Digital Marketplaces and their value for the Materials Modelling Ecosystem

Gerhard Goldbeck, Alexandra Simperler and Gabriele Mogni

Goldbeck Consulting Ltd, St John's Innovation Centre, Cambridge CB4 0WS, UK

Contents

1. Overview

Digital marketplaces are online platforms that support and streamline transactions between sellers and buyers of products and services. (Shah, 2021) We provide some historical insights into their development, types of marketplaces and their business models as a background to elaborating current and emerging digital marketplaces that serve science and engineering R&D in general, and materials in particular.

As markets evolved from physical to e-commerce consumers moved from physically attending a market to purchasing a variety of goods and services online. Noticeably, there is a trend towards one-stop-shops where customers can purchase goods from different providers but settle their bill in a single transaction. Often, customers wish to borrow or gain access to tangible or intangible goods, such as cars, dwellings, music, movies, cloud computing, etc. without owning them.

Digital marketplaces can enable collaboration between two parties, orchestrate an overarching business environment to harmonise business models of different providers, permit creation of new products and services, and match consumers with suitable providers and vice versa. They may serve a particular community and offer bespoke products and services to them, or concentrate on generalised offerings and function like an online department store. An overview of pertinent business and revenue models is provided in Section 5. Business Models of Digital Marketplaces.

In the area of R&D (discussed in Section 6. Marketplaces serving industrial R&D), marketplaces have been developing from directories of experts and potential suppliers of R&D goods and services to digital marketplaces. Platforms for experts and information (e.g., patents) have been the first to develop as marketplaces. In the Pharmaceutical and Life Sciences sector, the wide use of outsourcing in R&D has been a driver for the growth of digital marketplaces. In the materials sector, e-commerce has been developing in the field of materials supplies, which has fed into the growth of a marketplace built around choosing materials based on their properties. In the field of additive manufacturing and engineering in general, marketplaces have emerged that connect customers requiring parts manufacturing with potential 'makers'. In simulations, a growing number of platforms offer Simulation as a Service provisions to the materials and engineering sector.

Finally, we discuss the emergence of materials modelling marketplaces in the US and Europe, in particular MarketPlace[1] and VIMMP[2]. Digital marketplaces are seen as a new avenue for materials modelling and its ecosystem of people, tools, data and processes/workflows to reach a wider customer base. Some marketplace type businesses have arisen from online modelling platforms that enable easy integration modelling tools.

2. A Retrospect

Markets emerged wherever supply and demand for different goods came together. In conventional markets, the buyers and sellers were present in person, and trading could take place in exchange of goods or money. Markets as permanent establishments were initially formed in connection with the demand for simple goods such as food or, increasingly, higher-quality and rarer products from handicrafts or mining. This resulted in differentiation according to local markets (mostly weekly) and regional markets that took place once or several times a year (annual markets) and supra-regional

[1] https://cordis.europa.eu/project/id/760173, https://www.the-marketplace-project.eu/
[2] https://cordis.europa.eu/project/id/760907, https://www.vimmp.eu/

trading facilities (fairs). Entry to the market was initially free, but over the course of time regulations were introduced that could also include a market ban.

Early on, markets formed in larger city centres. They can be traced back to ancient Persia, where they were called “bazaar”. Historical documents indicate that bazaars have existed in Iranian cities and towns since 3000 BC (Mehdipour & Rashidi Nia, 2013). We later find markets in ancient Greece and the Roman Empire, where the term “agora” (Ancient Greek: ἀγορά "gathering place" or "assembly") passed down for urban markets. The markets emerged because of the different needs of city and country. In Rome there were specialized markets (Latin: forum—area in the middle of the town used for public business) depending on the type of goods offered, e.g., markets for meat, vegetables, and pigs. (Holleran, 2012) The German word “Markt” - very similar to the English word “market” - goes back to the Old High German “markat” (first mentioned 765) (Köbler, 1995). There were also special markets for cattle, meat, fish, grain, hay, various handicraft products and firewood in the major cities of the Middle Ages (Verlag J.B. Metzler, 1999) such as Paris, London, and Vienna.

