tool has a set of eleven factors according Table 1.

Table 1: AMIEM's eleven factors

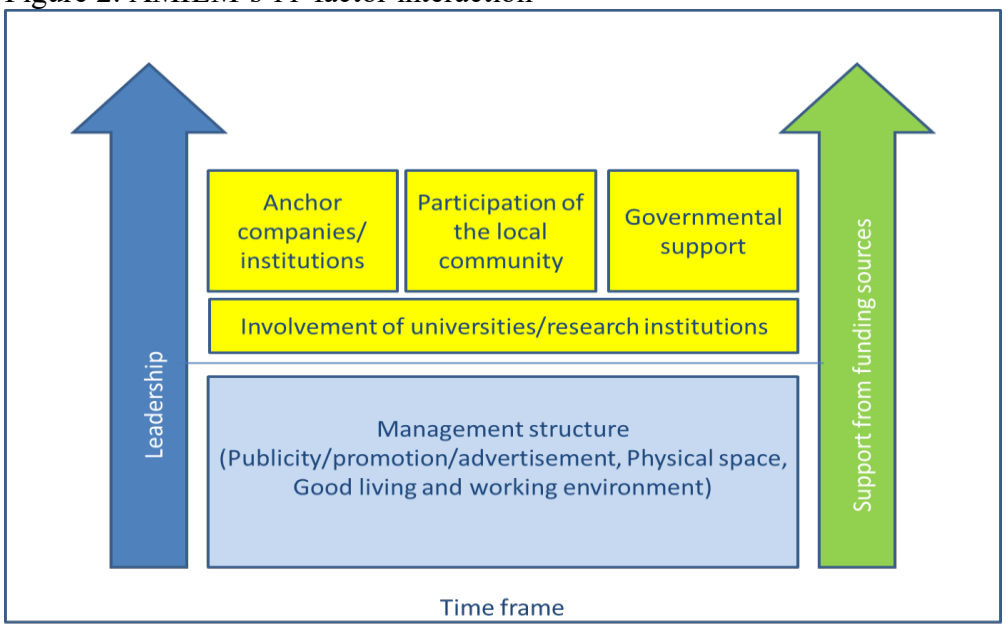
Factors	Definition
Time frame	Innovation environments need to go through a maturity process, in order to make their infrastructure and financial supporting mechanisms more organized, to have their specific regulations approved, and to help society understand their idea. Before a period of 5-8 years, it is hard to conclude that an initiative is unsuccessful. However, if the success indicators (developed technologies and graduated companies) do not begin to emerge after 10-12 years, the project falls into discredit.
Governmental support	It is crucial to provide infrastructure, funding, and tax breaks or incentives to make successful entrepreneurship possible. The presence of local governments reveals the perception that an innovative entrepreneurship will help boost the local or regional economy.
Participation of the local community	The mobilization of entrepreneurs and representative entities, as well as the mobilization of media, is important to consolidate BIs/STIPs, even if the main anchors come from outside of the region.
Involvement of universities and research centers	The presence of universities and R&D institutions is fundamental to help companies find technical support for new entrepreneurship. The management staff must encourage these institutions to improve their participation in the business scenario, through collaborative projects, provision of technical services (lab testing and prototype development), and patenting/licensing, among others.
Support from funding and promotional agencies	This is essential for infrastructure projects and to enhance the surroundings, as well as for the execution of feasibility studies and promotion/publicity activities. The creation of a public and/or private venture funding for entrepreneurs and infrastructure implementation is important. In some cases, BIs/STIPs have to set up investment funds, for the promotion of R&D activities and/or the capitalization of new ventures. Several support actions from the Brazilian Innovation Agency (FINEP), CNPq, and SEBRAE stand out.
Presence of leading companies and institutions	The attraction of relevant companies, as well as academic institutions, is fundamental to influence other companies' decisions. Governments can do this by transferring public facilities to the STIP and encouraging public sector companies to do the same.
Physical space and location	This includes urbanization, availability of transportation and communication infrastructure, landscaping to create pleasant environments, and construction of buildings with suitable premises at low costs for smaller companies, among others. Some projects are contained in single facilities while others are geographically distributed.
Governance and operational management	BIs/STIPs need a competitive, dynamic, creative, and affordable management structure, to attract companies and offer their services. In general, the management structure is small, with few experienced staff taking care of publicity, attraction of business, management, service provision, and sales promotion (including opening external markets). Moreover, the creation of cooperative networks among companies in terms of the use of services and equipment, and to publicize the scientific-technological knowledge, is important.
Leadership	It is necessary to have distinguished, devoted, active, persistent, and skillful leadership units, able to overcome barriers. The figure of an organizational leader is important: the person with the original dream/idea who fought to convince UIG actors and society about a particular BI/STIP. These people stand apart from the local leaders of BI/STIP staffs.
Publicity/ promotion/ advertisement	This is useful to attract companies, obtain financial and political support, and maintain a high level of satisfaction among entrepreneurs. Successful entrepreneurship settings are related to wide promotion/publicity, through courses, seminars, congresses and visits, among others.
Life quality and work environment	The concentration of activities with a high technological creation content needs a high level of engagement, for which it is fundamental to offer a pleasant working environment. The attention to architectural design has been fundamental in the successful development of BIs/STIPs. The same applies to the quality of life of executives/employees and their families. In these respects, the involvement of the government is important to deal with themes as mobility, communication, education, health assistance, leisure, and cultural activities.

