As pharma is to healthcare, so infrastructure is to city well-being

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Abstract— **This paper claims that many useful analogies exist between the pharmaceutical and the infrastructure industry, not least their roles in creating health and well-being for their respective customers. Ultimately, pharma delivers medicines for the health of individuals whilst infrastructure delivers energy, potable water, etc for places where communities and businesses live and work (cities for short). Medicines are the life-blood of people, whilst infrastructure products and services are the life-blood of cities: both aim for public health and societal good.**

The challenges affecting the two industries, including population growth, globalisation, environmental sustainability, and climate change, are having similar impacts, as are the failures and disruptions to them. The structures of the two industries, their large organisations, and particularly the need for regulation has similarities. Both industries and organisations in each industry are complex systems: they co-evolve with their environments including technological innovations; they are dynamic with non-linear flows of goods and services; lock-in and path-dependency is evident as is the need for continuous adaptation. By using a complex systems' lens the analogies are examined and learning opportunities are identified.

Keywords— **Pharmaceutical Industry, Pharmaceuticals, Drugs, Complex Systems, Cities, Infrastructure, Healthcare, Analogy.**

I. Introduction

COMPLEX systems are now a day-to-day reality in many fields of life. In fact, complex systems emerge out of simple needs which grow in structure and complexity over the time.

II. Pharma characterisation

Medical drugs to treat diseases have perpetually been a need in human history. The pharmaceutical industry has its origins in the emergence of companies producing drugs in large scale but also such with organic chemical and dye production in the late 19th century [1,2]. Back then, over the counter (OTC) drugs were sold directly to patients or 'ethical' medicines to doctors and pharmacists. Here, R&D was not established yet and few firms did marketing, with good profits. After the wars, pharmaceutical companies gained technological and organisational capabilities as well as innovative opportunities owing to the financial support through funding and support programmes. Due to this and the increasing medical knowledge, innovation became the core of the business [1]. Exogenous factors such as patent protection and growing demand as well as health insurances created a positive feedback loop, facilitating the self-sufficiency of the system. Due to patents being granted mostly on processes, not products, country-specific 'innovation tracks' emerged: while some countries focused on finding novel processes to produce existing drugs (often named 'me too' drugs), others did not experience such negative feedback on the innovation capabilities (perhaps other than producers of generics) [1].

The pharmaceutical industry transformed into a high-growth sector with high innovation and profitability. Investments into formal in-house R&D programmes facilitated the entrance into the drug market based on innovation, broadening the range of tools medical doctors could use to treat their patients.

Fundamental restrictions were introduced by the United States Food and Drug administration (FDA), requiring firms to show safety and efficacy to obtain marketing authorisation [3,4] and launch the drug into the market. This in turn had a negative impact on the returns: the R&D efficiency, defined by the number of new drugs introduced into the market per billion US dollars of R&D spending, halved around every 9 years, from the 1950s up to 2010 [5].

Since then, the pharmaceutical industry has established itself with relatively smaller ups and downs, constantly developing new strategies to optimise drug delivery.

Manuscript received 31 August 2022; revised 6 January; accepted 13 January 2023; published 15 June 2023.

This article has been subject to single-blind peer review by a minimum of two reviewers.

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Digital Object Identifier: https://doi.org/10.55066/proc-icec.2022.45