Supra-regional markets also emerged in connection with important trade routes, some of which go back to a Roman tradition. For Austria (Knittler, 2019), this would be the market at Petronell, (Mitterauer, 1980) which was held near the old Roman city of Carnuntum and the intersection of the Amber Road with the course of the river Danube. Occasionally, there were annual markets in the succession of older cult sites, sometimes near mountain shrines. Normally, such markets lasted several weeks—such as the market at the church of Saint-Denis near Paris (Cave, 1965), which was privileged by the Merovingians[3]. The market visitors were under special royal or later princely protection during their visit, which included even the duration of their return journey. In general, the connection between market trade and religious centres played a major role. Numerous annual fairs were held on church consecration days, where a confluence of church visitors and thus also a demand for special goods, was to be expected.

Originally, the market right (German “*Marktregal*”) was a *jura regalia*[4]. The granting of the right to hold markets, mostly annual fairs and rarely weekly markets, by the city or sovereign, which was already established in the Late Middle Ages, corresponded with the development of a special right to protect market participants and to set up a corresponding apparatus for administration and jurisdiction. For example, in the Austrian counties as well as in Bavaria, a special form of bourgeois settlement developed in connection with market rights, that of the market towns. These were mostly smaller than the actual cities and had fewer privileges but could represent a preliminary stage to a city. In countries where villages represented their own legal district from the outset, especially in Lower Austria, the number of market places rose sharply in the late Middle Ages and the early modern period.

While the catchment area of the weekly markets was mostly limited to a few kilometres that of the annual markets could already extend far beyond the national borders. Long-distance markets (trade fairs) also appeared early on, with supplies from more remote regions of Europe and sometimes even beyond. An early example are the fairs in Champagne (Edwards & Ogilvie, 2011), which have been held since the 11th or 12th century, that connected the commercially highly developed areas of Italy in the south and Flanders in the north. The objects of trade were often expensive luxury goods, such as spices from Asia, and also goods from England (wool) or the Netherlands (cloth). In addition to the

[3] The Merovingian dynasty was the ruling family of the Franks from the middle of the 5th century until 751.
[4] Jura regalia is a medieval legal term which denoted rights that belonged exclusively to the king.

trade in goods, a flourishing money trade developed, with many goods being acquired on credit and often not by owners themselves but a factor[5] commissioned to handle the business. In the area of the Austrian duchies, the fairs in Enns, documented since the 12th century, and later those in Linz, and in Tyrol the Bolzano fairs—with certain restrictions—were representatives of this type.

The commodity markets[6] signal a further step into a new development, where some of the goods were no longer present (first in Bruges in 1409) (Lambert, 2016). To this day, all types of markets have survived and many only due to intervention of local people. People visit markets for commerce and social interaction but what they want to buy and what kind of interaction they seek also play a role in their decision making. Some London markets started to deal in antiques, artisan food, or organic produce and ethically sourced goods, attracting professionals to spend their lunchtimes there. Hence, a modern market needs a vision based on a holistic understanding of the needs of the market users, traders, and the community (Kim, 2017).

From the late 1950's onwards in the US, we can find large buildings or areas housing several shops with all sorts of goods, known as shopping malls, emerging as marketplaces (Warnaby & Medway, 2018). These marketplaces often have a solid roof and shopping takes place independently of weather conditions. They sometimes also offer infrastructure such as food places, entertainment centres, etc., to keep the shoppers for a longer period of time. Again, buyers make financial transactions with each vendor separately.

