



Digital transformation in the world city networks' advanced producer services complex: A technology space analysis

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ABSTRACT

The Advanced Producer Services (APS) sector, long considered to be the vanguard of the knowledge economy and world-city formation, is undergoing a digital transformation. Digital transformation entails an increased engagement with digital technologies in the operation, product offerings and strategies of APS firms, with potentially transformative implications. Such digitization processes are well-established in the morphing of finance into FinTech, with the other APS sub-sectors now allegedly catching-up as evidenced by the arrival of LegalTech, AccountTech, RegTech, PropTech, and AdTech. Moreover, the digital transformation could imply that Information and Communications Technologies (ICT) services are again becoming central to the APS complex after two decades of being largely omitted from world city research. Adopting an evolutionary economic geography perspective, we introduce a new approach that utilizes near real-time data sources to compare local technology spaces with the global picture of digital transformation in world cities. Building a dataset containing information from 40,754 APS start-ups and scale-ups derived from [Dealroom.co](https://www.dealroom.co), this paper explores the geographically uneven digital transformation of the APS sector across European and North American world cities. This allows gauging the extent of digital transformation within APS sectors for each selected city, develop new understandings of the division of labour between world cities, and highlight where sector coalescence between APS sectors is occurring and is more likely to occur. In the process we develop new technological indicators of world-cityness that can be used alongside the classic world city connectivity indicators.

1. Introduction

The world's economic geography is undergoing a major restructuring where digital technologies are one key upending factor to the global division of labour (Van Meeteren and Kleibert, 2022). What has so far been relatively stable within this turbulence, is that economic restructuring is still largely orchestrated from the same set of global- or world cities as before (Derudder and Taylor, 2020). However, such relative geographic stability may hide major changes in the orchestration practices under digitization. These operational reconfigurations could prompt changes in the geography of world cities further down the line.

Since the 1980s, the Advanced Producer Services (APS) sector has been theorized both as instigator and lubricant of globalization (Moulaert et al., 1995). From the defining account of *The Global City* by Sassen (2001[1991]) onwards, APS have been axiomatic ingredients to the evolutionary geography of world cities. The localized APS complex of agglomerated but globally networked APS providers orchestrates

pivotal flows of capital, people, goods and information all over the world (Sassen, 2001[1991]; Bassens et al., 2021). This APS complex is usually defined as being comprised of finance, law, accountancy, management consultancy, and advertising, and their local urban manifestation indicates the degree in which cities are a "world city". The geography of world cities and their position in the world city network signifies the relative importance of specific cities in animating globalized capitalism (Taylor and Derudder, 2016).

However, after the financial crisis of 2007–2008, the subsectors comprising the APS complex have increasingly become subject to digital transformations. New applications of digital technologies around big data, machine learning, Artificial Intelligence (AI), and digital platforms induce advanced services providers to innovate both their product offering and their internal organizational processes (Hendrikse et al., 2018; Wójcik, 2021). During the past decade, innovation in finance has become synonymous with narratives about FinTech, a compound term of "finance" and "technology". The FinTech innovation wave led some

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regions to identify opportunities to leverage their expertise in digital technology to become a more important financial centre (Hendrikse et al., 2020). Following suit, other APS subsectors are embarking on a similar transition. The neologisms LegalTech, InsurTech, AccounTech, RegTech, PropTech, and AdTech testify to these wider currents of digital transformation in the APS sector.

The rise of APS-Tech begs the question to what extent the increased importance of digital inputs in services will enhance the composition of the APS complex, and alter the geography of the world city network. In the “services revolution era” of the 1980s and 1990s, when the central role of APS in economic transformation was first acknowledged, ICT services were considered central to that revolution (Barras, 1985). Nevertheless, as world city network research matured, ICT services largely disappeared from view. The current moment of “digital transformation” (Van Meeteren et al. 2022) and the rise of “Big Tech” (Hendrikse et al. 2022) begs the question whether ICT-related technologies and firms need to become more prominent again in analyses of the APS complex.

Our aim is to make a theoretical, methodological and empirical contribution to the debate on how the increased prominence of digital technologies is changing the APS complex and the World City Network. Conceptually and methodologically the paper is grounded in evolutionary economic geography, advancing the technology space analysis approach (Boschma et al., 2015). Evolutionary economic geography has shown an increased interest in digital transformation technologies and the regions that are well positioned to take advantage of them (Balland and Boschma, 2021a; Buarque et al. 2020; Capello and Lenzi, 2021). Conversely, world city research has long since studied the geography of another subsegment of the knowledge-based economy: the APS that orchestrate. Hence, a key question is to understand the degree in which the multiple globalizations of high-tech and APS (Krätke, 2014) align and influence one another.

Positioned at the forefront of these debates, this paper reveals how the digital transformation is manifesting itself in the technology spaces of world cities. We introduce near real-time data on start-ups and scale-ups to build these technology spaces, proposing an alternative to patent data that is less suited for research on APS. In doing so, the paper offers an innovative systematic analysis of the digital transformation occurring in the APS-complex, and what this may mean for the future evolution of the world city network.

Using the near real-time data platform [Dealroom.co](https://dealroom.co), we built a dataset of 40,754 FinTech, LegalTech, AccounTech, AdTech and Consultancy Tech start-ups and scale-ups (start-ups hereafter) in the EU single market area, UK, and North America. We then utilize this dataset to illuminate a theoretical perspective at the intersection of the urban geography of world city research, technology space analysis, and the FinTech literature in financial geography. These perspectives frame our empirical contribution, analysing the localized technological composition of the APS, with a focus on individual world cities, and their role in the digital transformation of the APS-complex as a whole. In response to Derudder's (2020) call to explore other datasets and bipartite projections in world-city research, our results show that, particularly in the lower tiers of the hierarchical world city network, new places are gaining prominence due to their strengths in digital technologies.

The remainder of the paper is structured as follows. Section Two frames the paper in the literature on the APS-complex and its purported role in the world economy, emphasizing the increasing prominence position of ICT and start-up firms in these debates. In Section Three we modulate the technology space method developed in evolutionary economic geography to probe the start-up composition of APS complexes. Section Four provides the methodological operationalization to build local and global technology spaces from near real-time data. In Section Five we elaborate our results showing the variegated digital transformation amongst selected world cities. We then conclude by summarizing our contribution and reflect where this could impact the future of world-cities research.

2. Digital technologies and the APS complex

Over the last 50 years, sophisticated service providers alternately known as Advanced Producer Services (APS), Knowledge Intensive Business Services (KIBS), or Financial and Business Services (FABS) (Wójcik, 2020) have obtained an extraordinary position in the organization of the world economy¹. These service providers were key players orchestrating the economic restructuring of the world economy following the economic crisis of the 1970s (Derudder and Taylor, 2020), heralding the era of “neoliberal globalization” (Sheppard and Leitner, 2010; Hendrikse, 2018) and the “new international division of labour” (Van Meeteren and Kleibert, 2022). Indeed, summarizing the foundational argument, Moulaert et al. (1995, p.108) call APS the “methodological champions in fighting the crisis of Fordism at the level of the enterprise”. According to them, APS firms were central in implementing flexible organizational innovations and the technological digital infrastructure that enabled the post-Fordist globalized transnational corporation. The central role of APS firms is also stressed in Saskia Sassen's (2001 [1991]) *The Global City* that designated a select number of key cities (London, New York, Tokyo) as organizational pivots of the globalized world economy. Subsequently, the World City Network (WCN) literature (Taylor and Derudder, 2016, Derudder and Taylor 2020) theorizes this world or global city “orchestration” function as something distributed over a wider network of world cities, albeit not without its internal division of labour and hierarchy (Van Meeteren and Bassens, 2016). Most recently, APS firms have been observed to play key roles in the subsequent financialization of the world economy (Bassens and Van Meeteren, 2015; Pažitka et al., 2022) as well as in its nascent digitization (Clifton et al., 2020).

The notion of a corporate complex of “headquarter functions” in world cities projecting corporate power and reorganizing value chains across space can similarly be traced back to the late 1970s (Conservation of Human Resources, 1977; Cohen, 1979; both credited in Noyelle and Stanback, 1984, pp. 44-45). While originally comprised of corporate headquarters and the myriad APS serving them, as the global and world city literatures matured, the APS themselves increasingly stood centre stage in the argument (Sassen, 1991 [2001]; Taylor and Derudder, 2016). Following the literature in economic geography, the APS complex is a localized interdependent production system subject to agglomeration economies that also benefits from extra-local network externalities (Van Meeteren et al. 2016a). In a recent study, Bassens et al. (2021) show that APS sectors indeed reap the combined advantages of local agglomeration and global network effects. The urban nodes in this global network have a varied degree of “strategicness” (Taylor et al. 2014). Some places in the world city network have prominence because corporate clients are located there, others might allow the APS firms in the world city network to tap into the political, technological or favourable tax regime capitals of the world (Derudder and Taylor, 2021; Van Meeteren and Bassens, 2016).