Source: Amaral (2015)

Each factor receives a weight to rank its relevance in the IE's strategy (from 1-less relevant to 3-more relevant) and a grade to measure the level of evolution/development/maturity (from 1-low to 4-high). The result is a score which represents the total maturity of university-industry-government linkages. An environment with less than 50 points has a low-level maturity. From 50 to 75 the IE has a medium-level maturity. Only over 75 points can the IE be considered mature (Amaral, 2015).

The eleven factors have an internal dynamic, as seen in Figure 2. Leadership and funding are catalysts of the whole process. The nine other elements are organized into two levels: "structure" and "content." In the "structure" level, four elements (governance and operational management, publicity/promotion/advertisement, physical space, good living and working environment) compose the management structure and infrastructure aspects. Corporate culture and values can be included there. These aspects can be synthesized by the trends of sustainability (economic/financial and environmental) and corporate responsibility. The set of four elements, named "content", are related to the attraction and actors' interaction. They introduce and validate the knowledge creation, use, and needs of the process (the environment has to stay connected to the local requirements to be a regional economic development project). The presence of the triad academia-industry-government composes the 3H, the core driver of knowledge creation and use. With the addition of local community/society, the 4H linkages emerge. That means the project is anchored/connected to the local reality and needs. The second level of stakeholders was included in the IE perspective. When structure and content levels work together, the IE achieves 5H status. Differences between 3H and 4H/5H relate directly to the number of actors or aspects, but a conceptual difference from Mode 2 to Mode 3 and how players interact in the knowledge production process also exists. In this sense, AMIEM as a tool inspired by 3H linkages has limitations. In the 5H perspective, it is an updated framework to analyze real interactions in IEs.

Figure 2: AMIEM's 11-factor interaction



Source: Developed by the authors.

3. Research Procedures

This work is a descriptive applied study, in the sense of case-study storytelling, and exploratory, proposing a way to improve the comprehension of a region by studying the IE with a specific lens (AMIEM). Three phases were executed.

First, a search in the literature about IE management (and related themes) was performed in academic databases (Web of Science, Scielo, and Spell) and social networks (Research Gate and Academia.edu) in March 2016. The selected literature, which supports the review, was also found in a database with more than 2,200 documents from the Triple Helix Research Group Brazil. This step also involved a search for documents related to the RTR and its actors. This activity had support from the North Carolina State University (NCSU) library, scholars of the NC university system, and managers of the Research Triangle Foundation of North Carolina (RTFNC). Initially, on the topic "research triangle park", 349 articles were found, most dealing with technical issues, especially healthcare. We arbitrarily chose management segments, finding 21 papers.