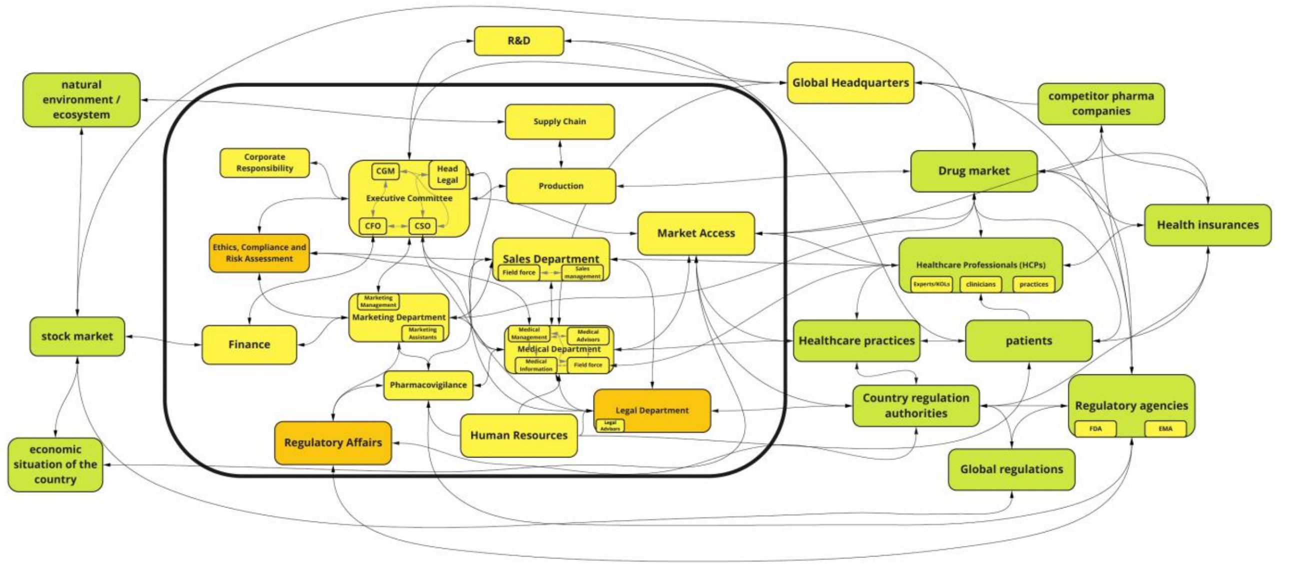

Fig. 1. *A gross schematic representation of the complex system of a pharmaceutical company, with some of the elements visualised as subsystems visualised. Arrows describe feedback between the elements. R&D, research and development; CFO, chief financial officer; CSO, chief scientific officer; CGM, country general manager; HCP, healthcare professional; FDA, federal drug agency; EMA, European medicines agency.*

Furthermore, cooperation with universities pushed basic and scientific research, facilitating the birth of new biotechnology firms and start-ups, typically university spinoffs. The big players also use the strategy to wait for new drugs to reach a certain stage before acquiring the start-up or licensing its drug [6] which has been shown to cost less compared to in-house development [7].

Once the marketing authorisation is granted, an optimal positioning of the drug is essential to make it available to the eligible patient population and achieve an efficient profit. The department for Market Access emerged from this very need and has become a critical component in the structure of a pharma company. In the classical sense, Market Access (MAx) developed to aid in pricing and reimbursement of drugs, which was based on efficacy and safety data thereof [7]. In contrast, the department "Ethics and Compliance" materialised from the reaction of agencies and legal authorities towards corporate misconduct, further posing negative feedback on the operation of pharma companies [8].

In general, the complex structures and elements of all pharma organisations are somewhat similar to each other [9], perhaps with slightly different names of departments or individual functions. The local country organisation consists of departments governing Medical, Sales, Marketing and regulatory issues (Fig. 1) [10].

Each of these elements is a complex subsystem in their structure and function. The various number of potentially interacting elements highlights the high degree of multiplicity and of interdependence of this system, while the heterogeneous elements inside and outside of it make up the diversity.

Additionally, the adopted matrix organisation leads to certain dynamics in the interactions where often new, temporary interactions and feedback loops occur in different phases. For example, Market Access has evolved into a cross-functional department over the last years, primarily due to exogenous factors such as increasing healthcare costs, more complicated pricing and reimbursement environment as well as decreasing R&D returns, creating a feedback loop to and from the payer [5,11]. This function has gained a central role in communicating the value of the drug to the stakeholders, becoming crucial for a successful launch [12]. Similarly, Medical Affairs transformed from the traditional supporting function into a strategic role with a responsibility of ensuring the launch readiness for the drugs [13].

The boundaries of a pharma company as a complex system are determined by the departments forming a tight network relationship with each other to ensure an efficient operation in the local country branch.

Although the connections look similar to each other, the feedback to and from each element is very diverse: for example, the executive committee (EC) has a connection to the finance and legal departments due to the heads being a part of the EC. In contrast, the feedback to the Marketing department is rather negative as it imposes regulations and defines a certain border for this subsystem.

