Open Innovation Environments and their Importance in Materials Modelling and Materials Characterisation

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1. Introduction: Open Innovation and Open Innovation Environments

1.1. Open Innovation in general

In this White Paper, we provide some historical context to the development of Open Innovation Environments (OIE), and make the case that such platform technologies are key enablers of open innovation in complex research fields such as materials science.

To start with, we would like to revisit the concepts of Closed and Open Innovation (OI), respectively. Closed innovation is often depicted as a funnel with a solid surface (Figure 1), that conducts a wide range of solely organisation-internal ideas towards a targeted market. Only internal ideas are researched, developed and converted to a product for a targeted market (Chesbrough, 2003). It has the advantage that an organisation keeps its ideas internally, shields them from competitors and can assure to reach a particular market in a controlled way.

In contrast to this closed funnel, Open Innovation can be depicted by a funnel with a porous surface. External ideas are let in and droplets of findings can ooze at any time towards new markets and new exploitation routes.

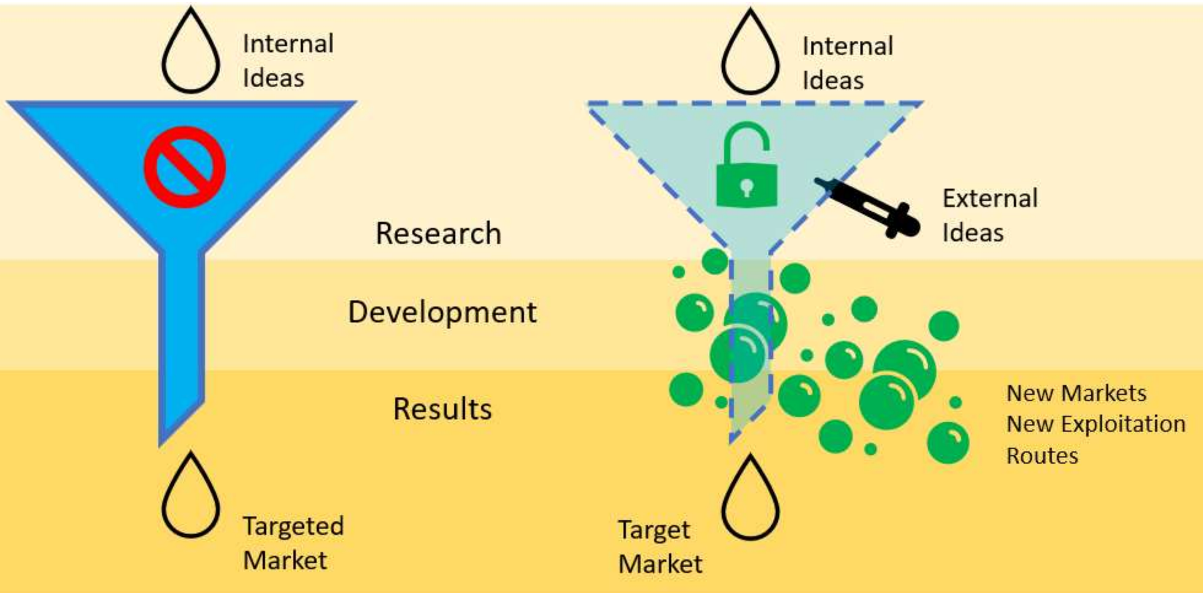

Figure 1 Corporate Closed (left) versus Open Innovation (right).

The funnels are usually owned by an organisation and correspond to a corporate environment. Strictly speaking, even organisations who favour a closed environment do have a certain openness to new ideas. They may hire external experts from both industry and academia to get new ideas, but internalise their ideas with non-disclosure agreements. Organisations who favour open environments will also use corporate environments and decide about the amount of porosity of their funnels.

Open Innovation is not only for industrial settings: Scientific research has also moved on from charismatic one-person research groups to multinational collaboration (Beck & al, 2020) as the latter provides more ideas from differently talented people around the globe.

An ideal OIE may form when two or more of these porous funnels supply both internal and external ideas, as depicted in Figure 2. Each funnel can be understood as an ecosystem that might provide equipment, knowledge, software, hardware to it, and most importantly, people.

By its design, the OIE therefore supports the evolution of innovation towards eco-system centric, cross-organisational innovation, termed Open Innovation 2.0 (Curley & Salmelin, 2013), which is based on integrated collaboration and co-created shared value.