Based on initial contacts with RTFNC and NCSU staffs, a series of recommended readings and relevant information about the region and experiences were found. In particular, the books written by Albert Link and William Rohe, and reports/studies from NCSU. These works "attracted" other references. Finally, the terms "research triangle park", "research triangle region", "centennial campus", "RTP", "RTI international", "TUCASI" were used for Google Scholar search and many new results were obtained. A database in MS Excel was built to deal with more than 300 items, including reports, academic papers, regional planning studies, and books. They were the basis to write case studies.

The second phase was the application of AMIEM in the RTR. Due to the complexity of the environment and the diversity of initiatives, as well as the low level of responsiveness in surveys, we decided to focus on two fundamental experiences: the Research Triangle Park (RTP) and the Centennial Campus initiatives. The diverse initiatives overlap like layers, creating a picture of success. Probably the main challenge for a project like this is to identify the initiatives and their boundaries and/or effects. The next is to connect these layers. We approached every initiative as an independent IE, each with its university-industry-government linkages, described in 11 factors, in different degrees. However, their impact in the region is interconnected.

AMIEM application involves a two-step method. First, it allows a qualitative description of the undertaking, chronologically, organized in the eleven factors and presented in a summarized table. The second step is the quantitative approach, where grades and weights are given, composing a score that represents the maturity level. We performed this part arbitrarily, so it reflects our opinion.

Lastly, in the third phase, these assessments (eleven descriptive factors, weights, and grades) were discussed with IE stakeholders through interviews, conducted during 2016 and 2017. An investigation at that level requires immersion in the region. The interviewed people were chosen more by their accessibility (and willingness to answer) and personal connections than through a structured method. From thirty-five key people contacted, we interviewed twelve with a semi-structured set of questions. Discourse content techniques were utilized, and the cases' description and assessment were reviewed and expanded.

Every research method has its limitations. In this case, it is possible to point to the complexity of the RTR, where the same actor has a role in different initiatives, and our biases and those of respondents, most of them involved directly with the study object. The way to

soften these obstacles was to expand the sample of individuals interviewed, looking for more critical opinions, beyond the "official" history. The RTR is a kaleidoscope of initiatives or, based on the concepts presented, a vast IE or an innovation ecosystem composed of many IEs or initiatives, each one with specific university-industry-government-society linkages.

4. The RTR

This part is organized into two topics to present some experiences over the past seventy years in the region. This division is arbitrary, and the experiences presented cover the most relevant initiatives but not all of them.

In the 1950s, North Carolina was a low-wage low-tech state, with an economy anchored by tobacco, furniture, and textiles. It was ranked near the bottom nationally in most important social and economic indicators. Some entrepreneurial individuals started to discuss how to develop the state, and the idea of a research park emerged in 1955, inspired by the Stanford University experience. A Research Triangle Committee, formed by Governor Luther Hodges, suggested a private real estate development as a strategy to attract companies to the area. The idea was to connect the expertise of the three major universities and attract investments (Tornatzky and Rideout, 2014; Link, 1995, 2002; Rohe, 2011).

After sixty-five years of initiatives, the RTR is today one of the most dynamic regions of the USA. Three world-class universities and more than 300 companies and organizations have settled in the area. Currently, more than 45,000 employees are engaged in R&D activities in biotech and life sciences (45%), information technology (20%), environmental science (clean/green tech), and financial activities, among others. Transnational corporations are installed there, like Dell, Microsoft, Google, Cisco, IBM, Basf, Biogen, Credit Suisse, Fidelity, GSK, Lenovo, NetApp, Bayer, EMC, Toshiba, and a large number of ventures were created in five incubators and accelerators (RTFNC, 2015). Some of the native-born startups, today big players, are SAS, Lulu, Citrix, and Red Hat. Technologies and products used in the whole world were created there, like AZT, 3D ultrasound, the bar code pattern, Red Hat Linux, and SAS analytics software.