3. The Marketplace as a One-Stop-Shop

In the above examples, markets had many traders and/or factors, and as a buyer one had to deal with them individually. In a one-stop-shop, buyers find many traders but only have to negotiate and transact once at the end of the trip. Among antecedent one-stop-shops were the early department stores, such as Harrods of Knightsbridge in London (BBC, 2010). Harrods was founded in 1849 by Charles Henry Harrod and became a department store in 1880 and was famous for its slogan Omnia Omnibus Unique – "All things for all people, everywhere." Living up to the name, Harrods offers fashion, food, artwork, funeral services[7], and at one point even a lion cub (Bourke & Rendall, 2010).

Amongst other things, Harrods is a marketplace for luxury brands and many of which have their own flagship stores. It seems, then, curious that they might offer their wares at Harrods at all. Of course, there is the historical ambience but, more importantly, Harrods offers a bespoke service for its vendors (Harrods, 2020). In a range of case studies, they demonstrate their value as a marketplace and how they aid a vendor in accessing a greater number of buyers. This approach may be referred to as experiential retail and aims to get buyers into the store and combine the purchase with an experience (Jahn, Nierobisch, Toporowski, & Dannewald, 2018) (Loranger & Greene, 2020). This is a very elegant way to attract buyers to a physical store, wherein the shopping is interlinked with a social experience.

On the other hand, people wanted the comfort of selecting/ordering their shopping from home and also get it delivered there. For example, a crucial instrument for the distribution of goods from the

[5] A factor is an intermediary agent that provides cash or financing to companies by purchasing their accounts receivables, i.e., the balance of money due to a firm for goods or services delivered or used but not yet paid for by customers.
[6] A commodity market is a market that trades in the primary economic sector rather than manufactured products, such as cocoa, fruit, sugar, etc.
[7] Harrods acted as funeral directors for Sigmund Freud in 1939, see (Turner, 2007).

East were the merchant trading companies that had been established in Europe: the English East India company (EIC) and the Dutch East India Company (VOC-Vereenigde Oostindische Compagnie) were founded in 1600 and 1602, respectively. The participation in the spice trade was their original main purpose but in time, the inclusion of luxury goods and "exotica" such as silks, textiles and porcelains became relevant. In addition to company trade, the EIC's private trade played an important role for objects that were special commissions, such as armorial porcelain[8] services. (Erikson, 2014) (van Campen & Eliëns, 2014). Stacey Pierson (Pierson, 2019) suggests that the EIC's imports and their fulfilment of private commissions had a significant impact on British daily-life activities of the late seventeenth to nineteenth centuries. The first English armorial porcelains commissioned date to the late 17th century and through their decoration, those objects establish both personal identity of the consumer and ownership of the piece. It has been identified that the British market was supplied with about 3000 armorial services at its peak. (Kerr, Mengoni, & Wilson, 2011) (Howard, 1974) These "mail orders" were exclusive to wealthy families and had to rely on a chain of brokers and porcelain dealers and manufacturers and trade ships. (Tang, 2018) The first mail order shopping for mundane people nationally was conducted by a Welsh man, Pryce Jones, [9] in 1859 when a batch of flannel swatches was sent to a customer. Jones's services were enabled by emerging train and postal services, both becoming more affordable to the wider public.

In the 20th century these mail orders were thriving and every country had their catalogues with pictures and pricing of a variety of goods. The catalogues were posted to households and one could order conveniently via phone call or filling in a mail order form. Some commonly known mail order shops are for example Littlewoods [10] in the UK, Neckermann [11] in Germany, or the Postalmarket in Italy[12]. These mail orders were often reasonably priced because renting storage space was cheaper than owning shops and allowed them to offer their own-brand goods. For customer convenience, transactions involved only one form and one bill at the end. Now, most mail order shops that are still active have switched over to e-commerce.