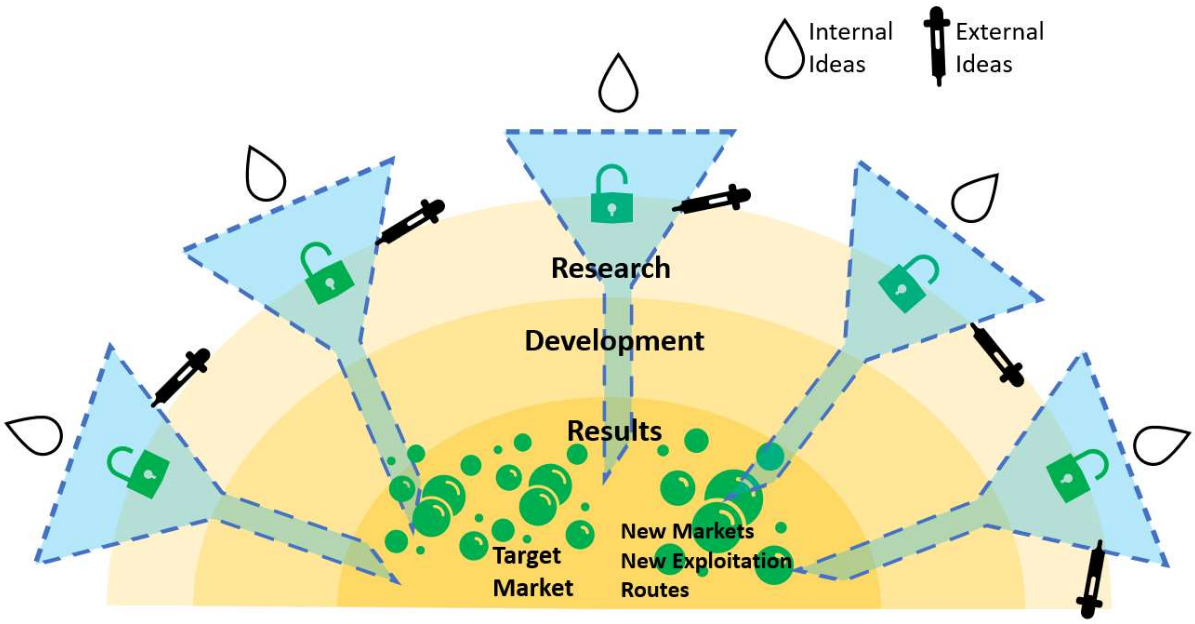

Figure 2 Open Innovation Environment

The OIE is not a physical place but a virtual place and the enabling technology is often referred to as Open Innovation Platform (OIP). The literal meaning of "platform" is "*a horizontal surface or structure with a horizontal surface raised above the level of the surrounding area*." (Dictionary, 2021) An OIP[1] welcomes all persons to enter it and raise above the level with new ideas, innovations, etc. These persons should be able to do this from wherever geographically they are located and at any time of day they wish to do so. Open innovation needs people to drive it and there are some historical examples to evidence that this fact is long known to humanity.

[1] E.g., https://openinnovationplatform.org/

1.2. Open Innovation from history to current times

The Romans are often synonymous with conquering most of Europe and beyond and building straight roads throughout the lands. However, they did recognise the value of openness as the different peoples of their empire could hone skills the Romans did not have. Hence, they found ways such as offering citizenships to people in return for their skills, especially to the Roman military and medical system. (Jeon, Kim, & Koh, 2015). The Romans realised that these skills should be provided for a duration of time to ensure them to be ingrained into their ecosystems. In more peaceful times, open innovation was driven by people to orchestrate people finding each other, and one example were the Salons (Simanowski, 1999) in Vienna, especially around 1900. The idea of a salon originated in France and was driven by nobility first and then the bourgeoisie took over and the orchestrators were women (salonnières). Women (Brantl, 2018) were not easily admitted to universities and leadership positions so they brought the arts, literature, music, science, politics and business to their homes. The Austrian elite in these fields would be regulars in those salons and exchange ideas. Austrian at the time meant many nations, religions and languages – one just had to be interesting enough to be invited or recommended. Another idea to bring people and nations together are the Expos[2], which started in 1851 in London. Crystal Palace was purposefully built there to house showcases of technological innovation. Nations send their brightest people, technology and openness to discuss more innovation to come. A similar event with industrial stakeholders happens, for example, at the world economic forum in Davos[3].

Instead of hiring a particular organisation or person to solve a problem, one could formulate the problem publicly and invite everyone to submit solutions or even produce a tangible solution in return of a reward. This innovation contests (Bullinger & Moeslein, 2010) could also be referred to as “crowdsourcing” (Acar, 2020) as anyone anywhere is welcome to offer a solution. An often referred to example was in 1869 the prize offering of the French emperor Louis Napoleon III to anyone who could make a substitute for butter. Also, the Opera house in Sydney[4] was the result of an architectural innovation contest - more than 223 entries were received from 28 countries.

People may want to control how open they wish to be towards their peers in an OIE. They also want to decide what role they take, i.e., themselves or a representant of an organisation, or maybe they wish to stay anonymous, i.e., separate their ideas from their persona. An elegant way to enable this is the Chatham House rule: “*When a meeting, or part thereof, is held under the Chatham House Rule, participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed.*” [5] Following this rule permits people to share ideas with their peers as much as they wish but gives them anonymity.

The implementation of open innovation principles can sometimes be slow and challenging due to common industrial practices, institutional factors, and cultural background. For example, in China, civil R&D was for years limited in many aspects and separated from the production. Due to international pressure, and with the aim to reach their economic goals, China started implementing an Intellectual Property Rights (IPR) protection strategy at the change of the century to be able to open-up the export and compete with external markets. Nevertheless, a comprehensive study of

[2] https://www.bie-paris.org/site/en/past-expos-a-short-history-of-expos
[3] https://www.weforum.org/our-impact
[4] https://www.sydneyoperahouse.com/our-story/sydney-opera-house-history/the-competition.html
[5] https://www.chathamhouse.org/about-us/chatham-house-rule

open innovation implementation and barriers in China (Savitskaya, Salmi, & Torkkeli, 2010) shows that the economic systems and institutions, especially the protection of IPRs, may have large effects on firms in the adoption and engagement in open innovation practices.