Moreover, ambivalent connections translate into different behavioural patterns of a pharma company, depending on the drug(s), its timepoint and phase the drug is in. Exogenous factors such as the drug market feedback to the different elements of the system: do the competitors have an advantage over a drug? If so, does this restrict the operation of the complex subsystem (e.g., Marketing) or encourage new ideas? These questions might be easy to answer for a given drug in a simple disease area (meaning known risks and no major competitors), however, even here one has to state that it all depends on 'who' is giving the answers. Field-based functions are important to prevent departments deciding based on their own beliefs and to consider exogenous variables outside the boundary such as the current drug market and customer mindsets, leading the companies to take a more inclusive approach, without restricting themselves to less future possibilities. An example can be the different mindsets of experts or key opinion leaders (KOLs) from those of non-KOLs. These and other reflections are essential to avoid locking into a path-dependency.

Therefore, a typical pharma company of today is the temporary 'result' of this evolution over the years, having 'accumulated' the departments that have become essential for the success of the corporate structure.

The fast-changing structure of and functions within the pharma companies is especially on account of their underlying fully privately funded and motivated business: digital solutions had to be deployed fast in order to maintain the business. An efficient operation is critical for a pharmaceutical company, as the development of a drug is a high-risk business: it is never clear whether it can be introduced to the market. First, a thorough decision-making takes place whether to proceed with the development of a drug candidate. If so, this drug candidate then undergoes many cycles of revision and testing (pre-clinical phase, phase I, phase II and phase III clinical trials before marketing authorization), under the supervision of scientific, medical and ethical committees to yield enough data for its safety and efficacy before being made available to the public. This development phase is a highly costly matter and is financed by the sales of other drugs, meaning, being privately funded translates into a necessity of the upkeep of a self-sustaining business. This is especially challenging given the probability from phase I to market authorization is only about 10% [14].

The pharmaceutical industry is the only source for the relatively fast supply of medicines to people and essentially arose from the medical needs and compromising health states. The operations and efficiency of the production of pharmaceuticals is the result of the interactions between the pharmaceutical industry and agencies, which both strive towards one goal: making drugs available to people. Therefore, toughening regulations can decrease the incentives of developing new drugs [15].

III. INFRASTRUCTURE CHARACTERISATION

Infrastructure systems are the source of critical services providing water supply, electric power generation, telecommunications, natural gas, roads, railways, etc. Improvements in the infrastructure industry are toward better – cost-effective, resilient and sustainable – critical services laying the foundations for the well-being of a society.

Many economic infrastructures were privatised globally in the 1980s in a push toward greater innovation and efficiency, perceived as coming from private organisations. Traditionally, infrastructure was state-owned and operated as a monopoly. But as economic infrastructures provide critical services (mobility, energy for heating, etc., clean water, sewage removal, and telecommunications) privatised parts of the industry are heavily regulated. Complexity arises from innovation from different forms of infrastructure and associated regulators, but the resulting emergence is often constrained by negative feedback [16].

The infrastructure industry arose in response to demand, as settlements emerged and each family/building had common basic needs for critical services. The purpose of the infrastructure sector is to provide security of critical services at an affordable price which does not compromise the quality of the natural environment.

Infrastructure is long-lived and needs capacity to adapt to unforeseen changes in patterns of demand, particularly the fast growth of urban environments (referred to as cities in this paper but meaning settlements of any scale). Cities are where society grows and diversifies, however this growth considerably intensifies demand in particular geographical locations which are often far away from points of supply, requiring long linear infrastructure networks. Plans for new assets, updates, and replacements must meet demand over several decades because of the long-lived nature of infrastructure assets. It is not surprising that national infrastructure plans span decades [17]. For example, sensors and actuators may be added later but will need integrating to improve control systems. Technologies generally improve efficiencies, provide better services, and enable avoidance of undesirable waste [18].

Infrastructure companies are risk averse and often locked into particular technologies which were already tried and tested at the time of implementation. Technological churn can be very fast and so any in-use technologies are retained and need integrating with newer ones.

The infrastructure industry comprises interdependent organisations from small companies to big multinational suppliers which provide products and services to larger agencies responsible for network operations. Overall, there are several transfers of goods and services between sectors. Some key ones are shown in Fig. 2. The complex system of national infrastructure is highly connected with the society, the economy, and the environment which bidirectionally pose restrictions or enabling factors within the system [19]. Integrated infrastructure sectors together provide the set of solutions for city welfare by keeping the lights on, providing potable water and uninterrupted telecommunications, ensuring the availability of modes of transport, etc.

Over the decades, and with increasing privatisation, regulation of infrastructure has become an industry itself. The origins of regulation are sectoral requiring sector specific skills for standards and codes for safety, etc.