Given the prominence of ICTs in the 1960s and 1970s for revolutionizing business and corporate organization, it is perhaps unsurprising that the initial APS literature focused on ICT services and the smaller-scale companies providing these services (Coffey and Bailly, 1991; Moulaert and Gallouj, 1993). Nevertheless, from the late 1990s, the focus on ICT and smaller firms gradually disappeared from view in this literature. The widespread adoption of ICT technologies across the APS sector saw them normalised (Moulaert et al. 1991; Coe, 1997; Wood, 2005), and so the focus on ICT and digitization became secondary to that of the APS complex as a whole. These developments coincided with a consolidation within the APS sector into large, diverse firms, epitomized by a notion like “the Big Four” (Peterson, 2017), where ICT functions became less central in the APS complex' composition (Bagchi-Sen and

¹ In order to stay consistent with the world- and global city literatures we maintain the APS acronym in this paper.

Sen, 1995; Coe, 1997). Moreover, the research focus in the world city literature shifted to larger firms for methodological reasons. As global relational datasets were almost non-existent in the 1990s and early 2000s, stringent firm selection choices had to be made when designing the longitudinal Interlocking World City Network Model (IWCNM) world city study. Low survival rates of smaller firms risked jeopardizing the longitudinal global perspective (Taylor et al., 2011). In this context, ICT services' global relevance was assumed to be covered by studying the large management consultancy APS².

Although the pragmatic methodological choices that guided the design of the IWCNM are justifiable in its original context, the consequence of the choices back then is that the model is rather inflexible to consider a changing sectoral composition of the APS complex. If innovative ICT services developed by start-ups would once again become prominent in the APS complex, the ongoing longitudinal world city research programme based on the IWCNM (Derudder and Taylor, 2020) would have difficulty registering the development. Nevertheless, the rise of FinTech seems to suggest exactly that the balance of power in the APS complex is shifting (Hendrikse et al. 2018). Dynamic technology start-ups are developing business models, alternative infrastructures, and advanced platforms using digital technologies that challenge routine operations in the financial sector (Hendrikse et al. 2018; Wójcik 2021; Lai, 2020; Lai and Samers, 2021). Observing the merger of digital technologies with Finance, Hendrikse et al. (2020) suggest that "sector coalescence" is occurring, i.e. that the rise of FinTech signals a convergence of formerly separate segments of the technology and financial sectors.

This renewed digital revolution is not limited to the financial sector. Underpinned by AI and big data, the use of optimisation algorithms, natural language processing, large language models, and predictive analytic technologies, is transforming the APS-complex. This is not simply about the intensification of ICT in APS, but rather marks a new era of digital transformation that is changing the nature of work. Brooks et al. (2020) identify how the advent of 'LegalTech' is seeing legal services work transform, and similar dynamics have also been flagged in the accountancy sector (Drew, 2018). Within the advertising sector, digital marketplaces and online advertising have radically transformed the field (Alaimo, 2022), a development designated with the neologism "AdTech" (Thomas, 2018). If similar processes are indeed happening in the other APS subsectors, one can assume that the ICT technologies have become more prominent in the APS complex. In their in-depth survey of the Brussels APS complex, that included ICT firms, Bassens et al. (2021) indeed found significant linkages between ICT and other APS sectors, particularly with finance and to a lesser degree advertising. Research on FinTech shows that the urban environments that produce FinTech start-ups tend to be regions that specialize in a new generation of digital technologies rather than finance (Laidroo and Avarmaa, 2020; Cojoianu et al. 2021), although cities like London that have a strong position in both certainly thrive the most (Sohns and Wójcik, 2020). This begs the question whether regions that have a strong tech profile are becoming more strategic within the world city network. However, the extent to which that is the case will depend on the degree of integration of technology within specific nodes of the APS complex. In some places, technology start-ups and APS firms may co-exist without interlinkages whether in other places technology start-ups could be the lynchpin forging new connections within the localized APS complex. We will now continue with developing the methodological strategy that allows us to explore this variegated economic geography of the APS-complex' digital transformation.

² When asked to clarify methodological choices in the 1990s world city network studies, Peter Taylor confirmed that low survival rates of smaller firms, and their limited presence on the then-nascent world-wide web were key reasons behind the choice to subsume ICT in "management consultancy". Peter J Taylor, personal communication 29 November 2021.

3. Technology space analysis as world city indicator

3.1. The pragmatic methodological history of the Interlocking World City Network Model

The way the APS complex is empirically estimated on a global scale is largely the result of historically embedded pragmatic choices. During the 1990s, theories on world-city formation were quite mature already, but the data underpinning these theoretical claims were scant at best, an artefact of what were then the main suppliers of social-scientific data: national statistics providers (Taylor, 1999). Utilizing the availability of the then-new phenomenon of corporate websites, the Globalization and World City (GaWC) research network³ developed the IWCNM to model the importance and strength of inter-city relations produced by the APS sector (Taylor et al., 2011). The classic GaWC IWCNM relies on a location dataset of a pre-selected list of large APS firms in a pre-selected set of world cities. Based on website information, for each subsidiary, an estimation is made of its relative importance to the multinational service provider (Taylor et al., 2011). From this dataset, a weighted co-location matrix of APS firms is constructed (Taylor and Derudder, 2016). Using projection functions and two-mode network analysis, this matrix can be transformed into different models that explain how world cities and APS interact (Neal, 2014; Van Meeteren et al. 2016a; Derudder 2021). Although the data quality and spatial reach has been significantly expanded in subsequent data collection rounds (Taylor and Derudder, 2016, Derudder and Taylor 2020), the IWCNM is still bound to some of its original pragmatic assumptions in the data structure, including the aforementioned omission of ICT firms as a separate category and a focus on the largest (global) APS firms.

The limitations of, and alternatives to, the GaWC approach are well documented (e.g. Wall and Van der Knaap, 2011; Pažitka et al. 2020) and rejoinders to these critiques were offered (e.g. Van Meeteren et al. 2016b; Derudder, 2020; 2021; Neal, 2020). Our contribution strives to alleviate the weaknesses of the IWCNM around sectoral composition and bias towards large firms. An important result of continued debate on data-analytical issues within world city research is the encouragement of exploration and utilization of other data sources and projections to offer alternative and complementary perspectives on world-city formation (Derudder, 2020). As noted, the digital transformation invokes questions whether the composition of the APS complex is changing, what the role of start-ups is in that transition, and whether this offers specific world-city nodes opportunities to enhance their strategic position in the world city network. These three questions are relatively unsuited to be addressed using the classic IWCNM. However, two-mode network analysis based on technological co-occurrence, as developed in the evolutionary economic geography theories on technology spaces (Boschma et al., 2015; Rigby, 2013; Van Meeteren et al., 2022; Whittle and Kogler, 2019), and alternative sources of data (Van Meeteren et al., 2022), can provide new and complementary insights.

3.2. An alternative two-mode network data source: technology spaces

Technology space analysis was developed in evolutionary economic geography to map related and unrelated technological variety as well as the degree of complexity of regional technological know-how (Balland et al., 2022; Hidalgo, 2021; Whittle and Kogler, 2019). With this information, economic geographers can predict where it is most likely that recombinant innovation—when new combinations are forged out of existing technologies—will take place (Castaldi et al., 2015; Neffke et al. 2011). Moreover, technology space analysis allows estimating which technological fields are converging and diverging, and what the missing links are to be compensated for if a region wants to jump on the bandwagon of an emerging technology (Balland and Boschma, 2021b).

³ <https://www.lboro.ac.uk/gawc/>.

Lastly, technology space analysis helps estimating what the “key enabling technologies are” that drive sector coalescence and new sector emergence (Van Meeteren et al., 2022). Translated to the debate of the digitizing APS complex, technology space analysis allows us to estimate 1) where and which digital technologies are transforming the practices in the APS-complex and; 2) whether digital technologies impact the different APS-complex subsectors separately, or through a shared technological base. From these two assessments we can infer whether we need to reconsider ICT to be a pivotal sector in the APS complex (cf. Bassens et al. 2021).