Recent studies from Eastern European countries show that vertical collaboration has a positive influence on open innovation. In contrast, horizontal collaboration with research centres and universities does not contribute to intensification of innovation actions (Saunders & Radicic, 2022). In most firms, international ownership increases the dissemination and implementation open innovation practices (Ebersberger & Mevenkamp, 2016). Still, most success in innovation is observed in interactions between companies and their suppliers, complementary partners and customers, and in some cases even through engagement with competitors as long as they are not direct competitors in end markets (Pop, Roijakkers, Coita, & Constantin, 2015).

1.3. The Development of Open Innovation and Open Innovation Environment in Europe

The European Union wants enable all their citizens to take part in open innovation, whether they are experts on or users of an innovation. (Directorate-General for Research and Innovation/ European Commission, 2016): The EU citizens "*create a demand for innovative products and services, they can fund and/or finance projects that are relevant to them, they can be at the source of innovative ideas worth spreading and scaling up and they can have a say in what research is meaningful to them and can impact their lives*."

"Open innovation, open science, open to the world; A vision for Europe", (Directorate-General for Research and Innovation/ European Commission, 2016) is the key publication setting out the direction and objectives of Open Innovation in Europe. It became clear that the EU was rather good at research but not so prolific when progressing from research to innovation.

The Horizon 2020 (H2020) framework programme, which ran from 2014 to 2020 with an €80 bn budget, was strongly interlinked with Open Innovation (Salmelin, 2013). It was recognised that Open Innovation thrives best if many actors/stakeholders are brought together and play to their strengths. It was also important to bring new innovations to life and let them be more than just a blue print. The applicants of H2020 were supposed to become more proactive and orchestrate their own OIE and become an open innovation hub and use their skills to contribute to provide better innovations to society as a whole. One of the key players were SMEs with their flexibility and enthusiasm and willingness to try something new. All this was enabled by the four freedoms governing the movement of goods, persons, services and capital within the EU. This means one can tap into talent and resources of all member states and a co-creation process can start with knowledge flowing across the entire economic and social environment (Directorate-General for Research and Innovation/ European Commission, 2016).

To enable this transformation from idea to actual product, the EU had to tackle the regulatory environment. Products have to have certain standards such as ISO[6], follow health and safety, etc. so the public can rely on them. This meant the regulation process still had to be reliable but needed to speed up from several years to shorter time frames. The European Commission is continuously

[6] https://www.iso.org/home.html

working to lower regulatory barriers in a sensible way to not hamper the innovation process but still protect its citizens (Directorate-General for Research and Innovation/ European Commission, 2016).

To push ideas toward products requires money so the European Union offers the European Fund for Strategic Investments (EFSI)[7] which was as launched in 2015 as a joint initiative between the EU and the European Investment Bank (EIB) Group. EFSI provides funding for economically viable projects to deliver a positive impact on the European economy.

Together with Open Innovation, Science had to become more open as well. In the past, papers were written in secret, submitted to a peer reviewed journal, and authors were given 50 copies of a reprint they could hand out. The process is long and tedious and a closed scientific environment until the science emerges. Practitioners of Open Science would make use of producing pre-prints of their papers and depositing these in a repository such as Zenodo[8], ResearchGate[9], etc. The advantage is that other scientists can read about novel findings straight away, use them, enhance them, give feedback, start collaborating, etc. Such pre-prints do have a clear owner and are citeable – hence the IP is protected. To make Open Innovation a global success, it has to be open to the world. Similar to the EU, a practitioner of Open Innovation may want to include everyone everywhere who wants to innovate.

1.4. Some examples for Open Innovation Environments

Creating an OIE was crucial for the development and growth of interdisciplinary technologies, such as Nanomedicine (Fontaine, Boskovic, & Ge, 2014). The Nanomedicine supply chain has a wide range of stakeholders, each of them with a substantial impact in the commercial outcomes of this technology. The environment becomes even more complex when public perception and ethical issues are included. The introduction of nanotechnologies into medical applications required stakeholders to understand and apply the process of open innovation to secure translation from excellence of science, scaling-up of manufacturing processes and establishment of an industrial nanomedicine sector.

idexLab[10], for example, is such an Open Innovation Platform, that was founded in London around 2009-10. Stakeholders of the telecommunications sector realised that they share challenges with their colleagues from the energy sector but never found each other due to using different jargon and missing places where they could find people outside their circles. ideXlab was then created to facilitate innovation by inviting people to share information, knowledge, questions and answers on a centralised platform to help persons who share the same problem to congregate.

An Open Innovation Network as tool for research, creation and exchange (e.g., sale or license) in the field of digital media was first time patented in 2007 in the US (US Patent No. US2007038754A1, 2007). This patent was followed by US patents for a system for a web portal framework for open innovation in 2010 (US Patent No. US7818372B1, 2010), a patent for system and method for conducting open innovation in 2012 (US Patent No. US2012203842A1, 2012) and a patent for

[7] https://www.eif.org/what_we_do/efsi/index.htm
[8] https://www.zenodo.org/
[9] https://www.researchgate.net/
[10] https://www.idexlab.com/about-us/

community led open innovation in 2017 (US Patent No. US2017262807A1, 2017). The open innovation patenting trend became then international with patents from the Far East on an open innovation type co-creation platform in 2010 (China Patent No. CN101877083A, 2010), on a training system for research and development making use of an open innovation platform in 2011 (Korea Patent No. KR20110092453A, 2010), on a method for operating an open innovation scale-up contest in 2021 (Korea Patent No. KR20210069133A, 2021), and on a circulating research support and start-up ecosystem trough open innovation in 2022 (Korea Patent No. KR102354270B1, 2022).