4. E-Commerce

4.1. A brief history

E-commerce (electronic commerce), "the buying and selling of goods and services over the internet," has existed for over 40 years (Bloomenthal, 2020) (Simakov, 2020) (Tian & Stewart, 2008). Fundamental to its emergence was the development of electronic data interchange (EDI)[13] – the exchange of business documents from one computer to another in a standard format. EDI originated in the mid-1960s, when companies in transportation and some retail industries were attempting to create "paperless" offices. The advent of web browsers in the 90's, the lifting of all commercial restrictions on the internet, and the increasing availability of personal computers led to e-commerce becoming more widely accessible (Tian & Stewart, 2008). Later in the same decade, many companies registered on the internet and claimed their ".com" domain and formed what is now coined as the "dotcom bubble" (Hayes, 2019), which infamously burst with a loss of billions of USD at the turn of

[8] Armorial porcelain is decorated with a coat of arms.
[9] https://newtown.org.uk/discover-newtown/newtown-heritage-trail/sir-pryce-jones
[10] https://www.littlewoods.com/
[11] https://www.neckermann.de/
[12] https://en.postalmarket20.shop/
[13] https://www.edibasics.com/what-is-edi/

the century (2001). As we all know, however, e-commerce survived and flourishes well into the 21st century, often only a swipe away on a person's smartphone. Amazon [14], launched in 1994 as Cadabra Inc (and soon thereafter renamed) as an online book store and a highly recognisable entity today, not only survived the burst but in 2020, its CEO, Jeff Bezos, became the richest person in the world. [15] These days this marketplace offers a wide range of goods and services, up to and including cloud computing. A list of the top providers for e-commerce [16] shows that Amazon is in the lead (at the time of writing) when it comes to customer visits per month.

Dedicated e-commerce sites [17] predict e-commerce sales of up to $5 trillion for 2021, with China being the biggest consumer. The Asia-Pacific region accounted for 42.3 % of the total retail e-commerce sales growth in 2020 (Cramer-Flood, 2020).

4.2. Some e-commerce of today's world

In today's world almost every vendor uses e-commerce, relying more on online platforms and less on physical shops. The vending comprises everything from buying tickets from an airline to groceries from the local supermarket.

Food take-away is also a big part of e-commerce and is a growing sector, wherein customers use marketplace apps such as Deliveroo [18] and restaurant websites to order food directly to their homes. Especially during the Covid-19 epidemic, restaurants that had to close their doors compensated for losses by providing takeaway options. However, even before that, many restaurants saw that this sort of marketplace enabled them to get more customers. Interestingly, McDonald's [19] in the UK is using JustEat [20] as their delivery service, gives evidence that even a fast-food giant with drive through options understands the advantages of large e-marketplaces. A recent study revealed (Heiss, Jakobitsch, Wiesinger, & Trebsche, 2021), that already Alpine Bronze Age miners (11th until the 9th century BC) had been supplied from outside with ready-to-cook and processed grain, a somewhat less elaborate cuisine but available without the use of a smart phone.

In some cases, customers are looking for access to a product without having to own it outright. For example, paying a subscription fee to access music on Spotify [21], reading borrowed books on an e-reader, or streaming on movies or box-sets with Netflix [22], Amazon Prime [23], NowTV [24], SkyTV [25], etc.

Similarly, e-commerce does not necessarily mean buying; people may want to borrow things. For example, a car with a driver can be ordered via the Uber [26] app and a dwelling can be borrowed from

[14] www.amazon.com
[15] https://www.forbes.com/sites/sergeiklebnikov/2021/01/11/elon-musk-falls-to-second-richest-person-in-the-world-after-his-fortune-drops-nearly-14-billion-in-one-day/
[16] https://www.webretailer.com/b/online-marketplaces/
[17] E.g., https://ecommerceguide.com/ecommerce-statistics/
[18] https://deliveroo.co.uk/
[19] https://www.bbc.co.uk/news/business-54538188
[20] https://www.just-eat.co.uk/
[21] https://www.spotify.com/
[22] https://www.netflix.com/
[23] https://www.amazon.co.uk/amazonprime
[24] https://www.nowtv.com/
[25] https://www.sky.com/
[26] https://www.uber.com/gb/en/

any person willing to share it on AirBnB [27]. Interestingly, in these cases some sort of "match making" happens–a person offering is matched with a person that has a requirement. Notably, neither AirBnB nor Uber own the dwellings or the vehicles, respectively, and they also do not employ the landlords or drivers. The later did often cause controversy regarding employment laws, and for example, the UK supreme Court ruled, that Uber drivers are workers and not self-employed. (Russon, 2021).