Like the IWCNM, technology space analysis uses two-mode network analysis to estimate relations between cities. Instead of examining co-location of firms in a region, scholars look at the co-location of technological indicators in a region. The matrix of co-located technologies can then be projected into a network of relatedness between technologies or alternatively into a network of relatedness between places. Once the full network is built, there is a global map of technologies, and this map can be compared to local spaces using an overlap analysis (Rafols et al., 2010; Rotolo et al. 2015). This provides an indication of the relative specialization of particular regions (Balland and Boschma, 2021a; Rigby, 2013). In turn, these indicators of relative technological specialization can be used alongside existing indicators of world-city formation based on location of firms and the relative specialization of the APS-complex in particular cities.

3.3. The advantages of near real-time data to map service technology spaces

Several indicators have been used to map technology spaces: notably skill indicators, trade figures, industrial classifications, but most dominantly patents⁴. In a patent-based technology space analyses, it is the co-occurrence of patent categories that fills the data matrix. However, patent data has a drawback that it is bound to a legacy taxonomy of patent classes where technologies are fitted into. Patent classes are eventually adapted to a changing technological environment but will always follow rather than anticipate the direction of innovation in the world. These well-known drawbacks of patent data produced a well-worn pattern in the literature where the shortcomings of patents are outlined along with an announcement that patents are nevertheless the data of choice (Balland and Boschma, 2021b; Rigby 2013), despite calls to take alternative indicators seriously (Balland and Boschma, 2019). In addition to the commonly lamented shortcomings of patent data, using patent data to distinguish technological change in the APS sector poses additional challenges. Patent data can be a less accurate source to reflect the APS economic structure of a region, as business models in APS businesses rely less on patents (Delgado and Mills, 2020). Indeed, many of the innovations in service companies, particularly around organizational innovations are difficult to patent (Griliches, 1991), suggesting a gap between the real extent of innovations that services contribute to compared to how this extent is reflected on the patent data. The extensive nature of the patenting process also leads to an inherent time lag between patent application and the actual use of technology/knowledge in the industry. These limitations make it difficult and less reliable to track the coalescence of service industries.

An emerging alternative to patent data for technology space analysis are new data platform service companies that offer near real-time data. This data is harvested from tracking the digital presence of companies on the web. By using web crawler and natural language processing technologies, such platform companies trace online digital footprints to

obtain data from companies across application sectors, populating dynamic datasets. The obtained insights from such data add depth and narrow down the time gaps that hampers patent data, and they offer dynamic representations of the application domains, the most up-to-date technologies, and the business models used. Like Van Meeteren et al. (2022), this paper uses the Dealroom.co near-real-time data platform, which has a large coverage of start-ups in the service sectors and offers detailed descriptors of the combination of industries and technologies that characterizes companies. In Dealroom.co, start-ups are described using a system of tags, which can be regarded as important components of their technological and business profile. When aggregated, the tags become an indicator of technological specialization and the role of service sectors in a region. We are using these tags, and clusters of these tags, to populate a co-occurrence matrix, through which a less rigid and potentially dynamic overview of local and global technology spaces is obtained (Van Meeteren et al., 2022).

Although near-real-time data offers important advantages compared to other data sources, it also comes with limitations. As a data-driven source, we rely on the capability of the data platform companies to capture the digital footprints and information from the APS start-ups. Resultantly, the degree of validity of the analysis relies on trust in a commercial proprietary non-disclosed algorithm. Furthermore, users can also provide information about companies, creating potential self-reporting bias. Finally, data platform companies can have an underrepresentation of some geographical areas. For Dealroom.co, the Asia-Pacific region is not comprehensively covered, despite it being a prominent location in the digital transformation (Lai and Samers, 2021). To address some of these limitations, data platform companies set essential quality check procedures and they are increasingly expanding to those locations where coverage has so far been limited. Resultantly, near real-time datasets and autonomous data tools such as GPT-3 are rapidly maturing and are increasingly promising for social science research. Consequently, researchers are progressively incorporating these data onto their research (e.g. Cojoianu et al. 2021; Zook and McCanless, 2022; Van Meeteren et al. 2022).

4. Methodological operationalization

This section will outline the six-step process (Fig. 1) on how to create a technology space from a near real-time start-up database such as Dealroom.co. Steps 1 through 4 produce a global technology space network visualization that allows analyzing how the APS-complex as a whole is digitally transforming. After geocoding the data (Step 5), we build local technology spaces of individual world cities (Step 6). These allow us to then perform topological map overlay procedures (Rafols et al., 2010; Rotolo et al. 2015) to estimate specialization of individual world cities and their relative contribution to the digitization of the whole APS complex.

Step 1: Data harvesting.

To obtain our base data, we harvested a dataset of 40,754 start-ups from the Dealroom.co data platform in April 2020. Dealroom.co's near real-time data on start-ups can be filtered based on companies' characteristics (e.g., industry, technologies, stage of growth, among others). When mining the data, we developed a filtering procedure to only obtain data on start-ups relevant for the APS complex (see Appendix 1). For each company, we obtained information regarding their industry and technology descriptors (known as tags), location (coordinates), and year of creation. Dealroom.co applies their proprietary algorithm to collect data on start-ups following their digital footprint (Dealroom.co, 2022). These footprints are composed of data traces harvested from realms like social media, domain and trade registers, job boards, analytics about web and mobile app usage, news articles, or investor portfolios. Dealroom.co partners and users can also contribute information, which then goes through automatic and manual verification processes. In each company's profile, it is possible to find tags that reflect their technologies, application sectors, and their business models.

⁴ Within the literature, it has become common to specify technology spaces according to the data source used. A skill-based indicator produces a “skill space”, a patent-based indicator a “knowledge space” (Whittle and Kogler, 2019; Hidalgo, 2021). In this paper, we will follow Boschma et al. (2015) and Van Meeteren et al. (2022) in using the overarching term “technology space”.

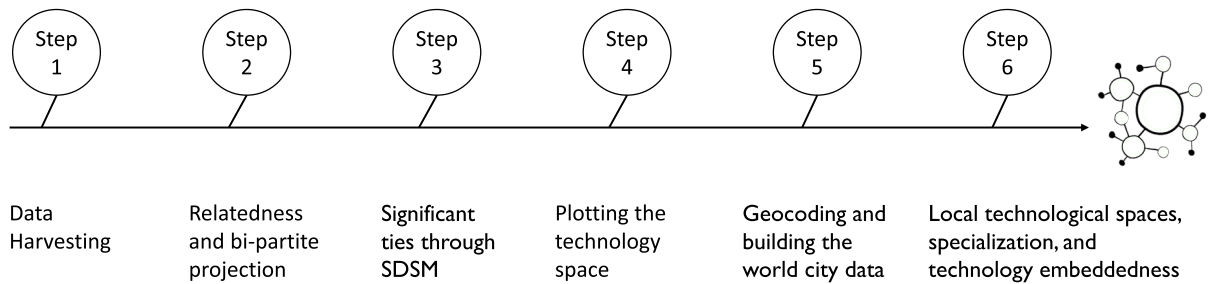


Fig. 1. The six-step methodological operationalization.

Step 2. Relatedness and bi-partite projection.

From the 40,754 companies extracted from [Dealroom.co](#), we collated a list of 1,882 tags associated with the APS complex subsectors. To reduce noise from less significant categories, we only preserved tags that appear in more than 10 companies and omitted tags that refer to events and awards. Ultimately 830 tags were retained. Using these tags, we built a bi-partite matrix with companies in the rows and tags in the columns. A value 1 was assigned when a company i has a tag j . We then transformed this matrix into a bi-partite projection that shows the tag co-occurrences. To account for the differences in the tags' occurrences, we calculated relatedness using a normalized measure based on the association strength approach ([Van Eck and Waltman, 2009](#)).

$$S_{ij} = \frac{C_{ij}}{\left(\frac{S_i}{T} \frac{S_j}{(T-S_i)} + \frac{S_j}{T} \frac{S_i}{(T-S_j)}\right)m}, i \neq j$$

The normalized relatedness (S_{ij}) is obtained using the co-occurrence of a pair of tags (i and j), the number of occurrences for i and j (S_i and S_j), the total number of occurrences for all the tags (T), and the total number of co-occurrences (m). The normalized relatedness values range from 0 to infinite, where a value higher than 1 indicates a deviation from statistical independence/randomness.

Step 3. Estimating significant ties through a Stochastic Degree Sequence Model (SDSM).

Before further analysis, we estimate the most significant ties through a Stochastic Degree Sequence Model (SDSM) with the package “backbone” in the suite R ([Domagalski et al., 2020](#); [Neal et al., 2021](#)). The SDSM compares the observed values from the bipartite projection to a distribution where each company shows the same number of industry tags, and each industry tag is shown by almost the same number of companies. As a result, we obtained an unweighted edgelist with ties significant at $p < .05$, which correspond to the backbone of the network. The backbone ties are then used to graph the technology space.