2. Open Innovation Environments in Materials Sciences

As already discussed in Section 1.3, the three Os (Open innovation, Open science, Open to the world) formed a key aspect in the Horizon 2020 programme. Open Innovation could be a way to create more and wider impact from research investments, improving the transfer of science to innovation. In particular, clustering of projects and initiatives in key areas such as nanosafety, modelling, characterisation, pilots and upscaling was supported to facilitate synergies and support open innovation. In particular, an initiative on Engineering and Upscaling, supported by the EC Head of Nanoscience and Nanotechnology Christos Tokamanis, conducted a large survey and workshops including more than 100 projects supported by the Industrial Technologies Programme (NMP) in advanced materials and nanotechnology. The findings are published in a report by Bojan Boskovic and Gerhard Goldbeck together with Sophia Fantechi from the European Commission. (Fantechi, Goldbeck, & Boskovic, 2015). The main conclusion was that in order to add value to engineering and upscaling activities and help to bridge the “valley of death” between materials sciences and the actual market supporting activities are needed: characterisation, modelling standardisation and pilot production. These activities have been illustrated as the supporting stones of the Greek Temple (Figure 3). The original Engineering & Upscaling Cluster formation ideas have been modified and individual clusters related to each of the supporting activities. This led to various initiatives by European Commission including development of the European Materials Modelling Council (EMMC)[11], the European Materials Characterisation Council (EMCC)[12] and European Network for Pilot Production Facilities and Innovation Hubs (EPPN)[13] to join the already existing NanoSafety Cluster (NSC)[14].

[11] https://emmc.eu/ EMMC ASBL
[12] http://characterisation.eu/
[13] https://www.eppnetwork.com/
[14] https://www.nanosafetycluster.eu/

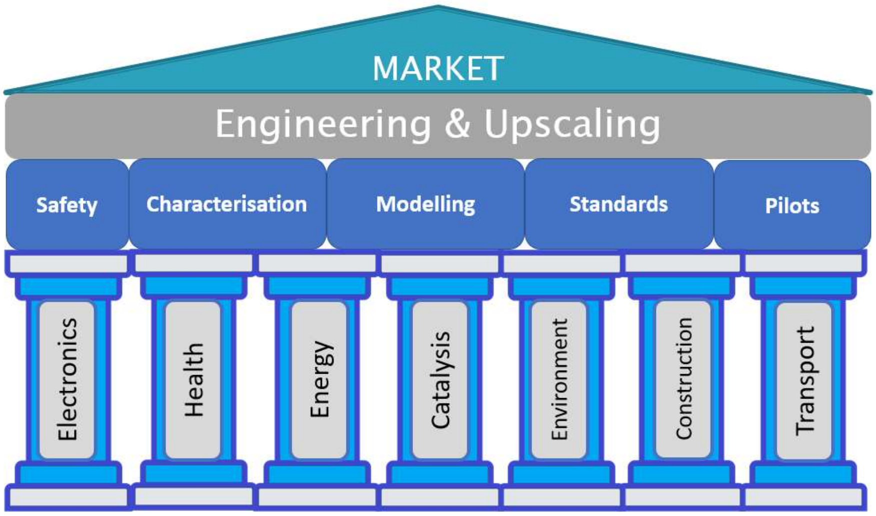

Figure 3 Activities in an EU Industrial Technologies Programme needed to support the Market.

The application orientated clusters (Electronics, Health, Energy, Catalysis, Environment, Construction and Transport) are the columns of the temple and these were producing domain specific roadmaps which were crucial in steering development towards successful products in these areas. As opposed to the architecture of an antique Greek temple, the Frieze precedes the Architrave: a relief of cross-cutting methods and topics such as Safety, Characterisation, Modelling, Standards and Pilots. If these were reliefs, all stakeholders of the application orientated clusters would be depicted using those, with the same enthusiasm as the people of Athens following their religious processions on the Parthenon's Frieze.[15] The Engineering & Upscaling supporting activities Safety, Characterisation, Modelling, Standards and Pilots depicted as an Architrave, i.e., a beam across all areas. Finally, these building blocks support the Pediment, the triangular upper part of the temple, which depicts the market.

At the time, all of the projects agreed to join the Engineering & Upscaling Cluster, with the objective to identify current gaps at the time in the toolset that supports engineering and upscaling so that they could be addressed in future policy and project calls. Also, the European Materials Characterisation Council (EMCC)[12] and the European Materials Modelling Council (EMMC)[11] took part and reported their surveys and consultation exercises in their respective reports and roadmaps.[16][17]. The aim was to summarise key strategic directions and potential actions designed to overcome the barriers and taken together lead to success in crossing the valley of death as shown in Figure 4.