Recognition of the increasing independency and co-dependencies between sectors and firms has shifted path dependencies toward integrated regulation [20] however sectoral regulators are strongly locked in to discrete government departments such as The Office of Gas and Electricity Markets (OFGEM) with the Department for Business, Energy & Industrial Strategy (BEIS). Exogenous factors influencing infrastructure are several: green banks who are funding the development of cleaner technologies, climate action lobby groups including the UK held COP27 [21] health and safety on construction sites, fair employment of overseas parts manufacturers, etc. There is also a growing body of prosumers, who can produce some of their critical infrastructure needs locally, reducing their demands of infrastructure services but also in some case providing many sources of smaller, distributed supply. An example is the increased use of photo-voltaic technology.

The infrastructure industry is a high-growth sector of the economy, increasingly implementing new innovations and attracting private investors, pension funds, etc. due to the stability of the industry.

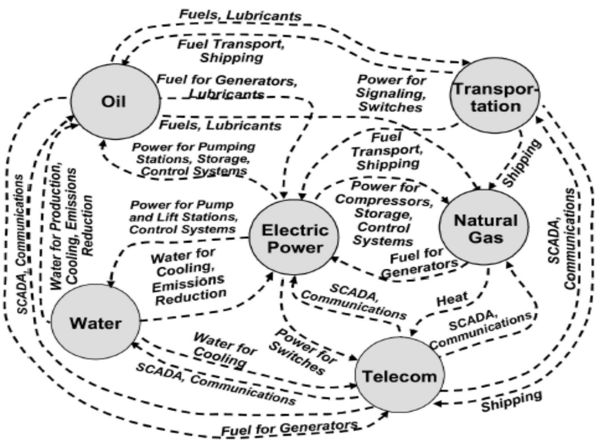

Fig 2. *Infrastructure interdependencies [22].*

IV. ANALOGIES

We utilise the framework of structure mapping theory for analogical reasoning to assess relative analogies and analogical inferences, while simultaneously avoiding any absolute analogies [23,24]. Hence, the relation of infrastructure to city well-being is put in analogy to the relation of pharmaceutical industry to healthcare. However, unlike the classical *source* (or *base*) to *target* projection, we apply a bidirectional analogy as both complex systems can be either of them, and leave it up to the open interpretation of the reader to decide.

Careful investigation of both complex systems revealed several analogies in complexity properties, emerging standards and direction of trends which we believe are noteworthy to analyse.

It is evident that both infrastructure providers and pharma companies have similar complexity properties. Both exhibit multiscalarity by operating under multiple modes of governance, i.e. hierarchically, self-governing and co-governing [25].

Additionally, we determined path dependencies such as the emergence of functions as a response to external regulations to be present in both systems but also how the collection of insights through engagement is essential for realistic strategies and successful operations to take place.

Furthermore, both systems are constrained, as the pharma industry has to operate within certain regulations and is constrained in resources, i.e., the amount drugs that have made it past the critical stages, while infrastructure systems, even when privatised, are constrained by regulations and resources, such as technologies using fossil fuels.

Therefore, both systems show rigidity as an additional complex variable and are locked in: the underlying infrastructure determines the development of cities into a set of certain directions, while the diversity and size of a pharma company's pipeline determines the development and future of the company.

When looked at the operations, several analogies can be determined in both complex systems in their services to cities and people (Table I).

Both systems have a similar social responsibility and so-called neglected areas. In infrastructure and cities, urban areas with less focus are less controlled which can lead to formation of slums with characteristics such as unhealthy living conditions, hazardous locations, poverty and social exclusion [26]. In pharma companies, decisions to shift focus from certain therapeutic areas due to e.g. lack of upcoming drug in near future and little budget for that department, can delay urgently needed solutions in diseases, leading to a certain neglect in that area and uncontrolled consequences. In fact, we believe these two situations are highly connected with each other through the social responsibility that emerged for both systems over the years. This is especially apparent, just as Winslow stated "Men and women were sick because they were poor, they became poorer because they were sick, and sicker because they were poorer." [27]. Increasing poverty and demand for access to medicines, as well as the high price tags of treatments turned into a major disadvantage for poor groups which contributed to the emergence of social responsibility in the pharmaceutical industry.