What yesterdays and today's world have in common is that a marketplace still ensures that vendors and sellers find each other, but instead of an agora we find an internet platform, that hosts this virtual marketplace 24/7 wherein vendor and buyer are not even required to meet at the same time in the same space. Furthermore, such platforms must provide value to both vendors and sellers, as both communities are their customers now, which needs to be reflected in appropriate business models (Täuscher, 2016).

One can see the immense array of offers and how a consumer may be overwhelmed with choices. This is where price comparison sites come in, allowing a consumer to search for and compare the relative value for money of various goods and services (insurances, hotels flights, computer hardware, smart phone deals, etc.) (Atticus, 2014). These sites can often compare several marketplaces and offer the consumer information about pricing. There are also service quality and feedback websites such as Which?[28], Trustpilot[29], feefo[30], etc., to aid consumers with their decision making as it is not only about the price but also about trustworthiness and quality.

4.3. Apps and app stores

According to the Cambridge Dictionary (Dictionary A. , 2021), an app is an "application: a computer program or piece of software designed for a particular purpose that you can download onto a mobile phone or other mobile device". An app store is then by definition, a marketplace for apps, yet another addition to the landscape of online marketplaces (Duch-Brown, 2017). Apps perform a specific task and they can be either, the programme the user wants interact with, like a game, or more often they connect to another program, i.e., an email app connects to an email server. Apps are typically very focussed and enable a customer to get exactly where they want to go with a tap of their finger on their smart phone; they can do this virtually everywhere in the world that has a decent mobile network. This convenience drives the continued popularity of apps (Solanki, 2020).

From a user perspective, the dominant operating systems are Apple's iOS and Google's Android, on which apps can be obtained via the App Store or Google Play, respectively (Maradin, Malnar, & Đipalo, 2020). Recently, the App Store has found itself involved in a lawsuit over an alleged app monopoly (Stempel, 2020). However, users are aware that apps are exclusive and only work on a specific OS and often have a preferred smart phone in mind (Duch-Brown, 2017). Aware of this, developers build their product for either Android or iOS operating systems and profit from the visibility provided by such large Apps marketplaces.

[27] https://www.airbnb.com
[28] https://www.which.co.uk/
[29] https://www.trustpilot.com/
[30] https://www.feefo.com/

5. Business Models of Digital Marketplaces

5.1. Business environment

Digitalisation has had a huge impact on almost every aspect of life, including how business is done. Industries formerly deemed resistant to it, such as transportation and hospitality, are seeing the creeping effects of digital solutions as everything from corporate governance to business modelling, contractual relations to best practices are transformed (Täuscher, 2016).

Today, most so-called digital 'marketplaces' provide digital platforms matching demand with supply, facilitating financial, service-based, and commercial transactions between the two sides. These new platforms provide greater product information, efficient and automated payment options, and fraud protection systems.

The increasing internationalisation facilitated by such digitalisation has, in turn, impacted notions such as 'quality of service', corporate responsibility and accountability, and more, with bodies such as the OECD, WTO, and IMF weighing in on standards and regulations. The growth of a few larger digital platforms (for instance, Amazon.com and Alibaba[31]) has further accelerated the internationalisation of digital marketplaces transforming first local economies and then widening their scope and reach.

In Europe, digitalisation facilitated the establishment of the European single market, including the introduction of a single currency in 2000 and the creation of the European Union Payment Area (EPA). Since then, the EU has continued to adapt and respond to the effect of digitalisation on the market by, for instance, introducing regulations designed to broaden the accountability and responsibility of digital platforms. A few of these platforms, depending on annual turnover and client figures, will be dubbed 'gate-keepers' and held responsible for guaranteeing a transparent and reliable flow of information through their sites, while preventing the spread of clandestine content. The aim is to simultaneously protect customers and the competitiveness of the EU single market on the global stage.