4.1. The RTFNC's initiatives

In 1958, Archie Davis (an executive from Wachovia) joined the project and changed its bearings, bringing the local civil society to be part of the future park. Davis raised US$ 1.2 million in donations and transferred the land to a nonprofit organization, the RTFNC. Following Davis' vision and strategy, the formal creation of the foundation, in 1959, was the materialization of a dream (Link, 1995). Currently, the foundation manages the park, in a development of 7,000 acres, and over time has promoted several initiatives, such as RTI International (former Research Triangle Innovation), Triangle Universities Center for Advanced Studies (TUCASI), The Frontier, and The Park Center (Rohe, 2011; RTFNC, 2015).

The attraction of companies was slow and only in 1965 did RTP take off with a facility of the Department of Health, Education and Welfare and a research center of IBM. In the beginning, the idea was to attract "R&D-oriented organizations, not involved in mass production on-site, but able to do product development and prototype manufacturing." Companies bought land and built their facilities according to some architecture rules to keep the landscape cohesive (Tornatzky and Rideout, 2014).

From the fifties until the eighties, the RTP was a typical first-generation technological park, an R&D facility in a closed innovation paradigm pushing science to business (Martinez-Cañas and Ruíz-Palomino, 2011). Every tenant company could buy the land, build, and work in its private space. Staying in the region brings several advantages, from advantages to accessing trained people and facilities like university researchers and laboratories.

In the seventies, the RTFNC also led important initiatives as RTI International and TUCASI, presented in the table 2.

In the eighties and nineties, the model evolved to a second generation (of parks) where the tenants led the process and oriented the R&D in their economic interests (demand pull stage) (Luger and Goldstein, 1991; Martinez-Cañas and Ruíz-Palomino, 2011). In the past ten years, the emergence of 3H, open innovation paradigm, and the development of ICT technologies has taken the RTP to a new stage, where the innovation process requires new interaction strategies and networks are more critical than internal capacities/competencies/infrastructure. Many companies now produce and offer/manage services in the RTR, not only perform R&D. To deal with these transformations, RTFNC has launched new initiatives, as The Frontier and The Park Center (RTFNC, 2016).

Opened in January 2015, The Frontier was the first effort to improve the density and create a more collaborative environment, which is essential to more collaborative technology development. The RTFNC defines it as an open collaboration space to be used by anyone in the community to work, hold meetings, or host events. It is a building where on the ground floor, a working space is available to everyone and, on the other four floors, several small companies are established. It also serves as a venue for events, courses/seminars, and has a program of activities to attract businesspeople and researchers. In August 2016, after 18 months of operation and 100,000 users, the RTFNC announced an expansion to adjacent buildings (RTFP, 2016).

The Frontier was an action included in The Park Center project, the redevelopment plan of the RTP, according to a new master plan from 2011. The RTFNC re-imagines what RTP can be, always emphasizing the core mission to enrich education, create jobs, and lift the people of NC. The Park Center project plans to build an innovation district (Katz and Wagner, 2014) in a 100-acre space with a high density of individuals and various activities, from tenants to art galleries and parks, from coffee shops and restaurants to homes. The idea is entirely different from the previous RTFNC actions. In the past, the big companies looked for private spaces to develop their in-house R&D and develop products pushed by science. Today, small and big companies are looking for interaction with other businesses and consumers to create new technologies and services (user-oriented) as a result of a complex match of knowledge flows. This innovation strategy is known as Open Innovation (Chesbrough, 2003), and it is a sign of an emergent Mode 3.

After the change of the RTFNC's management in 2016, the Park Center project was reviewed and renamed Park Hub in 2018.

Table 2: Actors and Role in the RTP Development

Actors	Role
RTFNC	The Research Triangle Foundation of North Carolina was created in 1959 to manage the RTP's development.
RTI International	A nonprofit organization headquartered in the RTP that provides research and technical services. Created in 1958, currently, it is one of the major independent research organizations in the world, with staff close to 4,000. More than half of its staff members have advanced degrees in one of 120 fields and work on approximately 1,200 projects. RTI now has more than 400 patents (Link, 1995).
TUCASI	In 1974, Archie Davis created this center to become the home of the National Humanities Center, the North Carolina Biotechnology Center, the National Institute of Statistical Sciences, and the Microelectronics Center of North Carolina. The impacts of this initiative and its research centers are broad, from the development of an internet network to the creation of a biotech hub in the state (Link, 1995).

