TRIPLE HELIX IN THE AGE OF THE FOURTH INDUSTRIAL REVOLUTION AND THE SPATIAL PATTERN OF HUNGARIAN INDUSTRY

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With 3 figures and 3 tables
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Summary: The fourth industrial revolution is one of the most significant challenges of the past decade in Hungary as well. Its driving forces are Industry 4.0 technologies, which result in radical changes in all areas of life. This also affects the spheres of the triple helix (university-industry-government) and how they cooperate. Based on various databases and qualitative research, the main goal of the study is to explore these changes in the field of higher education in technical vocations. We will also examine how all this affects the geography of Hungarian industry. Analysing the description of the technical courses, we have identified a new course (mechatronics engineering) and a new form of training (dual training) as a response to the new technological challenges. German companies, which are at the forefront of the application of Industry 4.0 technologies, have not only encouraged the introduction of dual training, but also the cooperation between the spheres. This is evaluated from the perspective of a multi-site German company (Continental) and a university (the University of Miskolc) using the example of mechatronics engineering training to present the major characteristics of cooperation in connection with new technologies. The main result and novelty of the study is that it points out that the changes in the spheres of the triple helix and their cooperation, which were also motivated by the technological revolution, can also reshape the spatial structure of Hungarian industry.

Zusammenfassung: Die vierte industrielle Revolution ist auch in Ungarn eine der größten Herausforderungen des letzten Jahrzehnts. Ihre treibenden Kräfte sind Industrie-4.0-Technologien, die radikale Veränderungen in allen Lebensbereichen bewirken. Dies betrifft auch die Sphären der Tripelhelix (Universität-Industrie- Regierung) und deren Zusammenarbeit. Basierend auf verschiedenen Datenbanken und qualitativer Forschung ist es das Hauptziel der Studie, diese Veränderungen in der höheren technischen Berufsbildung zu untersuchen. Wir werden auch untersuchen, wie sich all dies auf die Geographie der ungarischen Industrie auswirkt. Als Antwort auf die neuen technologischen Herausforderungen haben wir anhand der Beschreibungen der technischen Studiengänge einen neuen Studiengang (Mechatroniker) und eine neue Ausbildungsform (duale Ausbildung) identifiziert. Deutsche Unternehmen, die bei der Anwendung von Industrie 4.0-Technologien an vorderster Front stehen, haben nicht nur die Einführung der dualen Ausbildung, sondern auch die Zusammenarbeit zwischen den Bereichen vorangetrieben. Wir haben dies aus Sicht eines standortübergreifenden deutschen Unternehmens (Continental) und einer Universität (Universität Miskolc) evaluiert, um am Beispiel der Mechatronik-Ausbildung die Besonderheiten der Zusammenarbeit im Kontext neuer Technologien aufzuzeigen. Das Hauptergebnis und die Neuheit der Studie besteht darin, dass sie darauf hinweist, dass Veränderungen in den Sphären der Tripelhelix und ihre Zusammenarbeit, motiviert durch die neue technologische Revolution, die räumliche Struktur der ungarischen Industrie beeinflussen.

Keywords: Triple helix, Industry 4.0, mechatronics engineering, dual training, spatial pattern, Hungary

1 Introduction

As globalisation intensified and global competition sharpened towards the end of the 20th century, it became increasingly important for the production of knowledge by universities and the application of knowledge by companies to be more closely connected in order to increase competitiveness. Cooperation between institutions of higher education and economic actors can not only improve the efficiency of production and the quality of products, but also, for instance, the visibility and recognition of universities (Mora-Valentin 2000). Not to mention that the local economy may also grow and the socio-economic development of the given area as a whole is also favoured (Amin & Thrift 1994, Chatterton & Goddard 2000, Huggins & Johnston 2009). The realisation has also encouraged various governments to create special educational policies promoting co-operation between universities and companies. In fact, the connections and interactions among the three spheres (university-industry-government-UIG) are modelled by the triple helix (Etzkowitz & Leydesdorff 1995). Later on, the model was re-

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vised to include a fourth element (media and culture-based community space, civil society) thus creating the 'Quadruple helix' model, with the main goal of implementing innovation or otherwise the marketising knowledge (Carayannis et al. 2012, Kleibert 2021). Placed in a wider context the 'Quadruple helix' brought forth a fifth helix. The 'Quintuple helix' model represents the natural environment of society (Carayannis & Campbell 2012). In consequence, the model of knowledge creation became more complex, since in reality the cooperation of the three spheres in a given area is realised in interaction with the local socio-economic and natural environments.

The cooperation among and greater coordination of the spheres is particularly important in the age of the fourth industrial revolution (4IR), when radical changes have begun to take place in industry because of nine technologies (autonomous robots, simulation, big data, vertical/horizontal integration, internet of things, cybersecurity, cloud system, additive manufacturing, augmented reality). These are collectively known as Industry 4.0 (I4.0). This concept first appeared in Germany in 2011 and it has since become widespread (Bartodziej 2017). Today, it is often used in the same sense as the 4IR, although there is no complete agreement on the interpretation of the two concepts (Hermann et al. 2015, Fonseca 2018). This is also due to the fact that is not entirely clear whether the newer industrial revolution is evolution or revolution, i.e. is it the continuation and completion of the third industrial revolution, or a real revolution (Holodny 2017).

The actual large-scale transformation, however, is the 4IR which may take place over several decades affecting all areas of life (e.g. world of work, education) (Ford 2015, Frey & Osborne 2017, Schwab 2016, Terkowsky et al. 2019). Among other things, the profound changes in manufacturing will require the modification of education and training in harmony with the new circumstances, the rapid implementation of innovations and the increase of cooperation between the spheres, because other kinds of knowledge and different skills and competencies will be needed (e.g. technical and methodological skills such as coding skills, creativity, problem-solving and conflict resolution skills) (Hecklau et al. 2016, Longo et al. 2017). Furthermore, the acquisition of digital knowledge and skills, an important prerequisite for UIG cooperation, is also encouraged by the fact that in 2020, the value of the DESI, the indicator measuring the development of the digital economy and society in the EU, barely exceeded 52.6%. The value for ten of the 28 member states, including Hungary (47.5%), was lower than this (EU 2021). Another important reason for the improvement of collaboration among the spheres and the modernisation of education is the need to reduce the large gap between the skills acquired by graduates from higher education and those needed for the economy. In fact, such efforts have been made in European education policy for some time, and to some extent in Hungary too, but only recently have they received more attention and become more important (EU 2018, Varga & Erdős 2019).