Additionally, failures in infrastructure delivery, such as unaffordability by the poor, match with pharma failures to provide equitably to all individuals: the poor cannot afford the best drugs. The urban sprawl in cities and the rise of informal settlements without sufficient infrastructure, can be observed in health care by the rise in use of alternative and unreliable medications by sections of the population who are excluded from pharma penetration. The availability of generic drugs at lower prices can substantially enhance patient access and is an important channel for healthcare systems to save costs while supporting well-being [28,29]. Likewise, increasing transport prices and missing availability can prevent poor groups from accessing public services, contributing to their social exclusion [30]. When looked at the physical accessibility, boundaries in planning were not set in a way to include disabled groups and had to be changed accordingly to be much more inclusive.

Apart from this, standards continue to raise the bar for the performance of critical services and drug delivery. Health and Safety standards in particular require that working conditions of employees do not create accidents and chronic illnesses. Likewise, safety and efficacy standards are critical for pharmaceuticals to prevent any serious adverse events and protect human lives. It is striking how further standards for both systems evolved in an almost identical way: transparency and fairness gained importance in both systems, leading to e.g. Construction Sector Transparency Initiative (CoST) for infrastructure or Anti-Bribery and Anti-Corruption Policies adopted by pharma companies [31,32]. For both systems, these regulations posed further restrictions, however, at the same time paved the way to other opportunities. With the increasing ecological sensitivity, the current standards for both systems are evolving in a comparable direction, e.g. sustainability has become a central topic in every industry. City planning considers smart infrastructure, while the pharmaceutical industry considers the CO2 footprint from manufacturing to final product. In fact, sustainability is now a big component of the concept of corporate responsibility.

By analogy, infrastructure operations with distinct supply systems delivering specific critical products and services, pharmaceutical companies have become the exclusive suppliers of drugs within the healthcare system. Increasingly traditional public sector infrastructure provision has been privatised, as has national health services drug development, resulting in high levels of regulation in each, constraining innovation and profitability, which are hallmarks of the private sector.

Furthermore, we also identified similar challenges that both systems have to face: e.g. climate change and the rising planetary consciousness but also service shortages due to the pandemic. Resilience, and the capability of infrastructure systems and pharma companies to prevent disruptions, absorb hazards and recover quickly will allow them to address shortages in critical services and drugs. Pharma and infrastructure organisations have to increasingly adapt to major changes to the ways they are organised in order to make step change in the performance and reliability of their operations. For instance, infrastructure contributes substantially to the heat island event, requiring infrastructure solutions to deal with heating and ventilation or to reduce their emissions and the problems they create, e.g. by decarbonising as required by the Carbon Act In the UK [33]. However, because of the long-term investments in both infrastructure solutions and drugs, these have to integrate with previous solutions: new methods of electricity generation for example have to integrate with an existing distribution network. Likewise, new drugs have to work with drugs that people are taking for other health concerns, which is partially mitigated by the knowledge of the pharmacokinetic properties and potential drug-drug interaction of pharmaceuticals, but also due to an established pharmacovigilance system for adverse event monitoring after drugs receive market authorisation.

In case of the pandemic, pharma companies have shown a certain agility as a complex system: a fast and early understanding of the changes in the environment, if possible, even foreseeing them, gave an advantage in turning on the correct levers early enough to make sure that the results are obtained at the right time when the changes happen. According to a survey published in the latter half of 2020, respondents indicated that their companies acted 20 to 25 times faster than expected [34]. Digital assets and digitalization became a top priority within no time, increasing the funding into digital initiatives, leading to more digital roles and number of customers. Most pharma companies responded well in the new era of 'becoming digital' and, most importantly, created new strategies of communicating with the healthcare professionals (HCPs). There is an increasing focus on 'omnichannel' or 'multichannel' engagement strategies, trying to find out the best and most efficient ways to interact with the customers through different channels by finding their preferred channel(s). According to a US survey, 44% of companies stated to be rolling out multi-channel activity plans [35]. Identifying the preferences of each HCP translates into a huge amount of data to be analysed in an efficient way to obtain key strategic findings and insights, and enable better services.