Source: developed by the authors.

4.2. The NCSU's initiatives

Although the RTP was formed around three major universities (UNC-Chapel Hill, Duke University, NCSU), and all have been instrumental in its success, NCSU (a land-grant university) also decided to create a university research park. Founded in 1887, as North Carolina College of Agriculture and Mechanic Arts, NCSU started as a university conceived as a "people's college," aiming to promote the economic and cultural transformation of the state during the post-Civil War period. It remained a small institution until the end of the Second World War. In the fifties, expansion of education and R&D activities occurred under federal support. In 1965, North Carolina State College officially became NCSU at Raleigh, known nationally as NC State and by the Wolfpack athletics teams. The university emphasizes its scientific and technical strengths and its focus on outreach-based economic impact (Tornatzky and Rideout, 2014:171).

In 2016, NCSU was the biggest of the sixteen campuses of the NC's university system, with 34,015 students and 2,336 faculty and staff. The focus is on science and engineering (fourth largest undergraduate program in the USA), and it has 12 colleges and 57 multidisciplinary institutes or centers, offering 61 doctoral degrees. It is a leader in R&D, investing annually US$ 349 million in sponsored projects, with over US$ 40 million coming from business partnerships.

The university's mission is to support research; translate research into products and services that benefit the public; and support entrepreneurs and aid job creation (NCSU, 2011). The motto "Think and Do" is reinforced daily. Some examples in fostering and maintaining industry-research partnerships are presented in the Table 3.

In 1984, under the urging of Bruce Poulton, then NCSU's chancellor, Governor Jim Hunt allocated a 355-acre parcel to the university. In 1985, Governor James Martin transferred 450 acres more. Then NCSU developed plans for building a research park, formally launched in 1987, during the celebration of NCSU's 100th anniversary.

In the last thirty years, the Centennial Campus (CC) has a history of supporting industry, government agencies, and nonprofits. It is a "live-work-play-learn" environment that

fosters unique collaborations and educational experiences (Faria and Kekas, 2016). A total sum of US$ 1 billion was invested in building four million square feet of space. CC is the home of 70 companies (ABB, Red Hat, WebAssign, and Eastman Chemical are the biggest ones); university schools and departments (College of Textiles and Biomedical CC); the two major NSF-funded ERCs; the Hunt Library; and students dormitory housing and apartments. The project became an enormous and lengthy architectural planning effort to apply high standards of physical design, optimal usage patterns, and environmental stewardship (NCSU, 2015; Tornatzky and Rideout, 2014). The Association of University Research Parks (AURP) named CC its outstanding research park in 2007 (Faria and Kekas, 2016).

In 2012, NCSU created the Springboard Innovation Hub (SIH), as a new model for engaging and catalyzing industry and government needs and aligned R&D and innovation. It is a space and a concept where, "under the same roof," people and organizations with interest in innovation discover ways to engage, collaborate, and partner with NCSU. The SIH is the operational arm of the Office of Research, Innovation and Economic Development (ORIED), the formal structure of NCSU that embraces all technology transfer mechanisms. The ORIED has four core activities, executed through SIH: 1) Coordinating R&D activities across the campus and directing institutional units that support research; 2) Operating units responsible for intellectual property protection, technology transfer, and venture development; 3) Operating units responsible for developing industry relations, including CC; and 4) Managing ten cross-disciplinary centers and institutes.

SIH offers a way to more readily connect people, ideas, projects, and resources for accelerating relationships, partnership, and innovation, as proposed by the 3H approach. It is a "one-stop shop" for businesses looking for creative solutions and partnership, for researchers to find collaborators or promote their inventions, and for faculty, staff, and students looking for entrepreneurial training. Its goal is simple: "to make NC State the easiest university to work with" (Faria and Kekas, 2016).