[15] https://www.britishmuseum.org/collection/galleries/greece-parthenon
[16] https://emmc.eu/emmc-roadmaps/
[17] http://characterisation.eu/wp-content/uploads/2022/02/EMCC_Roadmap_2017.pdf

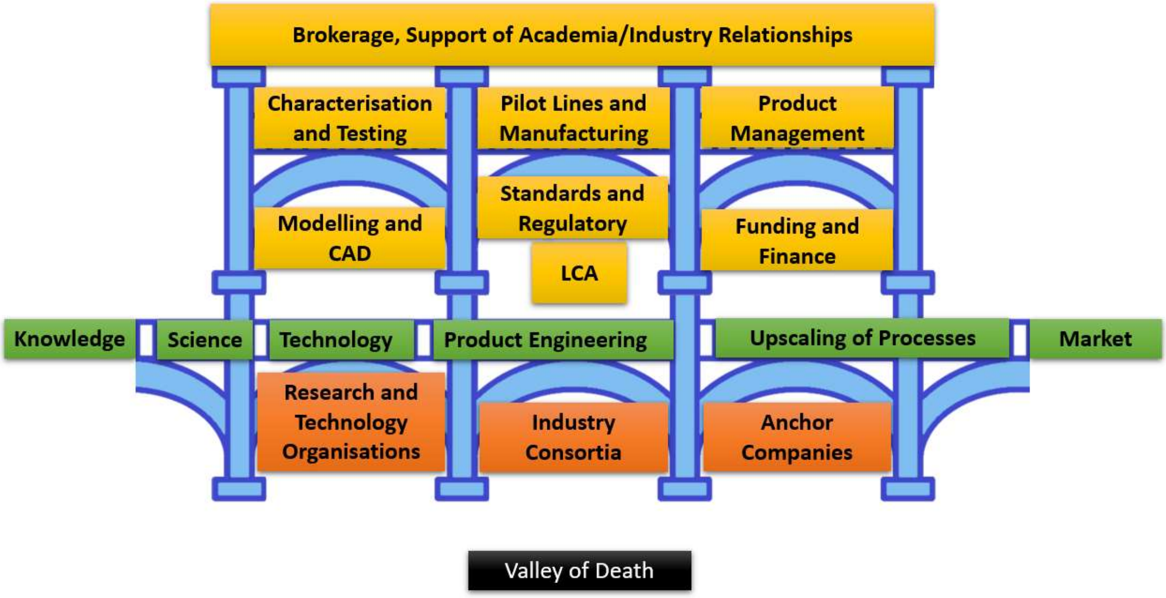

Figure 4 Bridging the valley of death by means of addressing specific topics for engineering and upscaling.

To bridge the valley of death, one needs to build a crude suspension to start with knowledge and reach the market (green building blocks). To solidify this construct, Research and Technology Organisations, Industry Consortia and Anchor Companies can come in as a basis (red building blocks). Originating from the surveys and workshops of the Engineering & Upscaling Cluster, a number of key topics emerged which need to be brought in as counterweights (yellow building blocks) to keep the bridge under tension: Characterisation and Testing, Pilot Lines and Manufacturing, Modelling and CAD, Life Cycle Analysis (LCA), Standards and Regulatory, Product Management, Funding and Financing, and Brokerage and infrastructure supporting industry and academia relationship.

The EMMC and EMCC are still thriving and engaging with their many stakeholders to keep the innovation bridge stable and contribute their yellow building blocks, i.e., Modelling and Characterisation, respectively. (Adamovic, et al., 2021). The European Materials Modelling Council (EMMC) became a non-profit organisation in 2019 after a successful EU CSA project[18]. The EMMC enables stakeholders to form and join focus areas and use a bottom-up approach to develop methods, policies, strategies, and best practises. It caters for its stakeholders with events, workshops, surveys and encourages discussion which is key to enabling changes and realising the benefits of Materials Modelling. The six Focus Areas are Model Development, Interoperability, Digitalisation, Software, Impact in Industry, and Policy.

The European Materials Characterisation Council (EMCC), which is a European initiative that was set up at the beginning of 2016, is based on and strengthening the existing European Materials Characterisation Cluster (created at the end of 2014). Similarly, to the EMMC, the EMCC is a bottom-up activity based on the involvement and support of a wide range of stakeholders. The aim of the

[18] https://cordis.europa.eu/project/id/723867

EMCC is to support the process of developing and improving characterisation tools to enable the successful conversion of nano- and advanced materials to actual products in Europe.

Pilot Lines are looked after by the European Network for Pilot Production Facilities and Innovation Hubs (EPPN)[13] whose mission is to connect a European Network of Pilot Production Facilities with SMEs, Start-ups and Large enterprises.

A crucial step towards such an OIE in the Materials Sciences was the NMBP - Work Programme 2018-2020, whereby NMBP stands for Nanotechnologies, Advanced Materials, Biotechnology, and Advanced Manufacturing and Processing". In the materials modelling field, based on EMMC Roadmaps[19], digital materials modelling marketplace developments were funded. The MarketPlace[20] and VIMMP[21] projects push forward the implementation of digital marketplaces fostering a collaborative, open innovation ecosystem (Goldbeck, Simperler, & Mogni, 2022).