Step 4. Plotting the technology space.

The backbone extraction is used to build a network representation of the industry tags that belong to the APS complex. Using a force-directed drawing algorithm (Fruchterman-Reingold) and the R packages *igraph* ([Csardi and Nepusz, 2006](#)) and *ggraph* ([Pedersen, 2017](#)), we visually plot the global technology space. In that visualization (see [Fig. 2](#) in [Section 5](#)), the nodes represent the different tags (that have been used to designate companies identified as APS-relevant start-ups), and the edges represent the relationship between tags. The proximity between the nodes is an indication of their relatedness. That is, strongly related nodes are located closer to each other. Node colour is used to indicate the main industries in the APS complex: finance, legal, advertising, consultancy, and accounting services, as well as an additional group of technologies (Tech) that are connected to the APS-related tags (see [Appendix 2](#)). Grey nodes refer to tags outside tech and the APS complex.

Step 5. Geocoding and building the world city data.

Having obtained the global technology space representation of the APS complex, we delve into the localized economic geographies of the APS complex in world cities in Europe (The EU single market area and the UK) and in North America, to probe the uneven digitization of start-

ups companies across metropolitan economies. We geolocated the companies into metropolitan regions using the geographical information of the start-ups from [Dealroom.co](#). We matched the coordinate location for each company with the MREG-COD metropolitan region delimitation for Europe ([Eurostat, 2016a; 2016b](#)), and the CENSUS Bureau's GEOID (US [Census Bureau, 2018](#)) and the CMAPUID ([Statistics Canada, 2011](#)) identifiers for metropolitan area codes for US and Canada, respectively. As the functional scale of world cities tend to be larger metropolitan regions ([Waiengnien et al., 2020](#)), aggregating the data allows for a more valid assessment of regional differences in specialization and the embeddedness of technologies in the APS complex. We select those regions in our sample that have at least 50 companies and are also part of the Globalization and World Cities Research Network (GaWC) database. In total, we analyse 77 metropolitan regions, which we name according to the GaWC nomenclature. For each of these regions, we calculate the frequency that companies in our data will have a tag corresponding to the APS-categories. Using this information, and following [Hidalgo et al. \(2007\)](#), we calculated the Relative Comparative Advantage (RCA) index using the EconGeo package in R ([Balland, 2017](#)). RCA is a binary variable that assumes 1 when a region possesses more companies that use a technology i than the reference region (Global – all the regions together). The $RCA_{r,i}$ will therefore be equal to 1 if:

$$\frac{\frac{c_{r,i}}{\sum_i c_{r,i}}}{\sum_r \frac{c_{r,i}}{\sum_i c_{r,i}}} > 1$$

With $c_{r,i}$ being the number of companies in the region r that use the tag i . The values of the RCA are used in a matrix of cities and tags and then used to calculate regional specializations (Step 6). Finally, for each region, we also constructed a technology space following Steps 2 to 4.

Step 6. Local technology spaces, specialization, and technological embeddedness.

To capture the differences between regional specializations and technological embeddedness across regions in Europe and US, we use two indicators. First, to understand the degree of diversity within localized APS complexes, we constructed an indicator based on the inverted Krugman specialization index ([Krugman, 1991](#)). The Krugman index captures the relative specialization of a region in relation to all the other regions based on the relative over-representation of certain sectors ([Palan, 2010](#)). We inverted the score, such that higher values are indicative of a more diverse APS complex, while lower values represent a more focal specialization in specific APS subsectors. We calculate this index for each of the five subsectors in the APS complex using the EconGeo package in R ([Balland, 2017](#)) and standardized the values. We subsequently used principal component analysis to calculate an aggregate composite measure of specialization in the APS complex, which explains 86% of the variation of the five specialization measures. We name this composite index the APS Complex Index (ACI), which provides an indication of diversification within a local APS complex. Higher scores on the ACI show cities with a broader development on the five industries (i.e., complete world cities with a broadly developed APS complex) and lower scores reveal economies specialized in particular

sectors. This index, which is based on the distribution of specialized knowledge, is a complement for the GaWC's Global Network Connectivity (GNC) measure that is based on inter-city connectivity (Taylor and Derudder, 2016). In order to capture technological embeddedness in each world city, using the APS classification, we calculated the average weighted version of the bridge closeness centrality (Jones, et al., 2021) for each group of tags in each local technology space. This measure reflects the average geodesic distance from a set of nodes belonging to a particular group (in this case Tech) to all the other nodes outside of its own group considering the relatedness (weight) between them.

We also use the composite ACI estimation and the bridge closeness centrality to run a cluster analysis. As a result, we obtained three different groups of world cities, reminiscent of the three-tier classification (alpha-beta-gamma) that has long since characterized much quantitative world cities research (Beaverstock et al., 1999). These groups (here simply called "Tier 1", "Tier 2", "Tier 3" to avert quickly jumping to conclusions on ranks and hierarchy, see Van Meeteren et al. 2016b) are shown together with the scores of regional specializations in the APS Complex and technological embeddedness for each metropolitan region in Europe and North America in Fig. 4 in Section 5. This allows us to develop a typology of world cities with technological embeddedness on one dimension and degree of world-cityness on the other. Finally, to further demonstrate the differences between the three tiers and the typology, we select six cases of local technology spaces which are shown in Fig. 5 in Section 5. By examining the local technology spaces more in depth and relating them to how these cases have been discussed in the literature, we are able to provide a more context-sensitive geographical network analysis (Uitermark and Van Meeteren 2021) on the degree of digital transformation in the APS Complex.

5. Results

In order to establish (1) whether ICT is becoming a more important component of the APS complex; (2) where digital transformation is particularly salient; and (3) to gauge whether near real-time data provides a useful addition to the world city researcher's toolkit - we lay out the results in the following fashion. First, we discuss the global technology space in section 5.1 to understand how far the digital transformation has progressed in the various APS subsectors. We then analyse local knowledge spaces in order to make three comparisons. In section 5.2 we compare our near real-time data findings to the scores of the same cities according to GaWC's Global Network Connectivity (GNC) measure. In section 5.3, we examine the embeddedness of digital technologies and the degree of specialization of localized APS complexes. This allows assessing the uneven proliferation of the digital transformation across world cities. Lastly, in Section 5.4, we delve deeper in our typology by examining six local technology spaces in detail that correspond to typical world city patterns in various tiers of the world city network.

5.1. Examining the global technology space

We first analyze how the APS-complex as a whole is undergoing digital transformation and which APS subsectors are particularly affected. To appreciate the state of digital transformation in the global APS complex, we graph the technology space of the whole dataset (Fig. 2). Fig. 2 highlights the tags associated with the accounting (light blue), advertising (dark blue), consulting (yellow), finance (orange) and legal (green) subsectors while also grouping the "tech" categories in red nodes. The technology space depicted in Fig. 2 provides a picture of the technological composition of the APS complex. The tech nodes tend to be located in the centre of the network and connect different sectors in the network. In this global technology space perspective, the digital transformation seems indeed to be central to the composition of the APS complex from a start-up point of view. The classic APS subsectors, despite overlapping, form distinctive regions within the global

technology space. Both the finance (orange nodes) and advertising (blue nodes) categories are in well-defined subsectors, but they are relatively distant to each other. Advertising engages primarily with technologies such as Software as a Service (SaaS, Node 3 in Fig. 2) and platforms (Node 1 in Fig. 2), as well as mobile technologies (Node 18 in Fig. 2). A technology like Blockchain (Node 6 in Fig. 2) lies more in the exclusive region of applications in the financial sector. The areas of strongest overlap between the APS subsectors, seems to be in the realm of Legal and Accounting.

The legal sector's digital transformation is focused on AI, machine learning and natural language processing (Nodes, 8, 2, and 5 in Fig. 2 respectively), primarily technologies related to automated reading of documents (Brooks et al., 2020). The digital transformation in accounting seems to be around big data and information systems (Nodes 14 and 10 in Fig. 2). The legal and accountancy sectors and the technologies relevant there are those that may indeed be weaving the APS complex closer together. The overlap between them is about a common usage of predictive analytics and data analytics (Nodes 7 and 9 in Fig. 2). Consultancy categories (yellow nodes) are more dispersed throughout the global technology space. This corroborates Van Meeteren et al.'s (2016a, 75) observation that it is management consultancy that plays a role in tying other APS sectors together. Simultaneously, the less compacted distribution of management consultancy nodes and lower overall salience within the global technology space, suggests a limited role for management consultancy start-ups in the digital transformation. Finance (orange nodes) is closely related to legal (green nodes) and accounting (light blue nodes), providing evidence about not only the potential complementarities between those sectors (see Bassens et al., 2021), but also illustrate how the digital transformation may alter business models in these subsectors. These business model shifts are described in the literature as shifting from product consumption towards servitization, based on result-oriented demand (Frank et al., 2019). These digital offerings allow more customized tailored services (Enkel and Gassmann, 2010) across sectors at relatively lower prices, for instance in insurance (Rubin et al., 2022).