The main aim of this study is to explore how the spheres of triple helix and the cooperation between them are affected by the challenges of Industry 4.0. Furthermore, the relationship of all these with the spatial processes of Hungarian industry is also examined, as we assume that the intensity of relations between industry and education also has an impact on the territorial processes of industry. It is also assumed that among the degree courses announced by the universities, it is the one in mechatronics engineering that best expresses a kind of reaction to the 4IR by the Hungarian higher education institutions. The cooperation between universities and manufacturing companies is thus evaluated through the example of this course, though there is no doubt that the former spheres are also affected by the governmental sphere (central and local) to a greater or lesser extent.

Structurally, the study is divided into six main sections. Based on the literature, the development of the cooperation among the three spheres is evaluated in section 2, paying special attention university-industry cooperation. Data sources and methodology of the research are discussed in section 3. Section 4 presents the results of the research in three subsections: How Hungarian higher education has reacted to I4.0 challenges and what are the major characteristics of UI cooperation regarding Continental and Miskolc University. Discussions are in section 5 followed by the conclusion in the final section.

2 Research background

2.1 Cooperation by literature

UIG cooperation has a long history in the developed countries where modern universities appeared in the early 19th century, though their functions have since undergone significant changes. The beginnings date back to the late 19th century, but the cooperation only deepened and gained more impetus one hundred years later, from the 1990s (Etzkowitz & Leydesdorff 1995, Kaupilla et al. 2015). In general, the links between universities and industry are framed by various government policies and measures, which can impact the cooperation directly and indirectly. This has been encouraged by a number of factors (e.g. globalisation of the economy, intensification of international economic competition, changes in requirements affecting the labour force, differences in theoretical and practical knowledge in higher education, new ways of knowledge-based economic development). Furthermore, government attitudes and policy decisions have significantly facilitated the development of cooperation, and the guidelines of international organisations (e.g. Davey et al. 2011, EU 2018, OECD 1997, 2019) have also encouraged universities to participate more actively in local and regional socio-economic development. This has also contributed to the further expansion of the universities' function and to the increase in their socio-economic role. The appearance of the third mission, the university's entrepreneurial and developmental function, was also in response to environmental expectations (Etzkovitz 2003, Teperics & Dorogi 2014). To a certain extent, the universities also needed renewal and wider cooperation, since those that are not willing to cooperate with other sectors (economy, culture, society) can become economically and academically marginalised (Davies 1998). Nevertheless, the companies also had to be willing to cooperate and to recognise that this could be highly advantageous for them.

Based on a systematic analysis of the most important articles on UIC published in the literature between 1990 and 2014, six main groups of factors motivating cooperation have been identified (necessity, reciprocity, efficiency, stability, legitimacy, asymmetry), which may be important to differing degrees in terms of universities and companies (Ankrah & Al-Tabbaa 2015). The 'asymmetry' category is applicable only to industry, as many firms try to maintain control over the direction of research in universities. In general, industry is motivated by more reasons to cooperate with universities than vice versa (21 in total as compared with 17). These motivations play differing roles in the generation of collaborations in space and time.

During recent decades, the number of forms of cooperation has increased, but the level of UIC is still quite low in most cases (EU 2018). There are many kinds of options for UIC nowadays, these usually being determined by those who wish to cooperate. Ankrah & Al-Tabbaa (2015) have distinguished 41 organisational forms of cooperation in six main groups. Among them, cooperation in the field of education and training is one of the most important, and this is why it is in the focus of our investigation. Its most popular form is the provision of practical placements for students for longer or shorter periods. Dual training, one of the closest forms of UI cooperation also belongs to this category. This was first introduced at the technical college in Baden-Württemberg in 1974 (Poór et al. 2019). The essence of the so called 'Stuttgart model' is that students studying in higher education acquire theoretical knowledge in institutions of higher education, while practical knowledge is gained in factories. By today, dual training has spread not only within Germany, but also to other countries such as Austria, China, India and the USA, especially where there are German subsidiaries (Pilz 2016). Dual training is often seen as an 'export product' and a tool for improving the competitiveness of German subsidiaries in the global economy (Gessler 2017). However, the original German dual training is often not fully implemented in the same way as in Germany, mainly due to cultural differences (Euler 2013, Lewis 2007). But even where it has been implemented (e.g. in Central Europe), it is considered just one and not the only form of vocational training. Subsidiaries of multinational companies (MNCs) play a significant role in the training of the local workforce, in the creation of knowledge, in the strengthening of local knowledge, and in the local embeddedness of companies (Fuchs et al. 2021a, 2021b). MNCs can contribute to the development of the host country's human capital in various ways (e.g. development of educational institutions), which also has a positive effect on economic and regional development (Wrana & Diez 2016, 2018). By creating branch campuses, universities can also function as economic actors in a given region (Kleibert 2021). Attempts have already been made to model and map their spatial strategy, these studies highlighting the geographical-spatial aspect of UIC. Exploration of the territorial effects of cooperation is also a priority aim for research (Bodas-Freitas et al. 2013, Glückler et al. 2018, Lilles et al. 2020).

The factors hindering cooperation have also been determined, as well as how effective and successful these are (Bruneel et al. 2010, Schartinger et al. 2001). The drawbacks have been classified into four main groups (deviation from mission or objective, quality issues, conflicts, risks), and the outcomes into three groups, as basically the economy, the institution and society benefit from the success of cooperation (Ankrah & Al-Tabbaa 2015). These factors may be of varying importance to the cooperating parties, and an assessment of them may also depend on where and what the benefits of the cooperation are considered (Mascarenhas et al. 2018).

In the post-socialist countries, UIG cooperation has only accelerated in the past decade. The main reason for this is the special historical path dependence of East Central Europe (Bajmócy & Lukovics 2009). There are many other factors (e.g. underdevelopment of infrastructure, lack of financial interest and unpreparedness of institutions, inherited dominance of the educational function in higher education, low level of government involvement), which have hindered cooperation between the spheres (Gál & Ptácek 2011). In addition, representatives of the economic sector were not prepared for the practical application of scientific results. Not least because, mainly in the 1990s, the economies, including the industries in Central and Eastern European countries were undergoing a radical transformation, businesses were less capital-efficient and foreign-owned companies were not yet embedded, but were operating almost 'island-like' in local economies (Kiss 2007). Because of all this, it was considered that the production, transfer and application of knowledge are only made possible by means of complex economic policy measures (Varga 2004). Furthermore, it took some time for countries and governments in the eastern half of Europe to realise that cooperation between the economy and higher education is both a huge opportunity and a great challenge from which both parties can benefit. Joining the EU and the education policy objectives and directives that have since been implemented at EU level have also promoted cooperation among the spheres in Central and Eastern Europe (EU 2018). Despite this, even today there is still a significant lag in the progress of UIG cooperation compared with that observed in developed countries (Varga & Erdős 2019).