Prominent examples of OIEs in the materials sciences are the Open Innovation Environments (ref OYSTER[22], Cornet[23], MMAMA[24]) and Open Innovation Test Beds (OITB)[25], to "*provide for development and upscaling of advanced materials and nanotechnologies, combining digital, chemical and physical advances for innovative new products and services*". The three things one had to take to the OIE were "*Advanced characterization tools, predictive modelling of materials at different scales, and support for a framework to ensure public safety in nanotechnology*" and 18 OITB projects have been funded.

As an example for an OIE, that follows the suggestions as described above, we will use the H2020 project OYSTER (Figure 5) offering an environment for the characterisation of hard/soft materials' interfaces materials characterisation which comprises people (experts), materials, materials characterisation tools, FAIR data, standards to ensure quality and data valorisation, and soft- and hardware. This environment is created by 14 member organisations from both industry and academia originating from 9 different countries and it will be accessible to all innovators who wish to interpret adhesion data of their novel materials on the nanoscale and extrapolate in a standardised way to macroscopic data.

As depicted in Figure 5, the materials innovators requesting a particular service will immediately tap into the OYSTER OIE. A match making service will link them to experts, equipment and information/knowledge.

[19] https://emmc.eu/emmc-roadmaps/
[20] https://www.the-marketplace-project.eu/
[21] https://www.vimmp.eu/
[22] https://cordis.europa.eu/project/id/760827; https://www.oyster-project.eu/
[23] https://cordis.europa.eu/project/id/760949
[24] https://cordis.europa.eu/project/id/761036; https://www.mmama.eu/
[25] https://www.h2020.md/en/call-h2020-nmbp-ind-2018-2020-foundations-tomorrow%E2%80%99s-industry-two-stage