5.2. Comparing the near real-time data indexes to Global Network Connectivity (GNC)

A key analytical procedure in world city network research is to gauge the relative contribution of local APS complexes to the full world city network, a theoretical construct labelled the degree of "world-cityness" of a particular place (Knox, 1995). Taylor and Derudder (2016, Chapter 5) developed the measure of Global Network Connectivity (GNC) to measure the degree of world-cityness. GNC indicates the overall centrality of specific cities in the aggregate global networks of advanced producer services. From our technology space data, we constructed a complementary measure to gauge world-cityness: the APS Complex Index (ACI) (see Section 4.2). The ACI shows which cities score high in specialization on all five APS subsectors (excluding tech) and are thus diversified world cities. Of course, both indicators do not measure the same attribute (technology tags in start-ups for the ACI and connectivity for the GNC) and the measures were calculated on a different geographical basis, but comparing the cities for which we have both scores is nevertheless insightful.

We found that for the 77 cities studied, the score on the APS Complex Index is significantly correlated to the GNC 2016's scores ($r = 0.63$, $p < .05$). The correlation suggests that both indicators are indeed capturing world-cityness. Nevertheless, it is interesting to see where the scores on both indicators diverge.

We observe that places that score higher on the ACI than on the GNC tend to be places with a strong tech focus. The San Francisco and San Jose metropolitan area that together form Silicon Valley score higher, suggesting that the ACI does pick up on this technology-driven strategic attribute of the world city network (Taylor et al., 2014). London and New York score relatively much higher on the GNC although they are

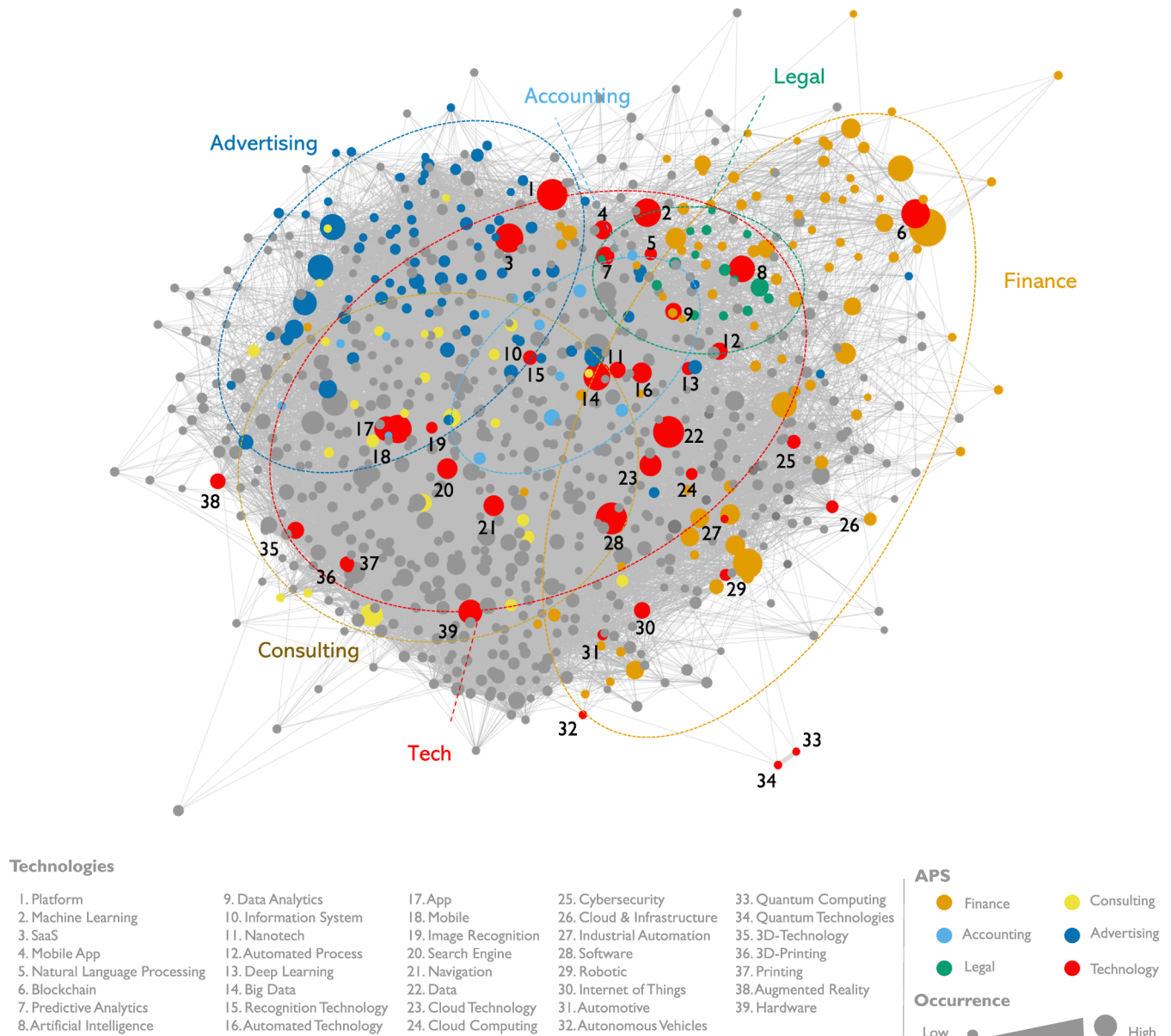


Fig. 2. The global technology space of the APS complex.

also the apex from an ACI perspective. This suggests that an urban hierarchy based on connectivity may be steeper than the one based on technology. Other cities scoring higher on the ACI than the GNC also tend to be cities renowned for their technology and start-up profiles: San Diego, Austin, Boston, Seattle, Berlin (compare Adler and Florida, 2021). Conversely, cities that have a stronger GNC than ACI in the top half of Fig. 3 tend to be cities that score high on indices of brokerage (Sigler et al., 2023) such as Paris, Chicago, Madrid, Warsaw, Milan, Frankfurt. These brokerage functions are more associated with the political and cultural aspects of world cities (Van der Wusten, 2007) than the technological dimension. When we compare the ACI and GNC indicators it thus reveals that they bring different dimensions of world-cityness into focus. Nevertheless, the patterns revealed by the ACI do sufficiently corroborate expectations from the literature, thus calibrating the indicator.

5.3. Establishing the importance of technological embeddedness and classify world city nodes

The cluster analysis results in Fig. 4 generate three distinct different clusters of world cities which we name Tier 1, Tier 2, and Tier 3. The three tiers are reminiscent of the Alpha-Beta-Gamma distinction classically applied to World Cities Research. Nevertheless, although there is certainly overlap between the rankings, there are also differences (see Table 1). Spearman's rank correlation was computed to assess the relationship between the Tier ranks and the Alpha-Beta-Gamma distinction, showing a positive and significant relation between the two variables ($r(72) = 0.49, p < 0.01$).

In addition to understanding the overall hierarchy of the world city network based on the ACI, we are particularly interested in how important digital technologies are in stitching the APS complex together. We have seen this is the case on the global level, but it is likely that this degree will vary from city to city. In some cities the technology and APS sectors may exist side by side without much interaction while in