Over time, NCSU has contributed to the economic development of NC with 100 startup companies and more than 500 products released in the market. In 2015 (last year available), the Office of Technology Transfer headed 130 commercialization agreements raising US$ 7.6 million. For five years, 797 patents applications were filled, and 434 were granted, resulting in the creation of 40 startups and signature of 544 commercialization agreements, collecting US$ 33.5 million (NCSU, 2015). Data from 2012 show outputs of one disclosure at every US$ 1.47 million in R&D and one license for every 4.6 invention disclosures (Tornatzky and Rideout, 2014).

Table 3: NCSU initiatives

Initiative	Description
IUCRC	The National Science Foundation's Industry-University Cooperative Research Center program. A consortium of member companies working with faculty-based researchers to execute an agenda addressing an industry or a technical problem. NCSU leads four centers: Center for the Integration of Composites into Infrastructure; Advanced Processing and Packaging Studies; Silicon Solar Consortium; and Center for Advanced Forestry Systems. All of them were established with many partners.
NSF-ERC/ ASSIST	The Engineering Research Centers is an University-Industry program from National Science Foundation. NCSU established the Nanosystems Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST) in partnership with other universities and thirty companies.
NSF-ERC/ FREEDM	The Future Renewable Electric Energy Delivery and Management Systems Center is other NSF-ERC, which receives support from 46 participating companies and spends US$10 million for research annually (Tornatzky and Rideout, 2014).

Source: developed by the authors

5. AMIEM application

After a brief presentation of RTP/RTFNC and NCSU initiatives, the information collected allowed the proposal of the quantitative part of AMIEM to the RTP and CC, as shown in Tables 4 and 5. The second column (from left to right) summarizes the information based on the 11 factors. The third and fourth columns present the assessment (done by us arbitrarily) and then discuss with the key managers of both IEs.

We did not find any evaluation of the economic impacts of The Frontier on the generation of new ventures or businesses. The Park Center, as a project not yet implemented, cannot be assessed yet. Regarding TUCASI and RTI International, we also did not find enough information about their economic impacts. We considered them part of the RTP. Future research can explore these experiences, as well as initiatives from Duke University, UNC-Chappel Hill, and other RTR actors.

Table 4: RTP/RTFNC

11 factors	RTP/RTFNC	Weight	Grade
Timeframe	Beginning in 1955. Formally created in 1959. Ten years from conception to attracting first tenants/anchors. Failed business model at the beginning (real estate). Twenty-five years to reach good level of development. Big growth. Being rethought, redesigned.	1	2
Governmental support	Strong since the beginning. County and state government presence with investment (mobility I-40) and legislation (land use rules). Startups also access SBIR funding.	3	4
Participation of the local community/ networking	Strong at the beginning with fundraising. Decreased over the years. Currently, RTP is so big that people do not comprehend well what it is (and why they are there). On the other hand, there are many professional networks and events (like the Triangle Techbreakfast).	2	3
Involvement of universities and research centers	More active in the first years (Duke, NCSU and UNC-Chapel Hill). Currently, less presence due to internal projects and the high complexity of all organizations. R&D organizations were created/installed, and they have a relevant role in knowledge creation and diffusion (like RTI International, TUCASI centers), some of them public or publicly funded.	3	4
Support from funding and development agencies	Many publicly funded projects and organizations (NSF, DOE, DOD). Companies make their private investment, in general. There is not a state/local development agency, but a Board of S&T&I which supports new ventures in the SBIR program (One NC)	2	4
Presence of leading companies and institutions	Anchors are IT and biotech companies (transnational corporations like IBM, Cisco, GSK) and relevant startups/unicorns (Red Hat, SAS, Lulu), for a total of 220 companies; three world-class universities; R&D organizations. Many companies are not doing R&D only but are also producing. Venture capital is present also.	3	4
Physical space and location	Strong concern for spaces and landscaping (planned, big lots, trees, low density). A perfect model for closed innovation (in-house) R&D centers. Limited interaction in an open innovation paradigm. New initiatives (The Frontier, Park Center) to improve density and increase interaction.	2	3
Governance and operational management	Stable. The RTFNC acts as a propeller ("animator"), trying to set the route. However, as the RTFNC does not control the land and the park is too big, it is hard to coordinate/control/"push" some actions, to collect data/information, and to involve universities and companies in activities.	2	3
Leadership	In the beginning, a group of enlightened men such as Archie Davis. Currently, professional management. The values and the vision of building a better future for NC remains.	3	4
Publicity/promotion/advertisement	The effort to attract companies and support startups. The RTFNC also has actions to promote interaction of actors. However, the relation between the universities has some aspects of cooperation and some of competition.	2	3
Living and workplace quality	There is strong concern for life quality and the environment. There are worries related to the rapid regional growth, as in the transportation system (traffic jams and lack of public transportation), air pollution, water shortage, and basic education supply.	2	3
AMIEM Evaluation		25	88