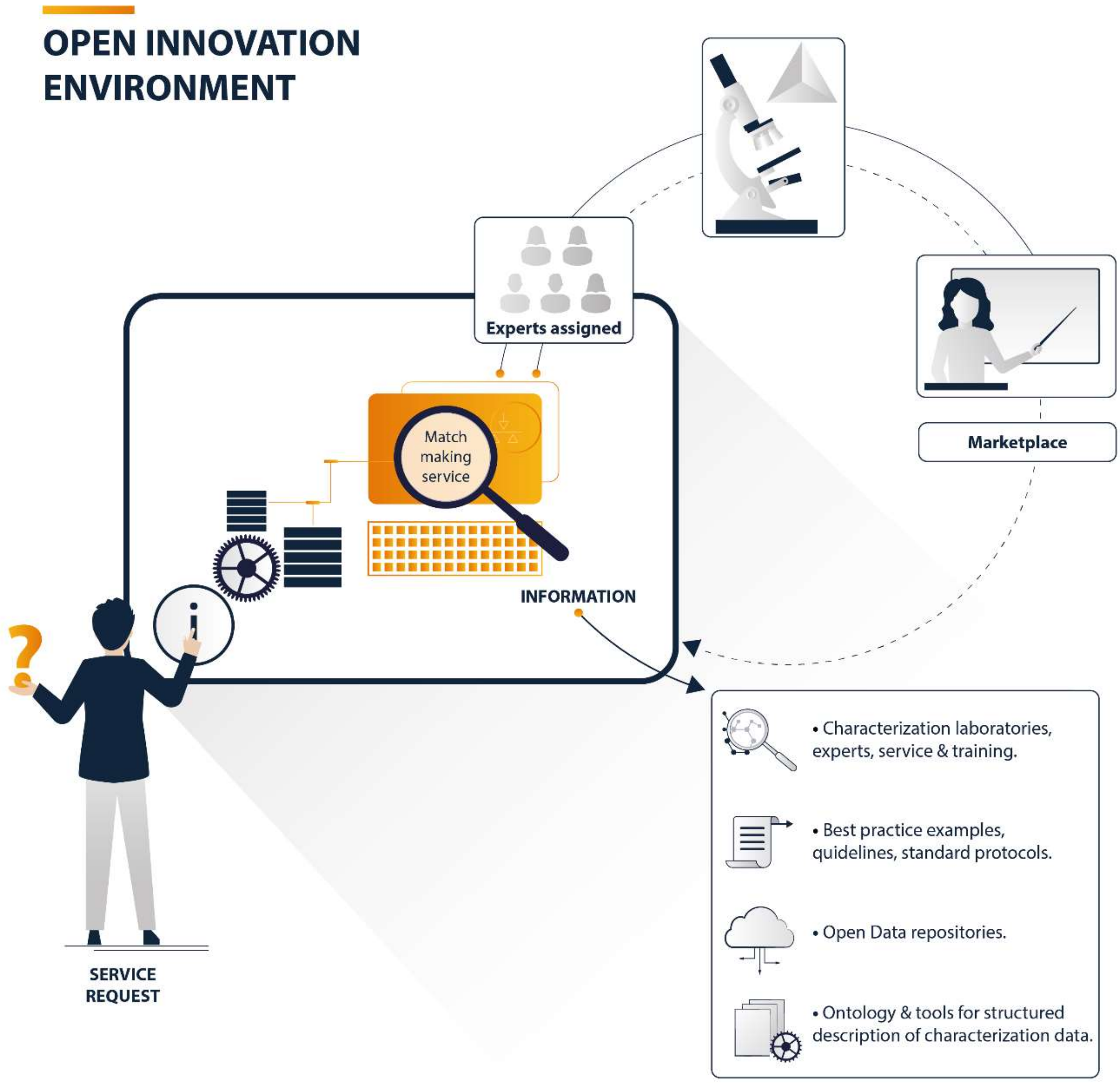

Figure 5 OYSTER Open Innovation Environment, © CNT

An OIE can be either a physical location or a digital (virtual) platform of some sort to enable innovators to join independently from their geographical location. What will flow freely are data and knowledge; however, this flow must follow standards, protocols and best practices so open innovation can happen FAIR. The FAIR principle is well known from data science (Wilkinson & al., 2016) and stands for Findable, Accessible, Interoperable and Reusable. Open Innovation results are expected to be findable to avoid inventing the wheel twice so the process of how an invention was developed should be documented appropriately. This ideally is done by following guidelines, and protocols should document how the innovation happened; the latter makes sure open innovation procedures can be re-used as they followed standards and thus, are trustworthy. For example, the OYSTER project developed the CHADA (Characterisation Data) (Sebastiani, Charitidis, & Koumoulos, 2019) and then initiated a CEN workshop, CWA on Materials Characterisation - Terminology, classification and metadata, (CWA 17815, 2021), to standardise these protocols. Open Data repositories, well curated, are pertinent to enable accessibility to these documents. OIEs of the 21st century may have artificial intelligence (AI) partnering human inventors aiding them with making sense of vast amount of data and reveal the knowledge it carries. To take full advantage of AI data have to be semantic interoperable and in OYSTER this is achieved by using ontologies. Hence to make Open Innovation FAIR, one must add standards, protocols, open access database and ontologies to the inventory of their OIE.

Hence to move forward faster with the development of new materials good access to experimental and simulation data is key. This was also recently discussed by the Research Data Alliance (RDA)[26] International Materials Resource Registries Working Group (IMRR-WG) [27] in their final report and recommendations. (Becker, et al., 2021). Projects like OYSTER should not only make data accessible exclusively to their OIE but see the bigger picture and open them up globally. Thus, the IMRR-WG is strongly suggesting that an international federation of registries should be established that can be used for global discovery of data and information resources for materials science. A federation of multiple registries is seen beneficial as opposed to a central registry; each registry can then be responsible for their own data curation as they have the experts on hand. However, what is key will be a common Application Programming Interface (API) for data harvesting and a common metadata schema. Both the latter are still ongoing work beyond the lifetime of the IMRR-WG. Thus, orchestrators of OIEs will need to keep their ears close to the ground and follow developments by future RDA WG, NIST[28], Center for Hierarchical Materials Design (CHiMaD)[29], Optimade[30] for common APIs, the Elementary Multiperspective Material Ontology (EMMO)[31] and the CSA Project OntoCommons[32] to have their data ready for global exchange.

3. Conclusions and outlook

We have reviewed the history and evolution of Open Innovation and Open Innovation Environments in general and in a European and Materials Science context (e.g., OYSTER[22]) in particular. The key is to generate an environment where innovation can be truly collaborative, networked and open. In order to move forward faster with the development of new materials good access to experimental and simulation data is key. A wide range of projects and initiatives are part of that emerging ecosystem. including OIEs, OITBs, marketplaces, and OIPs[33][34][35]. The latter got together to publish a Position Paper on Open Innovation in Horizon Europe (Konchakova, et al., 2022) highlighting the "aim to accelerate innovation realisation in Open Innovation Frameworks that foster broad consensus on the European way to implement its headline ambitions".

It is hence very important to involve the citizens and for OIEs to be nodes in an Innovation Networks Ecosystem (Curley & Salmelin, 2013), with the customers/citizens becoming co-creators of value.

[26] https://www.rd-alliance.org/
[27] https://www.rd-alliance.org/groups/working-group-international-materials-resource-registries.html
[28] http://materials.registry.nist.gov/
[29] https://chimad.northwestern.edu
[30] https://www.optimade.org/
[31] formerly European Materials & Modelling Ontology, https://github.com/emmo-repo/EMMO
[32] https://www.ontocommons.eu/
[33] https://cordis.europa.eu/project/id/953187; http://musicode.eu/
[34] https://cordis.europa.eu/project/id/953167; https://open-model.eu
[35] https://cordis.europa.eu/project/id/952903; https://ms.hereon.de/vipcoat/

This Open Innovation 2.0 paradigm can be depicted as a "quadruple helix model" where government, industry, academia and civil participants work together to co-create and innovate and shape the future. (Figure 6)

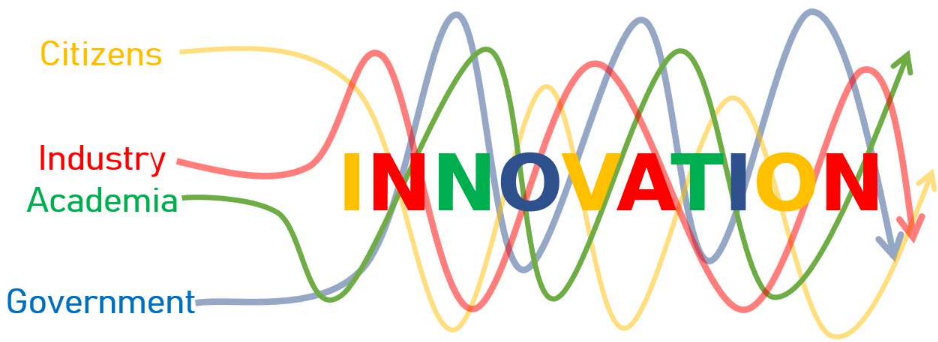

Figure 6 Innovation quadruple helix, carrying the DNA of Citizens, Industry, Academia, and Government

Open innovation Environments bring together all stakeholders, masters in their respective fields, "translators" as well as citizens. It will require some leadership to move innovation forward for the greater good but still nurture and respect all participants. Open innovation requires being open about who contributes what and gets the merit for their contribution. If this is a given, participants feel safe and see their contribution to an innovation validated.