During the past decade the spread of new technologies and the completion of the fourth industrial revolution, as well as growing global problems (e.g. climate change, pandemic, energy crisis), on the one hand can accelerate the growth of UIG collaboration, because it is even more essential for innovations and new knowledge produced by universities to reach industrial companies and be applied as quickly as possible (Petruzelli & Murgia 2020, Mikhailov et al. 2020). And on the other hand, they can provide new opportunities and new ways of interaction in cooperation. The revolutionary transformation of industrial production, the interconnection of entire value chains, and the deepening of vertical/horizontal integration open up much wider opportunities for cooperation with universities, from which industry can expect more rapid adaptation. This may affect training, methods, technical backgrounds, etc., and even a considerable shift in the functions of higher education may occur to the detriment of traditional activities. But a 'turnaround' may also occur in UIG cooperation, because the reasons, conditions and circumstances of it will also change. And this could mean the beginning of a new era in UIG cooperation, which will probably arrive sooner in the more developed Western countries that are at the forefront of Industry 4.0.

2.2 Development of cooperation in Hungary

In Hungary, closer UIG cooperation began in practice in the years following the turn of the millennium and intensified after the recovery from the 2008 crisis, since after 1989 the conditions were not right and a number of factors hindered cooperation (weak R&D role of universities, lack of finance and managerial skills, organisational and structural limitations, unwillingness of companies to collaborate etc.) (Rechnitzer 2009, Teperics & Dorogi 2014). During the transition period, interactions between the three spheres were mostly characterised by the isolated pattern and R&D collaborations were very rare (Inzelt 2004). At the same time enormous social and economic changes took place, in which foreign direct investment (FDI) played a relevant role. Foreign investors mainly created resource- and efficiency-seeking companies in the European semi-periphery (Kiss 2007). Foreign capital contributed to the integration of Hungarian industry into European and global production networks, to technical-technological modernisation, to the formation of a dual and dependent market economy, as well as to the reproduction of the centre-periphery relationship.

From the beginning, German investment has been the most significant in Hungarian industry. Even today around one third of foreign capital comes from Germany. Among the TOP 500 companies there were 180 industrial companies, of which 50 have German interests (28%). Several of these are connected with the automotive industry, which is the leading industrial sector. Many sectors of manufacturing industry are connected to this to some extent, and thus they depend on the situation in the automotive industry. It also plays a significant role in the maintenance of the centre-periphery relationship and the truncated development of Eastern Europe through the vertical specialization experienced in the automotive value chains (Gerőcs & Pinkasz 2019, Pavlinek et al. 2017). This sector also affects territorial processes of the industry by the location of car factories (Molnár 2013, Molnár et al. 2020). The first car factory was established in 1991 (Suzuki in Esztergom), the second in 1993 (Audi in Győr), the third in 2012 (Mercedes in Kecskemét) and a fourth is under construction in Debrecen (BMW) (Fig. 1).

By the second half of the 1990s, the large-scale foreign capital investments had markedly rearranged the spatial structure of Hungarian industry, and the focus of industrial production had shifted to the north-north-western part of the country (Kiss 2010). A considerable proportion of FDI and industrial firms with foreign interests are concentrated in the Budapest agglomeration and in the northern half of Transdanubia. These can be considered the more developed, core areas of Hungarian industry, where the values of various industrial indicators are generally more favourable than in other parts of the country (Kiss & Nedelka 2020).

The embedding of foreign companies has become increasingly important after 2000, which may also be favourably influenced by the cooperation with universities. Since multinational companies are the most directly connected to the global production network, they are able to react the most quickly in taking advantage of UI knowledge creation (Lengyel et al. 2006). The government also began to recognise the importance of the embedding of foreign companies, which may be attributed to the fact that the role of the government also changed during the transition period. Greater emphasis was placed on R&D, the transfer of technology and the stimulation of UIC, for which an innovation scheme providing different financial resources was developed at the turn of the millennium (Inzelt 2004).

During the last decade, the increasing labour shortage because of unfavourable demographic trends (population decline, ageing, migration) (Kocsis et al. 2021) and the difficulty in providing a workforce with the right skills for both new and

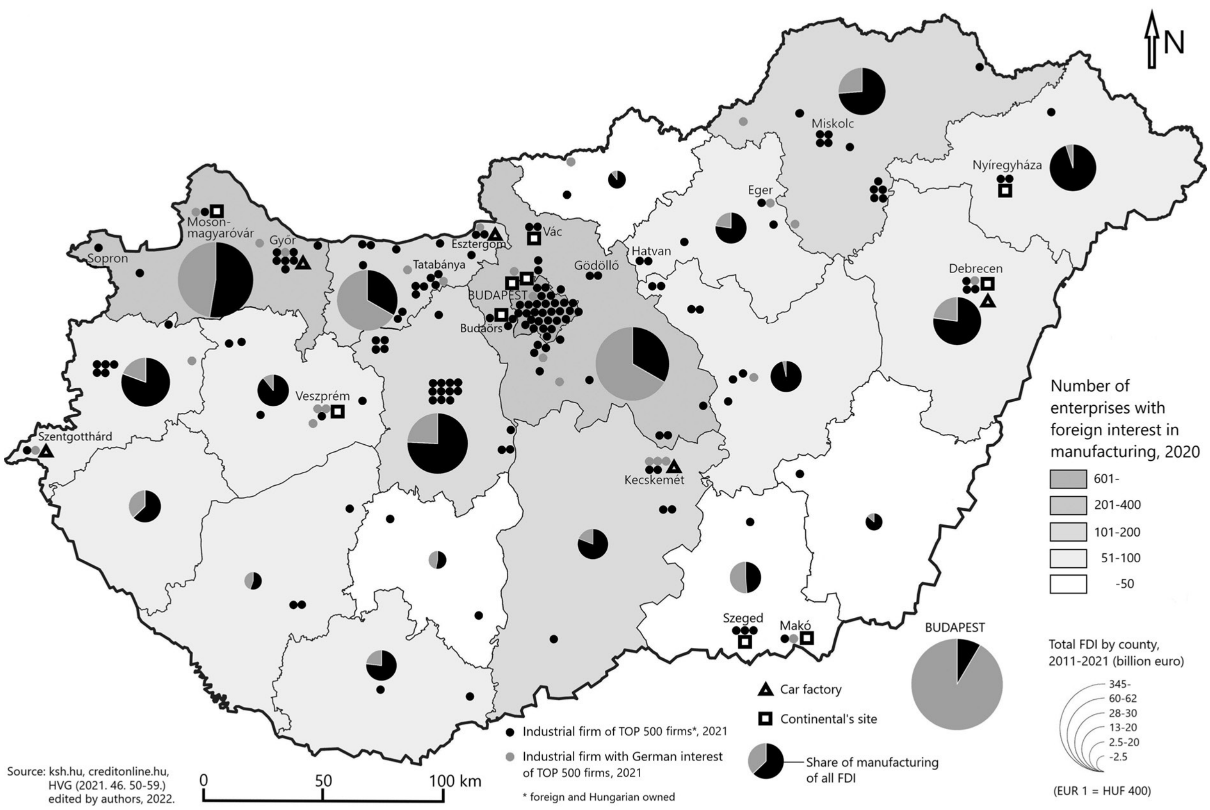

Fig. 1: Foreign direct investment and enterprises with foreign interests in Hungarian industry, 2011-2021