5.2. Types of marketplaces

A good summary can be found in (Shah, 2021), comprising Business-to-consumer (B2C) marketplaces (e.g., Amazon[14]) and Peer-to-peer (P2P) or consumer-to-consumer (C2C) marketplaces – (e.g., eBay[32]) as well as Business-to-business (B2B) marketplaces which are the focus of this White Paper. As stated in the reference, B2B marketplaces tend to be more niche and vertical industry focused. B2B marketplaces are traditionally focussed on e-procurement and digitising existing buyer/seller relationships. In recent years B2B have developed into a much more varied and vibrant sector with many different business models and integration of actors both within and across sectors.[33]

5.3. Business and Revenue models

The broad and rapidly evolving digital landscape gives rise to new business models that are more varied and complex than traditional business, where providers produce a product and sell it to their customers (one-sided market), in a linear process. Digital marketplaces gather sellers, consumers and ecosystem partners so all create and consume value and often do this by bringing their own business

[31] https://www.alibaba.com/
[32] https://www.ebay.com/
[33] https://www.bvp.com/atlas/b2b-marketplaces

models with them. Thus, a business model for a marketplace must be inherently "two-sided" or "multisided" to start with. (Van Gansen, Valayer, & Allessie, 2018)

In the following sections we shall discuss how a marketplace generates value, i.e., what business models are possible, and how it generates revenue.

5.2.1. Platform Business Models (PBM)

We will start with the findings of (Van Gansen, Valayer, & Allessie, 2018) and use their four-platform business model (PBM) types based on the way organisations create business value in an online marketplace. These four PBM types differ by their value creating mechanisms: collaboration, orchestration, creation or matching.

Collaboration

These marketplaces enable clients to find new partners from different backgrounds, location, ecosystem, knowledge, etc. and explore new ways of working together.

Orchestration

The aim of these marketplaces is to enable the integration of business processes between clients and providers. The providers bring their own business ecosystem, but the platform enables transactions, scheduling, common terms and conditions, etc.

Creation

Providers are invited to create something new (like an APP, or a service) on the actual marketplace and offer it to clients. To enable this, the marketplaces will need to offer software development kits (SDKs) or similar, to enable this.

Matching

This happening in all marketplaces; providers who offer a product/service are matched with consumers who are interested in the offering.

5.2.2. Digital Market Business Models (DMBM)

Here we apply the findings of (Täuscher, 2016) and discuss six possible Digital Market Business Models (DMBMs). The business models can be applicable to vertical and horizontal market penetration, i.e., goods and services within specific industrial sectors and across various sectors, respectively.

Efficient product transactions

This model works for marketplaces that offer physical products. Buyers want to find sellers offering a product of interest and be able to see the pricing. Customers may also be attracted because the platform effectively meets a particular need or because the platform simplifies or streamlines a user's experience, whether exchanging or networking. They also like to see some sort of rating to enable them to judge the quality of a product and or seller. Sellers, in turn, would like to access a large consumer base and let the marketplace become their vendor. Hence, infrastructure to enable an easy search and billing process are a must.

Product community

Here the focus is on particular tangible or digital products, and such a marketplace attracts a community around this product. These communities are knowledgeable and provide sophisticated

user reviews around the products. This enables the exchange of information both provider and users: the providers can follow user comments and improve their offering and the less knowledgeable users can find guidance from expert users.

Product aficionados:

This DMBM is similar to a product community but concentrates on values that makes a physical product desirable. The customers are looking for attributes such as “independent”, “organic”, “ethically sourced”, “fair trade”, “handmade”, etc.

Offline services on-demand

Consumers on such marketplaces would like to find service firms, book a service and receive it in person. This may comprise personal care, ordering a meal, booking a tour, etc. These services are often bound by a certain time-frame and specific geographical location.