Similarly, the concept of "smart cities" builds on using technology in a purposeful way to translate data into insights and actions, having the potential to better understand and cater to the needs of subgroups or emerging generations [36]. This is especially important as current infrastructure in cities is rigorous and permanent due to assumptions of stationarity, not allowing much space for change and improvement. The current planning and design have been elegantly described as obdurate, disconnected and mechanistic among others, being in stark contrast to adaptive infrastructure [37]. The latter has been described as being connective, modular, compatible and responsive. Here, lessons can be learned by the pharmaceutical companies, most of which are structured as a matrix organisation and operate in a trans-disciplinary (or cross-functional) way. This renders them advantageous for actions such as cross-functional communication possibilities, *i.e.*, the field force being able to communicate with not only their managers but also to give input to other functions, e.g. Marketing or Global, creates several feedback loops in the system, giving many possibilities and channels to respond to changes at different levels of the organisation. This kind of organisation is highly valuable for a company to prevent from falling into a rigid mindset. Also, providing a platform for exchange between country specific management and global management often gives rise to important insights that would perhaps not be contemplated. Smart cities strive for a similar mindset and look for ways to make the society a contributor rather than a consumer and recipient, close to the "empowerment" efforts of patients by the pharma industry through apps and collaborations with patient organisations. Just like the cross-functional communication within a pharma company to work efficiently, a cross-disciplinary communication is essential for the materialisation of a smart city but also any city could be rendered more agile and flexible to unforeseen changes, contributing more to the well-being of people.

The outlook for both systems is alike as well; interconnectivity, empowerment (of people and HCPs) and integration of machine learning algorithms are being investigated and tested to achieve more efficient operations [38,39] and involve the main parties involved, especially people using public services provided by infrastructure and people using medicines provided by the pharma industry.

V. CONCLUSION

Without a whole systems consideration, partial solutions can create emergent properties which are unintended and often undesirable, leading to new unpredicted issues. This is especially critical when there are external systems co-evolving due to the behaviour of a complex system. Both complex systems, through the various interactions with the external word, have an impact on the operations and evolution of those complex systems, e.g. new ways of working.

We attempted to identify some analogies between infrastructure and pharmaceutical companies in the hope of a better understanding of the operations of and connections with each other as well as inspirations about finding solutions from these two similar, yet distinct complex systems. Table I shows some of the identified analogies. The two systems are especially distinct when looked at the historical governance of each: while the pharmaceutical industry is fully private and has never been under state governance, the infrastructure has been under governmental management and is now only partially privatised. While "privatisation" has a negative connotation, it is also evident that companies have an incentive to succeed and hence have to decide and act fast, making it easier for the public to receive certain services. Additionally, the pharmaceutical industry can be an example showing how public regulations can help shape a private industry to be as beneficial as possible to the public. In fact, companies are increasingly understanding that achieving a mindset of serving stakeholders is critical to success, thus creating value for their shareholders.

Both infrastructure, in its provision of critical services to cities, and pharma in its provision of drugs to people are embracing social responsibility but still have lots to address. The increasing numbers of impoverished people in global populations mean that access to critical services and to drugs is more and more difficult to satisfy. This positive feedback loop just exacerbates the challenges of equitable provision of critical services and drugs.

Overall, we can state that both systems are long-lived investments with a legacy, are driving innovation in order to meet changing demand, have constraints to what they can do and must co-evolve with others outside their own boundaries, and can create unexpected outcomes despite investment in testing, modelling and trialling.

We believe that these analogies can serve as a basis for opportunities for both complex systems to learn from each other and serve as a basis to identify gaps. Best practices in the establishment of the pharmaceutical industry, e.g. in terms of compliance, digital transformation or the interaction with the public stakeholders might inspire city planning with new infrastructure concepts.

TABLE I
OVERVIEW OF ANALOGIES BETWEEN THE COMPLEX SYSTEMS OF CITIES AND OF PHARMACEUTICAL COMPANIES

	Infrastructure	**Pharmaceuticals**
Social responsibility	Access to infrastructure	Access to medicines
Neglected areas	Urban areas with less focus -> neglect	Therapeutic areas with less focus -> neglect
Challenges faced	Climate change, pandemic, changes	Climate change, pandemic, changes
Co-Evolution	Social structures, inclusion of scales	Continued medical education
Increasing standards	Safety & Efficiency -> Fairness & Transparency --> Sustainability, smart cities	Safety & Efficacy -> Compliance --> Corporate responsibility
Trend	Interconnectivity Machine Learning & AI	Cross-functional operations Machine Learning & AI

ACKNOWLEDGEMENTS

LV acknowledges the support of EPSRC grant EP/R017727/1 for the Coordination Node of the UK Collaboratorium for research in infrastructure and cities.