long-established industrial firms has also driven collaboration among the triple helix. These factors, which can be traced back, in part, to extensive (re) industrialization and the centrality of production in the semi-peripheral economy, also contributed to that we put the emphasis on cooperation in the field of education and training within the UIC during the research. But the more modest level of UIC still observed in the field of R&D can also be blamed for this (Varga & Erdős, 2019).

The pioneering role of German companies in promoting the UIC is no coincidence. The possibility of cooperation, and the university they can cooperate with is still determined by their location to a certain extent. First of all, in 2004 the Bosch company decided to enter into collaboration with the University of Miskolc on institutionalising and raising the standard of development in order to adapt education and training more precisely to company expectations and to ensure a continuous supply of labour. In 2007, Audi Hungaria established a Department of Internal Combustion Engines at Győr University. The changes in local government and the prominence of economic governance made a great contribution to deepening cooperation and creating closer ties between the city (government-university) and the company (Józsa 2014, Fekete & Rechnitzer 2019).

Industry 4.0 technologies have only begun to spread in Hungary in recent years, primarily through larger companies with foreign interests (Kiss & Nedelka 2020, Nick et al 2019). Their application also promotes closer cooperation among the triple helix in allowing companies and the labour force to meet the new challenges. Examining the UIG cooperation in the age of the 4IR from the perspectives of the cooperating parties in relation to industrial spaces constitutes a novel approach. It can thus contribute to filling in the research gap to a certain extent.

3 Data and methodology

To answer the research questions, various data and methods were used. Data were collected from Hungarian education and training databases to discover what new courses have appeared in connection with Industry 4.0 in the past decade, and from firm-catalogues to obtain more accurate information about the manufacturing companies investigated. Other data come from official statistical publications.

The research consisted of two main phases. First of all, taking certain conditions into consideration, the descriptions of degree courses announced by universities were evaluated. Since the industrial revolution first occurs in industry, we were looking for a course that provides new knowledge that can be used there. The assumption was made that the reaction of education to the 4IR would be the fastest in the technical training area. It was also an important consideration when making the selection, that the course should provide more specific expertise compared with the traditional training in, for example, mechanical engineering, and that it should be relatively new. The latter criterion was met because the new training identified was launched for the first time in the academic year 2005/2006 at some Hungarian universities.

In the second stage, the UIG cooperation was evaluated first and foremost through the example of mechatronics engineering training from the perspectives of a company and a university. The companies were represented by Continental, a large German company which has sites in many Hungarian towns. This fact made enabled the differences between sites to be demonstrated in terms of the impacts of Industry 4.0 on the cooperation. The reason the University of Miskolc was selected is that this university has the oldest mechatronics department in the country, with the name the Robert Bosch Department of Mechatronics (RBDM).

The two approaches (business, education) were based on qualitative research using a total of 11 semi-structured interviews as they reveal information that is not available from other sources. Nine of these were conducted online at Hungarian Continental factories between autumn 2020 and spring 2021. (Preparation for the interviews progressed more slowly than planned due to the epidemic and obtaining the necessary company approval.) The interview questions were related to the formation and development of the company's cooperation with institutions of higher education in connection with the site characteristics and Industry 4.0. Two interviews were conducted in-person at the University of Miskolc with the former rector and the current head of RBDM in the autumn of 2021. The questions focused on the development of mechatronics engineering education, on its current characteristics and on corporate cooperation related to education and local government. The interview materials were recorded in writing and then analysed according to different criteria.

4 Results

4.1 Mechatronics engineering training as a 'product' of the new age

After evaluating the descriptions of numerous courses on Felvi.hu (which is the information website on all courses), the mechatronics engineering training (both on the BSc and MSc levels) seemed the most appropriate to be treated a kind of reaction by Hungarian higher educational institutions to the 4IR, because in the description several features could be identified which have significant relevance to Industry 4.0. Consequently, mechatronics engineering education can be considered a product of the new age.

This training has a much longer history abroad than in Hungary (for example, it appeared in Germany and New Zealand in the early 1990s) (Grimheden & Hanson 2005). It was launched due to the rapid development of information technology in the second half of the 20th century, with electronics becoming the carrier of artificial intelligence. Electronic and IT elements began to be integrated into previously purely mechanical systems, and by the 1980s and 1990s, optimised systems could typically no longer be divided into separate mechanical, electronic and IT units (BME 2008). Mechatronics engineers can therefore combine mechanical, electrical engineering and IT knowledge, so they play an important role in the creation of new techniques and technologies for the practical implementation of I4.0.

In Hungary, there are 34 technical courses at 16 universities and mechatronics engineering is one of them offered by 10 universities. Over the past decade, the number of students taking a BSc in mechatronics engineering has not changed drastically, being around 1800-1900 each year. The number of MSc students per year is much less, because labour market opportunities are very favourable for them after graduating with a BSc. There is a considerable number of industrial enterprises in university cities, several of which have a foreign interest (partly German). They provide good opportunities for training and recognition of Industry 4.0 technologies as usually larger companies are the ones that are more advanced in their application (Horváth & Szabó 2018) (Tab. 1).

Although most students still study in Budapest, in recent years there has been a shift in their spatial distribution. The growth was the most spectacular in the educational centres of the Great Plain (Debrecen from 2009 and Szeged from 2015), where higher technical training and the mechanical engineering industry has had more modest traditions, especially in the town of Szeged. Since 2014, the University of Debrecen has had the highest number of undergraduate mechatronics engineering students outside the capital city. This is primarily due to the investments by BMW and related industries, which require a highly skilled technical workforce.