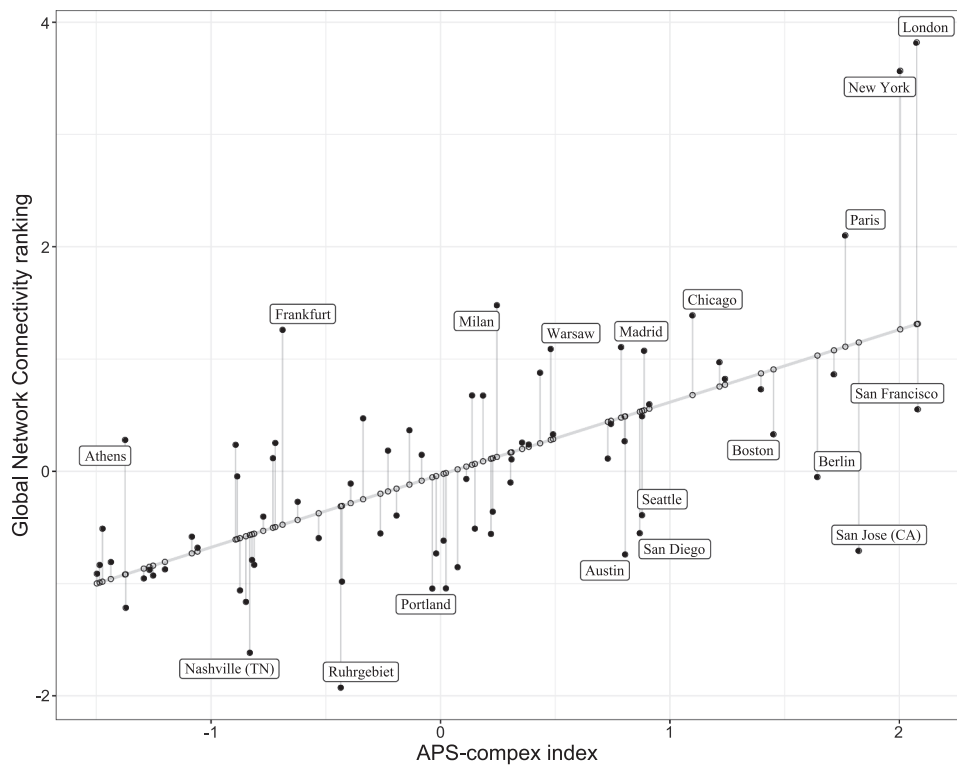


Fig. 3. The correlation between Global Network Connectivity (GNC) and the APS Complex Index (ACI).

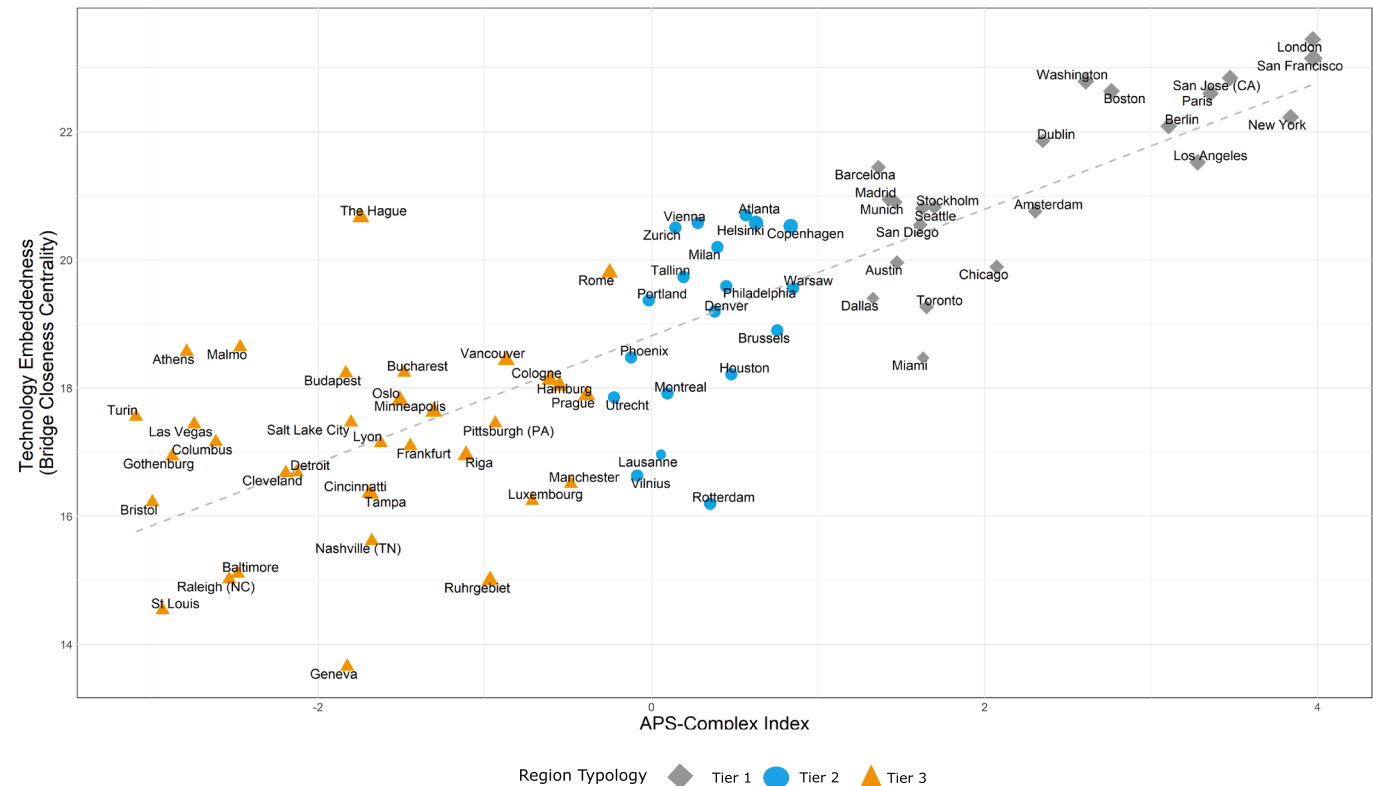


Fig. 4. Comparing the ACI and technology embeddedness indices for the three tiers of cities.

others, technology is central to the complex. The bridge closeness centrality indicator captures this dimension. If the bridge closeness score in a city is lower, the tech cluster and the wider APS complex will have less

interaction. We could say that these world cities are less tech-driven. A higher score indicates a local APS complex that has digital technologies fully embedded within the APS complex. We plot the bridge closeness

Table 1

Classification of the three tiers of the IWCNM and the ACI.

	Alpha	Beta	Gamma	High Sufficiency	Sufficiency	NA	Total
Tier 1 (22)	59%	36%	5%	0%	0%	0%	100%
Tier 2 (19)	32%	32%	21%	0%	16%	0%	100%
Tier 3 (34)	9%	38%	35%	9%	6%	3%	100%

together with the ACI in Fig. 4.

Comparing Fig. 4 and Fig. 3 signals a few salient differences. The ACI indicates cities that score well in all the classic five APS sectors based on our near real-time start-up dataset. Some cities that scored higher on the ACI compared to the GNC scores in Fig. 3 (San Diego, Austin, Seattle, Berlin) are no outliers in the correlation between ACI and Technology embeddedness in Fig. 4. Those cities have not only high diversification of APS sectors, but also their digital technologies are highly embedded within their APS complex. These cities could rise in the world city hierarchy if access to digital technologies continues to be a determinant of world-city formation.

Cities like Washington, Barcelona, Vienna and Zurich that were on the correlation line in the comparison between GNC and ACI measures (Fig. 3) exhibit a strong integration of digital technology when we take the technology embeddedness indicator into account. Thus, these world cities seem “technology ready”, although they might not lead in the digital transformation. Lastly, cities like Rotterdam and the Ruhr area (Ruhrgebiet) that score better on the ACI than on the GNC nevertheless score relatively low on the technology embeddedness indicator. Hence these cities do not appear to have a sector coalescence ongoing, at least not where start-ups contribute to the digital transformation of APS sectors. These are lower-tier cities that might fall further behind if the digital transformation continues at pace.

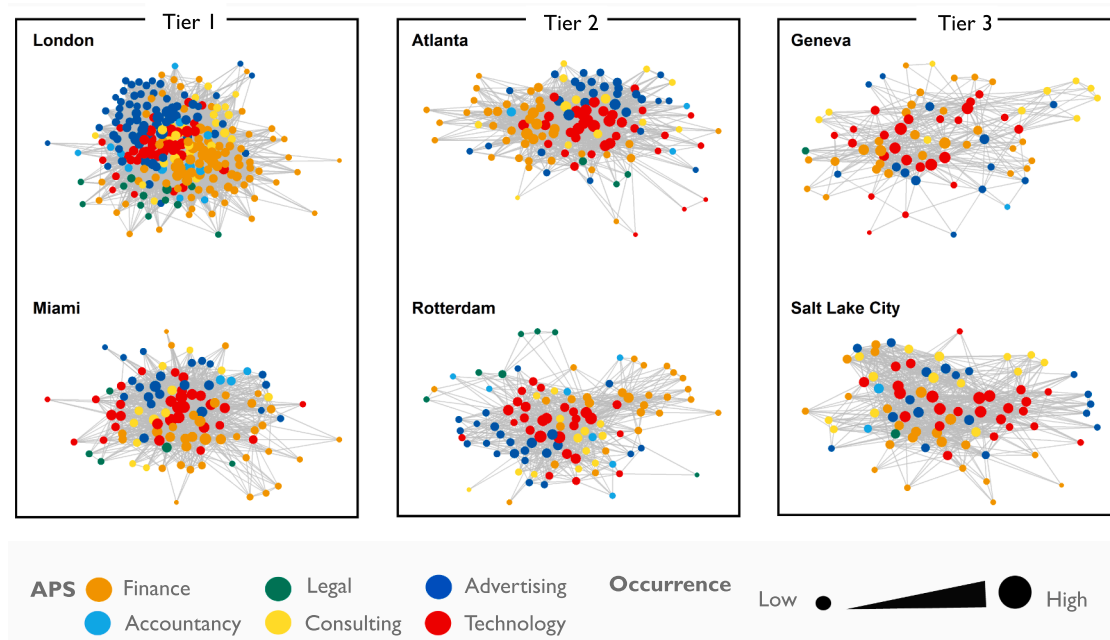
5.4. Comparing different types of local technology spaces