REFERENCES

[1] Malerba F, Orsenigo L. The evolution of the pharmaceutical industry. Business History. 2015 57:5, 664-687, DOI: 10.1080/00076791.2014.975119

[2] Taylor, D. (2015). The pharmaceutical industry and the future of drug development. Pharmaceuticals in the Environment, 2015, pp. 1-33.

[3] FDA website. Milestones in U.S. Food and drug Law. www.fda.gov/about-fda/fda-history/milestones-us-food-and-drug-law (accessed 7/8/2022)

[4] Rägo L, Santoso B. Drug Regulation: History, Present and Future. www.researchgate.net/publication/265533479_Drug_Regulation_History_Present_and_Future_1 (accessed 7/8/2022)

[5] Scannell JW, Blanckley A, Boldon H, Warrington B. Diagnosing the decline in pharmaceutical R&D efficiency. Nat Rev Drug Discov. 2012 Mar 1;11(3):191-200.

[6] DiMasi JA. New drug innovation and pharmaceutical industry structure: trends in the output of pharmaceutical firms. Drug Inf J, 2000 Vol. 34. pp. 1169-1194.

[7Y] Simoens S, Huys I. R&D Costs of New Medicines: A Landscape Analysis. Front Med (Lausanne). 2021 Oct 26;8:760762.

[7] McClearn C, Croisier T. Big pharma's market access mission. Deloitte University Press 2013. www2.deloitte.com/content/dam/insights/ 41 rticularles/big-pharmas-market-access-mission/DUP436_Big_Pharma2.pdf (accessed 7/8/2022)

[8] Whitelaw SB, Life Science Compliance from the Beginning, Pharma Congress 2019. https://2019.pharmacongress.com/wp-content/themes/ipc/documents/LS_Compliance_from_the_Beginning.pdf (accessed 24/12/2022)

[9] Chand S, Gupta GK, Gera B. Pharmaceutical Organization Structure and Functions. 2008. Conference: Proceedings of 1st Rashtreeya Yuva Vaigyanik Sammelan. (Researchgate, accessed 28/8/2022)

[10] Cockburn IM. 2004. The changing structure of the pharmaceutical industry. Industry priorities. Health Affairs. Volume 23; Number 1.

[11] Kumar A, Juluru K, Thimmaraju PK, Reddy J, Patil A. Pharmaceutical market access in emerging markets: concepts, components, and future. J Mark Access Health Policy. 2014; 2: 10.3402/jmahp.v2.25302.

[12] Corvino B, Elsner N, Wagh M, Jaeger J. Rethinking market access. Deloitte Insights, 2022. www2.deloitte.com/xe/en/insights/industry/life-sciences/pharmaceutical-market-access.html (accessed 28/8/2022)

[13] Gores M, Dyce G, Trkulja AK. Medical launch readiness. IQVIA, 2019. iqvia.com/-/media/iqvia/pdfs/library/white-papers/medical-launch-readiness.pdf (accessed 7/8/2022)

[14] Dowden H, Munro J. Trends in clinical success rates and therapeutic focus. Nat Rev Drug Discov. 2019 Jul;18(7):495-496.

[15] Report "Research and Development in the Pharmaceutical Industry". Congressional Budget Office. April 2021. https://www.cbo.gov/publication/57126 (accessed 10/11/2022)

[16] Kessides, Ioannis N.. 2004. Reforming Infrastructure: Privatization, Regulation, and Competition. Policy Research Report. Washington, DC: World Bank and Oxford University Press. ©World Bank. https://openknowledge.worldbank.org/handle/10986/13525 License: CC BY-NC-ND 3.0 IGO. (accessed 20/12/2022)

[17] Wang C, Sierra Huertas D, Rowe JW et al. Rethinking the urban physical environment for century-long lives: from age-friendly to longevity-ready cities. Nat Aging 1, 1088–1095 (2021).

[18] Gann D, Dodgson M, Bhardwaj D. (2011). Physical-digital integration in city infrastructure. IBM Journal of Research and Development. 55. 8. 10.1147/JRD.2010.2095750.

[19] Dolan T (2021) Fundamental Infrastructure and Utilities in The Intelligent Nation: How to Organise a Country, Beckford, J ISBN 9780367430573.