Due to the government's efforts, dual training has been introduced. Act XXXVI of 2014 created the legislative framework for the 'Stuttgart model', considered a solution to labour shortages and supplies (Renkó & Beke 2018). At the national level, dual training was basically built on the experience of Kecskemét College where dual training was introduced in the academic year 2012/13 (Berács et al. 2017). This was directly due to the announcement by Mercedes-Benz in 2008 that it would make a greenfield investment in Kecskemét. In 2019, only 92 of all dual students (2285) were involved in dual mechatronics engineering training, which means that dual training is still less popular in Hungary. The number of the partner organisations was 82 at the BSc level in six universities and 31 at the MSc level in four.

The number of partner companies varies by university and depends on many factors (e.g. path development, traditions, industrial structure, the attitude of UIG actors, the quality of the local socio-economic environment). The partners are major, big-name companies with significant industrial activity. The intensity of UIC and the spatial impact of universities may also be influenced by the territorial distribution of the companies. Barely a quarter of the partners are based in the same county as the university (Tab. 2).

The University of Pannonia cooperates with the highest number of partner organisations (e.g. Denso, BPW, Autoliv, Schaeffer). Two of the partners of the former university and one partner of the University of Miskolc (Balluff-Elektronika, VT-Assyst, Aventics Hungary) are also members of the Industry 4.0 National Technology Platform. This was created following a government decision in 2016 in order to promote UIC (even if indirectly), as well as the spread of and adjustment to I4.0 technologies.

4. 2 Cooperation from the perspective of Continental

Since the end of the 1990s, Continental has been present in nine cities, with ten branches involved chiefly in production activities. The sites are located mainly in the capital city agglomeration and the Great Plain (Tab. 3) (see also Fig.1).

Tab. 1: Number of BSc and MSc students in mechatronics engineering training by university in Hungary

University (city, population in 2021)	BSc 2008	2009	2010	2011	2012	2013	2014	2015	2018	2021	MSc 2011	2021
Budapest University of Technology and Economics (Budapest, 1706851)	399	497	521	515	519	509	511	511	467	523	107	133
Óbuda University (Budapest, 1706851)	185	197	236	254	294	323	359	405	436	436	9	145
University of Debrecen (Debrecen, 199725)		23	83	124	198	210	223	241	329	362	0	53
University of Szeged (Szeged, 157372)								22	106	179	0	22
Széchenyi István University (Győr, 132111)	143	146	178	203	222	219	192	178	144	170	11	17
University of Pannonia (Veszprém, 57145)	62	84	115	123	125	133	110	98	194	141	22	16
University of Miskolc (Miskolc, 147480)	54	79	107	124	147	153	149	148	121	78	9	6
Szent István University* (Gödöllő, 31494)	118	147	144	157	154	161	153	142	92	58	0	0
Edutus University (Tatabánya, 64305)					8	14	18	19	7	39	0	0
University of Sopron (Sopron, 62116)			34	64	100	135	126	112	16	7	0	0

* Hungarian University of Agricultural and Life Sciences from February 2021. Source: https://felvi.hu

Tab. 2: Dual partner organisations of mechatronics engineering training by university in Hungary, 2022

University	Location (city)	Number of dual partner organisations by headquarters	Of which foreign	Of which Hungarian	Number of German partner organisations of foreign companies	Number of partner organisations in the given county	Number of partner organisations in other parts of the county
Edutus University	Tatabánya	2	2	0	1	2	0
University of Miskolc	Miskolc	17	12	5	3	10	7
Óbuda University	Budapest	10	5	5	1	0	10
University of Pannonia	Veszprém	42	20	22	9	8	34
University of Sopron	Sopron	2	2	0	0	2	0
University of Szeged	Szeged	32	9	23	2	16	16
Total		**105***	**50**	**55**	**16**	**38**	**67**

* They have 147 branches in different parts of the country. Source: https://felvi.hu, https://creditonline.hu

Continental is not only a significant employer (with about 8,000 workers), but is also at the forefront of the development and application of industrial innovations. Industrial production was already underway at several sites (e.g. Szeged, Makó, Nyíregyháza, Veszprém) even before the appearance of Continental, which is responsible in part for the rubber production, tyre manufacturing and automo-

Tab. 3: Major characteristics of Continental's sites in Hungary, 2021

Name of Continental's site	Year of foundation	Location	Activity	Number of employees	Industry 4.0 technology
Continental Hungaria Kft.	2005	Budaörs	non-producing (marketing)	47	-
Continental Hungaria Kft.	2011	Moson-magyaróvár	non-producing (logistics centre)		-
Continental Automotive Hungary Kft.	1998*	Veszprém	producing (automotive industry)	2154	-
Continental Automotive Hungary Kft.	2002*	Budapest	producing (automotive industry)	1890	additive manufacturing, autonomous robots, vertical and horizontal integration, cloud-system, augmented reality
Continental Automotive Hungary Kft.	2018	Budapest	non-producing (machine learning competence centre)		AI, simulation
ContiTech Fluid Automotive Hungaria Kft.	1999	Vác	producing (automotive industry)	679	-
ContiTech Fluid Automotive Hungaria Kft.	2004*	Makó	producing (automotive industry)	1919	Internet of things, robots
ContiTech Rubber Industrial Kft.	2004*	Szeged	producing (rubber industry)	560	-
ContiTech Magyarország Kft.	2004*	Nyíregyháza	producing (rubber industry)	499	-
Vitesco Technologies Hungary Kft.	2020	Debrecen	producing (automotive industry)	117	smart factory, cybersecurity

* When the site became the part of Continental. Source: https://creditonline.hu and interviews, 2021.

tive activities that still continue today. The development and industrial functions are different for each site, partly due to the inherited past and partly due to local social and economic characteristics. In recent decades, a number of investments and developments have been made from various sources (EU, the state, local government). The Hungarian government also concluded a strategic cooperation agreement with the company in 2013. Among other things, this aimed at developing relations with domestic companies as potential suppliers. The 'opening' towards universities was primarily motivated by the need for a labour supply (necessary number and quality of workers), which the sites are trying to solve in various ways, including using new technologies. Finding a supply of highly qualified workers is usually the most difficult in the countryside, but the opposite can be experienced at sites in Budapest. Consequently, cooperation with higher educational institutions has become increasingly important for the Company.

UIC is realised in different forms and assumes relationships of varying intensities. The Company's oldest collaboration is with the University of Pannonia, with which they initially collaborated in the field of R&D, this being extended to education in 2010, as a new specialisation was introduced at the MSc level. At the same time, the latest cooperation agreement was concluded between the Industry 4.0 model factory in Budapest in 2018 and Budapest University of Technology and Economics. This plays an important role in the supply of intellectual labour (mainly engineers), basically due to attracting talents early. Their internship program involves 70-80 engineering students each year, who are usually recruited to the company as engineers after completing their university studies. On average, six out of the ten engineers taken on are carrier starters or those with little work experience. Because of the lack of labour force, the factory also uses robots, 10 of which are cobots, which represent Industry 4.0 core technology.