The outlier data points in Fig. 4 either signal places that have a diverse APS complex where the digital transformation is limited (cities in the lower right half of the graph) or cities that have a digital transformation ongoing but where the located APS-complex may not be diverse or even integrated (the upper left direction of the Fig. 4). To examine these two dimensions with more detail for the three different

tiers of world cities, this section highlights the local technology spaces of six cities. For each tier we selected one city scoring below the correlation line, and one above the correlation line in Fig. 4. We also ensured that one of the two comparator cities is from North America where the other one is a European city. We compare in Tier 1 London (UK) with Miami (US); in Tier 2 Atlanta (US) with Rotterdam (Netherlands); and in Tier 3 Geneva (Switzerland) with Salt Lake City (US).

London is the quintessential world city, often considered to be at the apex of the world city system (Taylor and Derudder, 2016; Van Meeteren and Bassens, 2016) while Miami has long been recognized as an example of a world city that is specialized in connecting the economies of North America, South America and the Caribbean (Sassen and Portes, 1993; Nijman, 2007). Hence Miami has a very specific functional specialization that is not necessarily connected to the digital transformation of world cities. The local technology spaces in Fig. 5, do show remarkable differences between Miami and London. London has a tightly-knit cluster where technology nodes are in the middle, albeit with clear regionalizations for the advertising, financial, consulting and legal sub-sectors while accounting is more spread. However, Miami’s local technology space is much more scattered and less dense, although it retains a core of technology tags. It is interesting that consultancy firms, which only had a limited density and coherence in the global knowledge space, seem to show a denser and more cohesive pattern in both Tier 1 cities, particularly in London.

For Tier 2 we compare Atlanta (US) as positive residual city with Rotterdam (Netherlands) as a negative residual city. Within world city research, Atlanta has been characterized as a “void city” (Derudder and Taylor, 2021), a city systematically ignored in their location policies by a significant group of APS firms (idem, p.1513). Derudder and Taylor (2021) explain this void character of cities like Atlanta by arguing that they are crucial to the structure of the US city system, but they are nevertheless underserved by international firms. Bearing that void

**Fig. 5.** local technology space, three tiers.

character in mind, the lower score of Atlanta on the ACI makes sense and from the local technology space (Fig. 5) we can observe that Atlanta is poorly served by accountancy and legal start-ups. Nevertheless, the technology tags in Atlanta are clustered in the centre of the local technology space suggesting that a degree of localized digital transformation is ongoing. By contrast, Rotterdam is a specialized type of maritime world city that has many globally specialized services serving the port (Jacobs et al., 2011). This specialization is apparent when observing that the legal and many of the financial tags of Rotterdam's local technology space are peripheral to the local network, they are a world apart. That peripherality also suggests a limited engagement with the digital transformation in these specialized APS. Technology tags in Rotterdam's local technology space tend to be meshed with the advertising and consultancy sector. In other words, while Rotterdam may be globally more relevant from a connectivity perspective than Atlanta, which has a domestic connectivity function, the opposite may be true for their relative degree of digital transformation.

Lastly, for our Tier 3 cities we choose Geneva (Switzerland) and Salt Lake City (US). Geneva has been characterized as a "political world city", serving many global political and non-governmental organizations such as the Red Cross, the World Health Organization, and the International Labour Organization (Hesse and Mei-Ling, 2020; Van der Wusten, 2007). Moreover, Geneva was historically an important financial centre, and although that position has been eroded somewhat, it is still an important place for transnational private asset management (Hesse and Mei-Ling, 2020). In other words, Geneva is a city with many reasons for a diverse range APS to be located there, but the digital transformation is not necessarily part of any of those narratives. Indeed, we see in Fig. 5 that although Geneva scores high on the ACI, its local technology space is almost donut-shaped. Management consultants are an important APS sector here but are not necessarily engaged with technology. The technology that is present in Geneva seems to intermingle somewhat with finance and advertising but does not hold the APS complex together. We compare that with Salt Lake City as a positive residual city. Salt Lake City was historically attractive to financial firms because of its legal regime, attracting shell companies, but has been increasingly popular because of the highly educated labour associated with the "Silicon Slopes" tech cluster (Urban et al., 2022). It is this cluster that likely is the cause of the higher score of Salt Lake City on the technology embeddedness indicator. According to Urban et al. (idem), it is the increasing prominence of technology for the financial sector that made Goldman Sachs invest in its presence in Salt Lake City. Although less donut shaped than Geneva, Salt Lake City also shows a limited cohesion within the local APS complex. Some technology tags integrate with finance, others with advertising. This is in line with Urban et al.'s (2022) narrative of a financial sector that is selectively but increasingly engaging with a pre-existing high-tech region.

These six short elaborations of local technology spaces suggest a distinction between two types of world-cityness. On the one hand there are world cities that primarily have a gateway/brokerage or political function and these may be specialized world cities that do not have a full complement of APS functions. The examples from Miami, Rotterdam and Geneva illustrate how this brokerage function (Sigler et al., 2023) really signals a different sort of world-cityness than aspects related to the digital transformation. In that respect it is important to remain mindful that the world city network is as much a collaborative network with a division of labour as it is a set of competing localities (Taylor et al., 2014; Van Meeteren and Bassens, 2016). That said, even within the technologically endowed world cities there is a difference in the degree of technological embeddedness. It is in the diverse cities that also have this degree of digital integration (London and Berlin come into mind in Tier 1, cities like Philadelphia and Copenhagen in Tier 2) where we would expect the greatest degree of cross-fertilization of digital technologies between APS sectors to happen. Although exploring that link in detail would require further in-depth research.

6. Conclusions

Our aim was to understand how digital technologies are changing the APS complex, and how these developments enhance the relative position of cities in the world city network. After playing an important role in the genesis of the contemporary world city, the prominence of and emphasis on ICT technologies has arguably declined since the 1990s, as the once cutting-edge technologies became widely adopted across the APS sectors. However, the emergence of 4.0 technologies' have brought a renewed focus on the digital transformation of the APS complex, given what is a 'new phase' in a technological revolution of ICTs (Van Meeteren et al., 2022). The large established businesses that once defined the APS complex are increasingly being challenged and disrupted by new entrants and technology providers, yet little is known about this emerging dynamic that is redefining the geography of the APS complex. The theoretical, methodological and empirical contributions of the paper extend our understanding of this variegated geography of digitizing world cities. Theoretically, we situated the paper's contribution between the world city literature and financial geography, using insights from evolutionary economic geography to understand the changing composition of the APS complex. We argued that many of the established ways of measuring the degree of world-cityness have a blind spot for the increasing relevance of digital technologies in the composition and strategy of the firms comprising the APS complex.

To address this gap, we developed a complementary set of measures of world-cityness applying technology space analysis. Using the [De alroom.co](https://de.alroom.co) derived start-up database, our bipartite technology space analysis enables examination of the technological composition of start-ups in European and North American world cities. To supplement GaWC's time-tested Global Network Connectivity (GNC) indicator, we built an indicator of world city specialization based on comparing local with global technology spaces, the APS Complex Index (ACI) as well as an indicator of the degree of technological embeddedness. Both measures are constructed from a near real-time start-up dataset providing a complementary population of firms to GaWC's focus on large incumbent service firms.

Using these indicators to understand the degree of digital transformation on the global level, the paper demonstrates the underlying variegated economic geography of digitization in individual world cities. Our analysis shows that the digital transformation is indeed happening, and that a shared set of new digital technologies is forging new connections between APS sectors. We therefore concur with Bassens et al. (2021) that world city research ought to renew its focus on the role of ICT in stitching together the APS complex. However, our analysis also shows that the geography of this digital transformation is highly uneven. New "tech cities" become more prominent on the world city map, while some cities that perform more classic "gateway", "political" or "brokerage" world city functions are not necessarily as involved in the digital transformation. Examining local knowledge spaces provided a first corroboration of this highly variegated pattern on different tiers of the world city hierarchy.