Source: Developed by the authors.

Table 5: NCSU/CC

11 factors	NCSU/CC	Weight	Grade
Timeframe	Started in 1987. Accelerated growth since 2005.	1	3
Governmental support	Strong. State government donated the area to NCSU. Federal R&D agencies finance centers and many activities.	3	4
Participation of the local community/ networking	The focus is the NCSU community. Several professional and academic networks were created. CC defines itself as a bridge between industry, government and academia.	2	2
Involvement of universities and research centers	CC is part of NCSU in an innovative organizational arrangement and strategy. Some academic units and labs moved to the park (Schools of Engineering and Textiles). ORIED/CC manages nine R&D centers in partnership with other universities.	3	4
Support from funding and development agencies	Many projects funded with different strategies (state bonuses, companies partnership/ leasing, donation). Ex: in 2016, US$ 45 million was raised for the science research building.	2	4
Presence of leading companies and institutions	Yes, anchors (ABB, Eastman, IBM), startups and organizations (NOAA National Weather Service, US DOE Nuclear Engineering University Program, USDA-APHIS-Eastern Regional Office, USDA-APHIS-PPQ-State Plant Health Directors Office). The presence of other universities and external R&D organizations is limited (as a partnership with SKEMA Business School and in some NSF-ERC centers).	3	3
Physical space and location	A typical university research park. Part of NCSU campus, in a well-located place in Raleigh, NC. Strong concern for spaces and landscaping (planned, high density, lake, golf course). A perfect model for open innovation paradigm mixing education, research, labs and business.	3	4
Governance and operational management	Governance is stable and well structured. The park and other technology transfer mechanisms are managed together by ORIED, under a vice-chancellor. They are not under the research area of NCSU (however, it controls R&D labs). The operational management is in a common physical space (Springboard of Innovation, "under the same roof"). This makes it easy for internal/external partners to make engage in negotiations and make agreements. The management is professional (lawyers, marketing specialists), not only academic staff. The involvement of faculty is low.	2	3
Leadership	Different from most parks, an individual or group leadership was not found. It is spread in the university spirit (Think and Do) and policies. It is possible to cite chancellors like Bruce Poulton (1981-1989) and Randy Woodson (2010).	2	2
Publicity/promotion /advertisement	A serious effort to attract and develop companies/ventures. A strong message of entrepreneurship and innovation values. There are aspects of cooperation and competition with RTP/RTFNC.	2	3
Living and workplace quality	A typical US university campus, mixing working areas, residencies, and recreational spaces. NCSU has transportation and security systems.	2	4
AMIEM Evaluation		25	84

Source: Developed by the authors.

Regarding the IE assessment, both parks reached more than 80 points, which allows concluding that the RTP and CC are mature initiatives regarding university-industry-government linkages. This high level of maturity does not mean they are perfect. It is possible

to identify achievable enhancements. The RTP can improve its density by changing some rules on land use (in partnership with cities and counties). It can enable a better connection of the RTFNC with resident companies and promote more interactive spaces among businesses and from them with other actors, creating new hybrid and consensus spaces. New initiatives, like The Frontier and the Park Hub, seem to go in that direction. It is a positive sign that the foundation leadership is observing the new paradigm trends. Rather than resting on past laurels, it is working to create a new future for NC. However, it is too early to evaluate the impact of these initiatives (regarding new ventures, technologies, and businesses). The RTFNC has to make an additional effort to induce big companies to perform original research in the RTR, not only bring technology from other environments. They can also lead an environmental care initiative of the park residents, as an open and live showroom for clean technologies.