The Makó site, which also develops cobots, is in cooperation with the nearby University of Szeged. In order to provide the skilled labour who will be able to program and operate them, a Department of the Faculty of Engineering has been outplaced to the Makó factory, where engineering training has been launched, knowns as the 'Continental' course. New courses (in mechatronic and mechanical engineering) were also introduced in the university in 2010, where the robotic laboratory was equipped with the most modern robots to contribute to the success of technical training, and a special competence centre for vehicles is also under development.

The establishment of the 'smart factory' in Debrecen is also a good example of UIG cooperation. An important condition for selection of the location by Continental was the availability of suitably qualified personnel. For this purpose, a committee was established in 2017 with the cooperation of representatives of the government, the city administration, the university and other companies, whose task was to transform the local technical training with the introduction of a new specialisation. The establishment of the factory was also helped by the fact that it is located in an area where investments can be made with the highest state support. In 2019, Continental and the University of Debrecen tightened their relationship by concluding a strategic contract and by launching an MSc specialisation in vehicle mechatronics installation technology (known as the 'Vitesco' course) at the Faculty of Engineering. Graduates can work in the local Continental factory known as the 'Vitesco' factory (named Vitesco Technologies Hungary Ltd. since autumn 2019).

Continental is also involved in dual training: four factories (Szeged, Makó, Vác, Nyíregyháza) contribute to traditional mechanical engineering courses, mainly at the BSc level in six universities, and the Szeged site to mechatronics engineering education at two universities (Szeged, Óbuda) that provides knowledge more closely related to Industry 4.0. This may be related to the fact that, in general, at sites where automotive and electronics products are produced, new technologies are used to a greater extent, so Industry 4.0 is more advanced. Most of the new technologies are found in the two newest factories (Budapest and Debrecen).

The relatively close cooperation with local or nearby universities indicates that Continental intends to be a trend-setter and not a trend-follower. This intention significantly promotes practice-oriented professional training in order for students to obtain such knowledge and skills which enable them to satisfy the labour market requirements of the given region.

4.3 Cooperation from the perspective of Miskolc University

Miskolc has a long history of industry. Heavy industry was developed during the decades of socialism (mining, metallurgy, mechanical engineering, chemical industry) and Miskolc was the second largest town in the country, where there was a Technical University. The crisis in traditional heavy industry became more severe after 1989, but later foreign investors played a significant role in the restructuring and renewal of the industry. One of these was Bosch, which appeared in 2001. Besides industrial traditions, fast and direct communication with the university management and support of the local government were important factors in their choice of location. By today, Bosch has two factories in Miskolc, employing close to 4,000 people.

The company introduced significant changes in UI cooperation. The creation of the RBDM as the first corporate-funded Department, the company's 'flagship' in Hungary, signified a higher level of cooperation. It was established with the close professional and financial support of the German company, but the staff of the first Department of Mechatronics (in the University of Duisburg-Essen) also contributed to coordination of the work, occasionally still providing professional advice. The curricula for the mechatronics engineering bachelor's and master's degrees in Miskolc were also submitted with their guidance. Although the university works out the curriculum, the company contributes to its development by indicating what needs to be modified and included to make the training even more effective. Corporate professionals are also involved in education and sharing practical experience with the students. In recent years, I4.0 knowledge has been in the focus of the subjects. Several subjects have been included in the training (e.g. microcontroller programmer, PCL programming), which include knowledge related to I4.0. A new curriculum is planned for development in the near future, with a focus on industrial robots in the specialisation, and this being in line with changes taking place in industry.

Following a mutual decision by the company and the university, mechatronics has become the core of the cooperation due to its multidisciplinary nature. The modern mechatronics laboratory system using Industry 4.0 technologies in the university has enabled high-quality practical training, which is constantly being renewed to keep up with new technologies that are appearing in industry. RBDM is actively involved in various developments and in solving manufacturing problems. The department has various functions in the cooperation, which have been modelled (Fig. 2).

Acting as a catalyst, RBDM accelerates certain institutional, financial and other processes in the university. It also functions as a multiplier and an integrator. The impact of the department can be observed in other training courses and also in a wider sense, in the local economy and society. Additional special knowledge and experts are also integrated, creating a bridge between the company and the university, likewise including openness to the local economy and society. RBDM also has a knowledge transfer function contributing to the faster implementation and corporate application of innovations.

Mechatronics engineering training was launched at the university in 2007. The number of students at the bachelor level is generally 15-20, but only 5-8 students graduate each year. In order to gain practical experience, students often put theoretical training in the background, thus university studies require a longer period of time and students graduate later. Many of the graduates become employees of the Bosch factories in Miskolc, Eger and Hatvan.

In addition to Bosch, the university has several other partners in mechatronics training. The number of partners involved in dual training was 17 in 2022, 12 of them foreign, 3 of which are German-owned. In 58% of cases, the headquarters of the partner companies are located in the home county, though they have 22 branches in other counties. Hence the influence of UIC stretches far beyond the borders of the given city and county.

It should also be mentioned that due to a change of model which took place in Hungarian higher education in 2020, several universities are no longer run as public institutions, but in the form of a foundation. This created a new situation calling for a new university leadership. For example, at the University of Miskolc, the state government, local government and the companies were represented, creating a new platform for cooperation. This could put UIG on a new foundation, the tools and framework for which being provided by new technologies and an increase in digitalisation in the future.