Our approach broadens world city research as our ACI focuses on technology spaces primarily generated by start-up enterprises. This augments the common preoccupation of world city research with the largest globalized APS firms while resonating with the early literature on the services revolutions predating contemporary world city research. Additionally, the start-up perspective adds a dynamic vector to understand change in the world city network. Those places with a lot of start-up activity in the APS sectors are expected to be on the forefront of new work practices and new integrations of APS activity. Using near-real time data sources will enable understanding the role of technological evolution dynamically as the position of tags in the sectoral categorization may change organically (Van Meeteren et al., 2022). Additionally, the paper integrates debates in financial geography with those in evolutionary economic geography, highlighting the potential cross-fertilization between research on services and finance on the one hand

Table 2

Dealroom.co Industry and Technology Filters Used for Data Harvesting.

Application Sectors	Enterprise Software, FinTech, Gaming, Health, Hosting, Jobs Recruitment, Legal, Marketing, Media, Real Estate, Security, Telecom
Technology Applications	3D Technology, Artificial Intelligence, Autonomous and Sensor Tech, Big Data, Blockchain, Computer Vision, Connected Device, Deep Learning, Deep Tech, Hardware, Internet of Things, Machine Learning, Mobile App, Natural Language Processing, Quantum Technologies, Recognition Technology, Virtual Reality

and innovation and technology on the other.

The current research has not been without limitations. Data availability meant we were limited to a set of 77 cities in Europe and North America and the relative newness of near real-time dataset still does not allow for longitudinal analysis (Van Meeteren et al. 2022). Particularly, data on emerging economies in Asia that have an important role in the global digital transformation had to be omitted. Such a geographical limitation falls short of the ambition of understanding the world city network as a global phenomenon. In order for a technology space analysis to fulfil its complete potential as a complementary perspective to conventional world city analysis, the geographical and temporal scope needs to be expanded. Nevertheless, this paper provides a significant conceptual and methodological stepping stone to a new generation of world city research that can increasingly leverage the potential of near real-time data as its scope increases.

Yet, the resulting economic geography of the variegated digital transformation in the APS complex provides us with a map that is more an explanandum than an explanans. It shifts our collective research gaze to new places, such as San Diego, Austin, Seattle, Boston or Berlin, where the salient digital transformation may have not been the focus of much world city research attention in the past. Conversely our analysis conjures a picture of “ageing” world cities, think of Miami, Rotterdam or Geneva, that are not in at the forefront of implementing the latest technologies. But how worrisome is that? These contrasts could also merely be the result of an enduring division of labour between complementary cities. Following the precepts of geographical network

analysis (Uitermark and Van Meeteren, 2021), answering such evaluative questions necessitates to complement our current extensive research endeavour with an intensive research phase (Sayer, 1992 [1984]) to ground truth the quantitative findings, corroborate their implications, and comprehensively establish the causal mechanisms that can explain the variegated digital transformation of the world city network.

CRedit authorship contribution statement

Francisco Trincado-Munoz: Methodology, Software, Formal analysis, Data curation, Writing – original draft, Visualization. **Michiel van Meeteren:** Conceptualization, Writing – original draft, Methodology, Supervision. **Tzameret H. Rubin:** Writing – review & editing, Resources. **Tim Vorley:** Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

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

Data availability

The authors do not have permission to share data.

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Appendix

Appendix 1. Data Harvesting

To obtain the data from Dealroom.co, we use the industry and technology filters available on the platform. The 40,754 companies were obtained through the combinations of filters, between industry and technology. Using the filters in Table 2, we obtained the final dataset. The filters were discussed within the research team to generously capture the APS sector. While the companies were selected using filters, our unit of analysis are the “tags”. Tags appear in each company’s profile and refer to categories that describe the companies’ technologies, application sectors, or other characteristics particular to that company usually obtained from their digital footprint. Dealroom.co applies their proprietary algorithm to ‘search’ and categorise the digital appearance into those tags. We selected companies with information of at least two tags (as companies with only one tag will not contribute to the further analysis).

Appendix 2. APS-Complex Tags

Financial Tags	FinTech, Finance, Cryptocurrency, Investing, Risk Management, Risk, Banking, Payment, Compliance, Bitcoin, RegTech – Compliance, Trading, InsurTech, Financial Service, Financial Management Solutions, Transportation, Payments, Commission, Mortgages & Lending, Insurance, Asset Management, Wealth Management, Peer-To-Peer, Credit, Ethereum, Brokerage, Mobility, Scoring, Consumer Money Management, Decentralised Applications, Wallet, Navigation & Mapping, Debt Collection, Personal Finance, Exchange, Due Diligence, Currency, Governance, Safety, Business Development, Search, Buy & Rent, Financial Exchanges, Smart Contracts, Car, Secure, Money Transfer, Fleet Management, Financial Management, Transaction, Loan, Retirement, Classifieds, Foreign Exchange, Credit Scoring, Mining Technologies, Card, Token, Telematics, Saving, See Cost Management, Cash, ICO, Fin-Tech, Lending, Lending & Mortgages, Portfolio Management, Budgeting, Forecasting, Transparency, P2p Lending, Scalability, Micro Lending, Digital Assets, Credit Management, Tax, Digital Wallet, Altcoins, Alternative Finance, Mobile Banking, Hedge Funds, Derivatives, Cash Management, Commodities Islamic Finance, Currency Exchange, Consumer Lending
Accountancy Tags	Accounting, Back Office, Enterprise Resource Planning, Invoicing, Point of Sale, SME
Legal Tags	Billing, Order, Inventory Management, Audit, Account, Treasury

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Financial Tags	FinTech, Finance, Cryptocurrency, Investing, Risk Management, Risk, Banking, Payment, Compliance, Bitcoin, RegTech – Compliance, Trading, InsurTech, Financial Service, Financial Management Solutions, Transportation, Payments, Commission, Mortgages & Lending, Insurance, Asset Management, Wealth Management, Peer-To-Peer, Credit, Ethereum, Brokerage, Mobility, Scoring, Consumer Money Management, Decentralised Applications, Wallet, Navigation & Mapping, Debt Collection, Personal Finance, Exchange, Due Diligence, Currency, Governance, Safety, Business Development, Search, Buy & Rent, Financial Exchanges, Smart Contracts, Car, Secure, Money Transfer, Fleet Management, Financial Management, Transaction, Loan, Retirement, Classifieds, Foreign Exchange, Credit Scoring, Mining Technologies, Card, Token, Telematics, Saving, See Cost Management, Cash, ICO, Fin-Tech, Lending, Lending & Mortgages, Portfolio Management, Budgeting, Forecasting, Transparency, P2p Lending, Scalability, Micro Lending, Digital Assets, Credit Management, Tax, Digital Wallet, Altcoins, Alternative Finance, Mobile Banking, Hedge Funds, Derivatives, Cash Management, Commodities Islamic Finance, Currency Exchange, Consumer Lending
Consultancy tags	Legal, LegalTech, Legal Documents Management, Document Management, Law Enforcement Legal Information, Contract Management, Self-Service and Lawyer Marketplace, Legal Matter Management, Case Management, Litigation, Dispute Resolution, Lawyer, Compensation
Advertising tags	Marketing, AdTech, Subscription, Social Media, Advertising, Branding, Publishing, Sale, Crm & Sales User Behavior, Management, Social Network, Marketing Analytics, Content Management, CRM Behavior Analytics, Market Intelligence, Ecommerce Solutions, Lead Generation, Customer Service Tracking, Campaign Management, User Experience, Publisher Tools, Targeting, Influencer Marketing, Mobile Advertising, Loyalty Program, Sales Analytics, Digital Marketing, E-Mail Marketing Retargeting, Online Marketing, Mobile Marketing, App Marketing, Marketing Automation, Smb Media Buying, Video Advertising, Mobile Commerce, Online Retailer, MarTech, User Engagement Promotion, Online Media, Multi-Channel, Behavioral Targeting, Audience Targeting, Programmatic Advertising, Marketers, Display Advertising, Online Advertising
Technology tags	Software, Data, Platform, Machine Learning, Artificial Intelligence, Mobile, Hardware, SaaS, Big Data App, Blockchain, Internet of Things, Cloud Technology, Mobile App, 3D Technology, Automated Technology, Navigation, Search Engine, Recognition Technology, Predictive Analytics, Augmented Reality, Nanotech, Data Analytics, Automated Process, Robotic, Printing, Information System, Cybersecurity, Deep Learning, Cloud & Infrastructure, Natural Language Processing, Image Recognition, Cloud Computing, Automotive, 3D-Printing, Quantum Technologies, Industrial Automation, Quantum Computing, Autonomous Vehicles

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