The CC though SIH/ORIED also needs to promote the 5H linkages, improving the university research park environment. This enhancement should be more natural because they do not have to migrate from a previous model. The CC was already created as a third-generation park, in the confluence of 3H spheres. The attraction of new partners, including other knowledge creators, is a significant step to improve the dynamics and avoid the transformation of the venture into a mere university campus. The Entrepreneurial Initiative, the Chancellor Fund, SIH, and other actions are the fuel to keep attracting people and ideas to the CC.

Looking at the RTR ecosystem, the bases of the RTP and CC are structured, and the impacts over time have been relevant. It is complex to measure an impact regarding economic indicators (value-added in the gross domestic product, e.g., and this was not a proposal of this work). However, there is no doubt that due to the resources invested, jobs/companies have been created/attracted, and technologies have prompted a structural change in the NC economy. Currently, the region is considered one of the best places to live and work in the USA. The population possibly will double, reaching two million in 2040 and advancement in themes like mobility, education, and water surplus are essential. Both IEs have conditions to play a critical and leading role (Rohe, 2011).

6. Discussion and final considerations

For better understanding, this section is divided into two parts, the first discusses the main objective of this paper “to apply AMIEM in the RTR and discuss aspects of regional development from the perspective of innovation management”. Followed by the discussion of the specific objectives, “to verify if the tool is adequate to evaluate a complex IE; and to verify that the tool covers the Quadruple and Quintuple Helix (4H / 5H) aspects ”.

As presented above, the application of the AMIEM tool allowed to verify the maturity of the university, business, government, and society relations of the studied environments. Thus, this study main objective was achieved. Due to the complexity of the RTR, it was divided into several layers/initiatives, and the tool was applied in the two most important initiatives: the RTP and Centennial Campus. Both initiatives have a high-level of development. The RTR is a vast IE with several successful initiatives over the last sixty-five years. These initiatives are complementary, like overlapping layers. This overlap of initiatives also explains the region’s high-level of development. Of course, some of them have had more success or impact than others (but this was not the discussed/measured). The key point is the

entrepreneurial spirit of the actors involved, looking for driving actions and economic success.

Also, it is possible to discuss the classification of the RTR as an IE. Although the RTR has all the characteristics of the concept, the level of complexity better fits the idea of an innovation ecosystem. In this sense, the conceptual discussion is less relevant. The adequacy of reality to the 3H/4H/5H approaches allows useful analysis.

The AMIEM's application led to subsequent discussions, listed in the introduction as specific objectives. The first one was to verify if the tool is adequate to assess a complex IE and what improvements are required. The following discussion is related to 4H/5H aspects. The outcomes showed that the application is viable in environments like the RTR, but more efficient when splitting the IE into more manageable parts. The tool's application is feasible but not simple. Critics can argue that the concept of IE is broad and includes different kinds of university-industry-government linkages, so AMIEM is not a robust analysis tool. A serious effort was made in this work to define the concept precisely. The current version of AMIEM was proposed as a generic tool to deal with all kinds of IE. The weights of each factor create a specific profile. A technological park is a different experience than a university research park, for example, or even among incubators. There are singularities in each experience. However, all of them are spaces where actors from different spheres interact in the way to create and use knowledge.

As a practical implication, AMIEM is consistent with 3H and 5H approaches and serves as a valuable management tool. Regarding its limitations, the main difficulty in the application was how to access a significant number of actors. In the case of the RTR, it was not easy to obtain survey answers or conduct interviews.

Regarding the weakness or limitations of this specific study, the results can be enhanced with more interviews and actors. The amount of secondary data was substantial, and analysis about other players and initiatives can improve the comprehension of the RTR. The access to the key people is a challenge, as mapping the relationship among the individuals and organizations.

About future studies, the facilitation of AMIEM's execution using electronic forms on the internet, like Survey Monkey or Google forms, can make the data collection more feasible and faster. A series of studies comparing other IEs is undoubtedly a desirable mid-term target, as well as the re-assessment of these parks in a 10-year horizon.

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