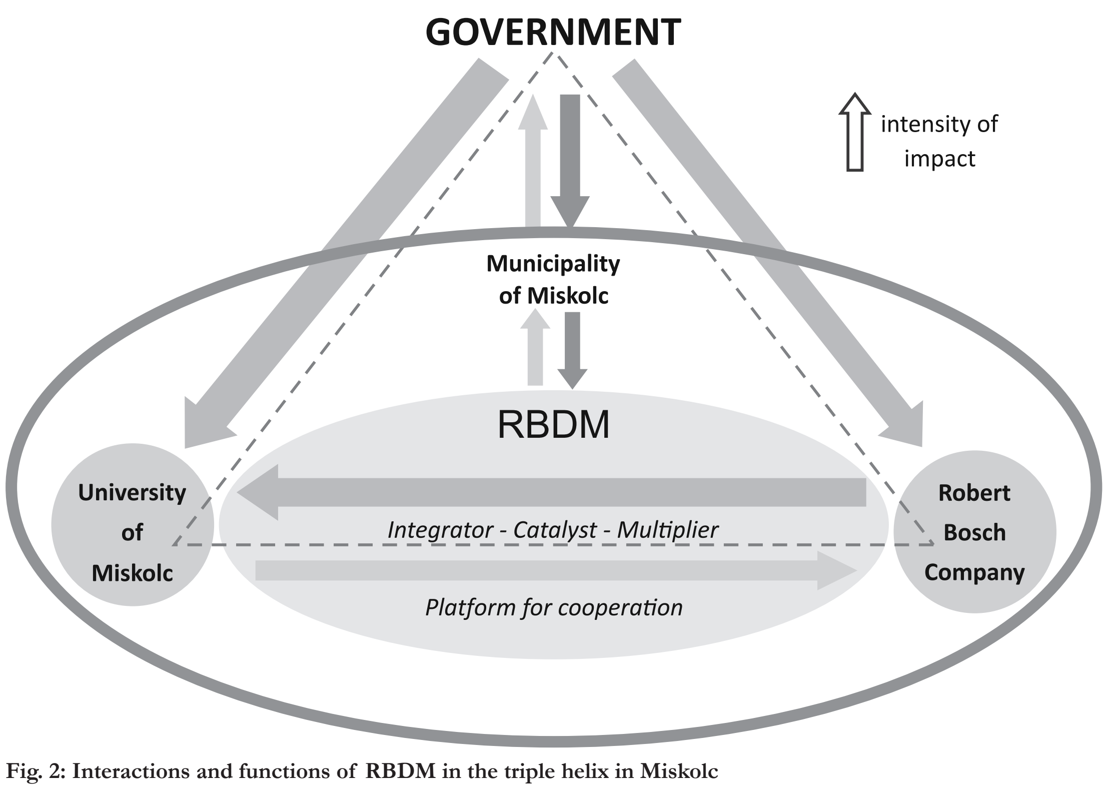

Fig. 2: Interactions and functions of RBDM in the triple helix in Miskolc

5 Discussion

The study examines the kinds of new courses Industry 4.0 technologies have stimulated in Hungarian higher education, and how these have affected cooperation between the spheres of the triple helix, with particular regard to university-industry cooperation. We also looked for an answer to the question of what effect all this has on the territorial processes of Hungarian industry. We assumed that there is a correlation between the choice of location by industrial companies and the quality of local education and training, especially in technical fields, which also contributes to the spatial expansion of new technologies.

According to our research results it appears that in the past decade, significant progress has been made in UIG cooperation in Hungary, which was motivated by various factors from the perspective of each sphere. It also became clear that large companies can fundamentally impact relevant state policies and the training structure of higher educational institutions (EU 2018). They also play a decisive role in shaping the demands of the labour market, because they require a large number of skilled workers. In the longer term, however, the problems of labour market will also prompt smaller businesses to cooperate with training centres.

Of the three spheres, the Government plays a major role in the development and determination of the framework for UI cooperation and thus in 'launching' collaboration. The functioning of the spheres and the success of their cooperation significantly depends on the cooperating parties and on local social and economic conditions (Lilles et al. 2020). The experiences gained from the interviews also confirmed this. The forms of cooperation are diverse and the intensity of interactions is varied, our results being similar to those of an Austrian study (Schartinger et al. 2001). The case of Continental and Bosch have also pointed to the different activities and influences of the spheres, which can change over space and time. Bosch's 'triple helix model' can also be generalised, and with certain changes it can be applied to other companies. Empirical experience suggests that Bosch has developed a closer relationship with the university and it has a longer history than Continental's sites, which have only started to forge closer ties with universities in recent years. Consequently, UIC shows differing maturity in different locations, in a broader sense it can be said that the 'triple helices' are in different stages of development.

Based on the literature review, it was discovered that the changes brought to higher education and UIC by Industry 4.0 in the last decade have not yet received sufficient attention, so we have tried to make up for this gap by presenting Hungarian experiences. The introduction of the new course (mechatronics engineering) can be seen as a kind of response to the challenges of I4.0 by providing up-to-date knowledge for the application of new technologies. This course can be considered an 'indicator' of the 4IR, as the number of students taking it has increased in recent years and the range of universities where it has been introduced has also expanded (e.g. University of Szeged). The profession of mechatronics engineer is essentially a new one brought to life and promoted by I4.0.

The appearance and expansion of dual training, a new form of education in Hungary, is also related to the current industrial revolution, as it provides good opportunities for learning about Industry 4.0 technologies in practice. Operating these requires the workforce to have different types of expertise, other skills and competencies than during the third industrial revolution, because since then there have been great developments in ITC, so much more complicated and complex knowledge is required, such as digital skills (Longo et al. 2017, Mourtzis 2018). A number of studies have pointed out that the lack of a properly trained workforce is one of the main limitations on the spread of I4.0 (Elhusseiny & Chrispim 2022, Kopp & Basl 2017). Cooperation in education and practice-oriented training thus become especially important in the new era. At the University of Miskolc, dual training is the result of a lengthy, in-house development with a bottom-up initiative leading to the creation of the RBDM.

German companies have played a pioneering role in adapting dual training to Hungary. As in other countries, dual training is only one form of vocational training in Hungary. It is applied in a special way, in a 'Hungarian way' so to speak, due to the local socio-economic milieu (Euler 2013, Lewis 2007). This is also apparent when comparing the German model with Hungarian practice (Poór et al. 2019).

A significant proportion of the dual partners of the universities are companies with foreign interests. Due to the large number of German-owned companies, a significant influence of these on mechatronics engineering education and training can be observed. In addition, German companies are at the forefront in the application of I4.0 technologies, as Germany can be considered the 'cradle' of the new industrial revolution (Bartodziej 2017). Consequently, these play an important role in the transmission of knowledge about Industry 4.0. Knowledge transfer, however, decreases in proportion to the increase in distance from universities (Varga 2004). The Continental sites are also good examples showing that the progress of I4.0 is not the same within a single company, because new technologies are not applicable to certain manufacturing sectors, or at least less so, leading to differentiation between the levels of cooperation with universities. Those involved in cooperation are usually connected to nearby universities.

In the past decade, the spheres of the triple helix have affected not only technical training, but also the spatial structure of industry. We have concluded that due to foreign capital investments and the appearance of a new university degree and a new form of training, manufacturing industry is opening up towards the southern and eastern parts of the Great Plain, towards the industrial periphery (Fig. 3).