Open Innovation can only thrive if this wide range of stakeholders can interact easily and securely with each other as well as with the multitude of relevant sources of data and knowledge. Open Innovation 2.0 is therefore a highly complex system which has not surprisingly taken some time since its inception to come to implementations that can really fulfil its ambitions. Here the advances in digitalisation play a big role as are advances in capturing data and knowledge, based on FAIR principles and working towards widely agreed standards. In materials modelling and characterisation, respectively, classification and formal documentation has been generalised and formalised in CEN Workshop Agreements (CWA 17284 , 2018) and (CWA 17815, 2021), respectively, and also by (de Baas, 2014) and (Sebastiani, Charitidis, & Koumoulos, 2019). Furthermore, knowledge capture in machine readable form is growing rapidly utilising ontologies such as EMMO[31] which will also support cross-sector interoperability, collaboration and valorisation of data and knowledge in an Industry Commons[36] approach. In particular, the CSA project OntoCommons[37] aims to lay the foundations for standardised documentation of data through taxonomies and ontologies[38]. The expected outcome will be that data can be used and re-used more widely in the materials and manufacturing sector fields. Complementary to this Coordination and Support Action is an Industry Commons Data Marketplace, DOME 4.0[39] funded under the Topic DT-NMBP-40-2020 – "Creating an open market place for industrial data"[40]. DOME 4.0, aligned with the Open Science and Open

[36] https://industrycommons.net/
[37] https://cordis.europa.eu/project/id/958371; https://ontocommons.eu/
[38] https://cordis.europa.eu/programme/id/H2020_DT-NMBP-39-2020
[39] https://cordis.europa.eu/project/id/953163; https://dome40.eu/
[40] https://cordis.europa.eu/programme/id/H2020_DT-NMBP-40-2020

Innovation objectives, "*aims to develop a comprehensive industrial data ecosystem that enables sharing of business-to-business data for the purpose of value generation and creation of new or enhanced products, processes and services*."

We conclude that Open Innovation is thriving and OIEs are key enablers for European Innovation. With the emergence of ontology-based Industry Commons approaches, each DNA (Citizens, Industry, Academia, and Government) in our OIE can transcribe their data and knowledge like RNA polymerase to convert into a transportable message that can be received by another OIE and transcribed into knowledge native to them. The result is a system of interconnected OIEs, an Innovation Network Ecosystem (Figure 7), in which various OIE quadruple helices intertwine.

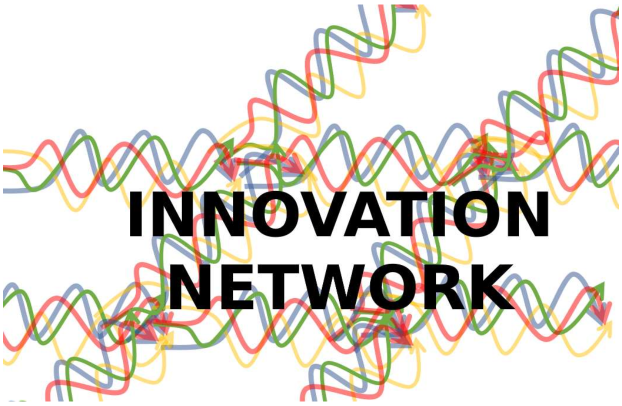

Figure 7 Innovation Network Ecosystem of interconnected quadruple helices.

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Acronyms and Abbreviations

AI – Artificial Intelligence

API – Application Programming Interface

ASBL - Association sans but lucrative (non-profit Organisation)

CEN - European Committee for Standardization (French: Comité Européen de Normalisation)

CHADA – Characterisation Data

CWA – CEN Workshop Agreement

CSA – Coordination and Support Action

EFSI - European Fund for Strategic Investments

EIB - European Investment Bank

EMCC – European Materials Characterisation Council

EMMC – European Materials Modelling Council

EMMO - Elementary Multiperspective Material Ontology

EPPN - European Network for Pilot Production Facilities and Innovation Hubs

FAIR - Findable, Accessible, Interoperable and Reusable

IMRR-WG - International Materials Resource Registries Working Group

ISO - International Organization for Standardization

NMBP - Nanotechnologies, Advanced Materials, Biotechnology, and Advanced Manufacturing and Processing

NSC – NanoSafety Cluster

OI – Open Innovation

OIE – Open Innovation Environment

OIP – Open Innovation Platform

OITB – Open Innovation Test Beds

RDA – Research Data Alliance

SME – Small and Medium Enterprises

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