[20] OFWAT (2022) Joint Regulators Group, www.ofwat.gov.uk/about-us/who-we-work-with/jrg/ (accessed 28/8/2022)

[21] UNCOP26 (2021) United Nations Climate Change Conference (ukcop26.org/) accessed 28/8/2022

[22] Little, R. G. (2012). Managing the risk of aging infrastructure. IRGC, Public Sector Governance of Emerging Risks Council, Infrastructure Case.

[23] Gentner, D. Structure mapping, a theoretical framework for analogy. Cognitive Science, 1983. 7:155-170.

[24] Walliser, B., Zwirn, D., & Zwirn, H. (2021). Analogical Reasoning as an Inference Scheme. Dialogue, 1-21. doi:10.1017/S0012217321000226

[25] J Kooiman, "Governing as Governance." London: SAGE. 2005.

[26] Global Report on Human Settlements 2003, The Challenge of Slums. United Nations Human Settlement Programme. www.un.org/ruleoflaw/files/Challenge%20of%20Slums.pdf (accessed 26/8/2022)

[27] Winslow CE. The cost of sickness and the price of health. World Health Organization. 1951. Bull World Health Organ. 2006 Feb;84(2):153-8.

[28] Elek P, Harsanyi A, Zelei T, Csetneki K, Kalo Z. Policy objective of generic medicines from the investment perspective: The case of clopidogrel. Health Policy. 2017 May;121(5):558-565.

[29] Report by Oxera, prepared for The British Generic Manufacturers Association. The supply of generic medicines in the UK. 2019. www.oxera.com/wp-content/uploads/2019/06/Oxera-study-on-the-supply-of-generic-medicines-in-the-UK-26-June-2019.pdf (accessed 28/8/2022)

[30] Gates S, Gogescu F, Grollmann C, Cooper E, Khambaita P. Transport and inequality: An evidence review for the Department for Transport. NatCen Social Research 2019 Jul 10. assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/953951/Transport_and_inequality_report_document.pdf (accessed 28/8/2022)

[31] Infrastructure Transparency Initiative (CoST), Construction Sector Transparency Initiative Programme Summary, 2012. infrastructuretransparency.org/wp-content/uploads/2018/06/CoST_Programme_Summary.pdf (accessed 29/8/2022)

[32] See anti-bribery and anti-corruption policies from various pharma companies, e.g. Pfizer (cdn.pfizer.com/pfizercom/corporate_citizenship/Pfizer_Anti-Corruption_Policy.pdf) or Novartis (www.novartis.com/esg/ethics-risk-and-compliance/compliance/anti-bribery-and-anti-corruption) – accessed 29/8/2022

[33] Climate Change Committee (2020), "The UK Climate Change Act", CCC Insights Briefings, No. 1 – www.theccc.org.uk/wp-content/uploads/2020/10/CCC-Insights-Briefing-1-The-UK-Climate-Change-Act.pdf. (last access: August 28, 2022).

[34] LaBerge L, O'Toole C, Schneider J, Smaje K. How COVID-19 has pushed companies over the technology tipping point—and transformed business forever. McKinsey, October 2020. https://www.mckinsey.com/capabilities/strategy-and-corporate-finance/our-insights/how-covid-19-has-pushed-

companies-over-the-technology-tipping-point-and-transformed-business-forever (accessed 27/11/2022).

[35] Underwood G, Experts discuss the field force's customer-centric future. Pharmaphorum June 2021 https://pharmaphorum.com/sales-marketing/experts-discuss-the-field-forces-customer-centric-future (accessed 27/11/2022)

[36] Bughin J, Manyika J, Woetzel J. Smart cities: Digital solutions for a more livable future. McKinsey Global Institute, June 2018.

[37] Gilrein EJ, Carvalhaes TM, Markolf SA, Chester MV, Allenby BR, Garcia M (2021) Concepts and practices for transforming infrastructure from rigid to adaptable, Sustainable and Resilient Infrastructure, 6:3-4, 213-234.

[38] McMillan L, Varga L. A review of the use of artificial intelligence methods in infrastructure systems. Engineering Applications of Artificial Intelligence. 2022 Nov 1;116:105472.

[39] Sahu A, Mishra J and Kushwaha N, Artificial Intelligence (AI) in Drugs and Pharmaceuticals, Combinatorial Chemistry & High Throughput Screening 2022; 25(11) .