The change in the spatial pattern is primarily due to the centre of gravity of the automotive industry shifting to the east of Hungary (Molnár et al. 2020). The adaptation of vocational training also contributes to this, however, as this follows the needs of the revolutionary changes taking place in the industry. The spread of new technologies in the reindustrialising lowland areas contributes to the reduction of regional differences and the reorganisation of the spatial structure of Hungarian industry. It is also important to note that the industry of Debrecen (the appearance of a car factory) may have a more direct and stronger impact on the spatial structure than the industry of Szeged, where there is no car factory, so it is only indirectly connected to the car industry. Engineers graduated here, e.g. can be employed at the car factory in Kecskemét. The example of the two cities also shows that the relationship between training and industrial space can change both in space and time. In Debrecen, industry motivated the strengthening of training and the increase in the number of students. At the same time, in Szeged, training rather 'preceded' industry, so it has less influence on the spatial pattern of industry. The introduction of technical training in the city can promote the development of local industry in the long term. The two case studies also provide similar experiences. It should also be mentioned that universities often cooperate with distant

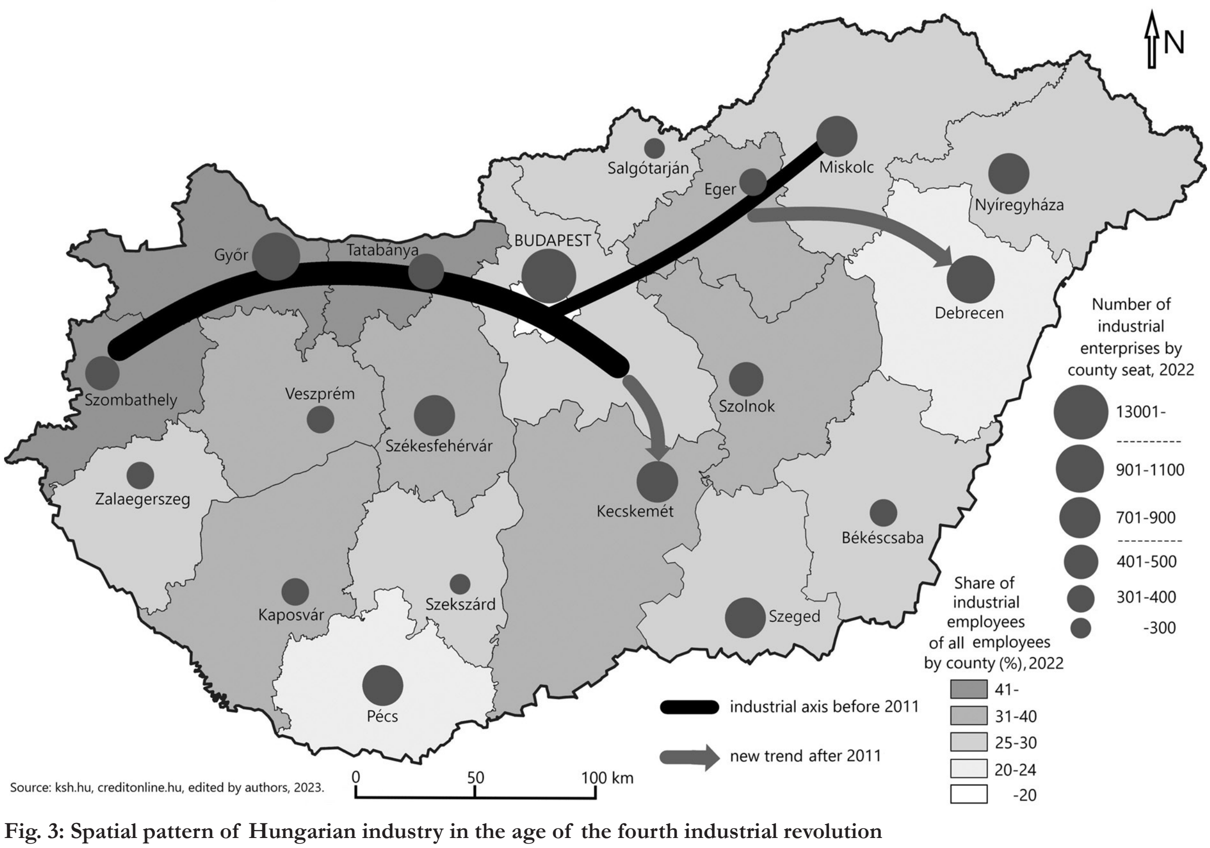

Fig. 3: Spatial pattern of Hungarian industry in the age of the fourth industrial revolution

industrial companies. Thus, their impact on the industrial space can be observed in a much larger area, but with different intensity.

Taken as a whole, the results should be treated with some reservations, as they are based on relatively few interviews, and the combination of the participants in the interviews is disproportional. Despite these limitations, the study has contributed to the increasing knowledge and understanding of the operation and implications of the triple helix during a period of major technological revolution.

6 Conclusions

Based on our exploratory research, it can be concluded that UIG cooperation has become closer in Hungary in the age of the 4IR, in part due to new technologies. In comparison with the developed western countries, however, the UIG cooperation started significantly later (Varga & Erdős 2019). The main contribution and novelty of the study was in highlighting that the change in the triple helix in connection with I4.0 technologies can lead to the spatial restructuring of Hungarian industry.

Industrial development driven by FDI and especially the large number of German companies and the adaptation of the 'German model' to Hungarian vocational and higher education constitute a fortunate coincidence and form a good basis for the further development of UIG collaboration. However, it is important to emphasise that there is a significant degree of multidimensional asymmetry between the participating parties, which makes cooperation difficult. This has also been affected in recent years by the fact that local governments have no real influence on the UIC, because their management role has become very narrow due to the strengthening of centralised control. On the other hand, UIG relations may change due to alteration of the university model. In addition, the varying degrees of digital development in the spheres may affect cooperation, since Industry 4.0 is spreading and digitalisation is increasing, which may open up new opportunities for the cooperation among the spheres.

The empirical research has revealed that in the future industrial production is likely to be concentrated in areas where there are higher educational institutions. Knowing this is essential for the territorial development policy and local and regional economic policy. This can promote decision-making and determine the long-term development and economic position of an area or a settlement.

The major findings of the research may also be useful for other post-socialist countries of Central Europe due to their common historical past, the similarity of the industrial structure which emerged after 1989, and to automobile production and the increase in German capital investment. A more precise knowledge of the collaboration between universities and industrial companies can greatly contribute to the further development of each region. These have great potential for regional development (Lille et al. 2020).

The limitations of the research stem partly from the qualitative investigation, which also provides additional opportunities for research. A more in-depth study of UIG cooperation could be one of the main directions, involving more universities and companies, in order to refine the specifics of the spheres and to reveal the quality of UI cooperations. Another option for continuing research is to study other forms of cooperation, because not only the Hungarian industry, but also the development of the entire eastern periphery of the European Union may depend on the success of UIG collaboration in the age of the fourth industrial revolution.

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