Online services

This business model brings value to customers by offering services that are delivered via the internet. These services can comprise education, SaaS, or the skill of a person.

Peer-to-peer offline services

The emphasis here is on sellers sharing their physical resources or providing their time and skills. Companies such as Airbnb and Uber are using this business model.

Typically, rather than relying on any one model, the most successful platforms tend to use a variety of models simultaneously depending on their product catalogue, population targets, geographical scope, and structure. Which model to choose, and how to implement it, also varies by geography.

5.2.3. Revenue Models

Reflecting the rather more complex business models and value generation, there are a number of revenue generation methods to discuss, each with various strengths and weakness. Among the most used in 2021, (Nesvit, 2021) lists revenue models based on commission, subscription, listing fee, freemium, featured listing and ads, lead fee and finally a mixture of them.

Furthermore, due to the platform nature of many digital marketplaces, they have been able to draw on substantial venture capital investments and high market valuations (e.g., Airbnb and Uber), i.e., DMBMs can be attractive to investors (Täuscher, 2016). However, because very few digital marketplace start-ups have proven reliably profitable in the long run, they remain risky investments. The ongoing need to find risk-taking investors presents a challenge to new digital platforms.

Besides funding streams, regulators also play a significant role in determining the overall sustainability of various business models. Debates surrounding the use of freelancers and tax avoidance have led to calls for greater regulation, which may challenge existing DMBMs while encouraging the instantiation of new ones. Uber, now banned in a number of countries, is a prime example of the power of policy-makers to regulate such companies (Täuscher, 2016).

Commission

A common revenue model is one based on **commission**, wherein a fee is charged on every successful transaction. Joining the platform, as buyer or seller, could be free and the fee may be only incurred

upon sale. Revenue is here produced by the users. There are different flavours to be found; for example, QuestPair[34] divides the commission between seller and buyer and offers reduced commission with existing subscription.

Subscription

The **subscription** model, as the name suggests, demands a subscription fee. In order to make such a model profitable, platforms must offer a service or product of distinct and unique value. From the point of view of the clients and vendors, the advantages of having a regular subscription have to outweigh the cost by a significant margin.

Free of charge/Freemium

Relatedly, the **freemium** model offers some of its service to users for free but provides extra, premium features in exchange for a recurring subscription fee. The challenge here lies in striking a balance between the services provided free-of-charge and those only accessible via the subscription.

Listing

Another model to be mentioned here is the **listing** model, wherein a charge is applied for every listing made on the platform. This is typical of markets dealing in high-value or complex items, such as property. In cases where consumers are harder to come by, vendors benefit from a hosting platform with ready access to a buying audience, internet traffic, and a high degree of visibility. Here the challenge is in setting the fee so as not to discourage vendors while returning a high enough profit. However, there can be non-monetary ways to pay for listing and customer data are a strong currency. For example, MatMatch[35] uses listing in exchange for data describing what users are looking for. This enables providers to offer more useful products to their customers.

The listing model can be enhanced by offering **Featured listing and Ads**. The vendor does not only want to be listed, but listed on top, or have their company advertised. This will be a challenge for the marketplace provider as there is only a few places on top and users do not want to be overloaded with adverts.

Lead fee

The **lead fee** model could be of interest for a marketplace offering services or bespoke products. Hereby, a user posts a request and suppliers pay the fee in order to bid for fulfilling the request. The advantage is here that the provider knows for certain that there is an existing customer. Such a model requires well written terms and conditions to avoid the customers being approached off-platform and also a "matchmaking" approach can help, i.e., the marketplace aids with bringing together the providers who exactly can provide what the buyers want to purchase.

In reality, one will find a mixture of the above models and the marketplace providers are well advised to charge all participants (i.e., both buyers and sellers) of the marketplace fairly (Nesvit, 2021) so they remain on it.

[34] https://questpair.com/
[35] https://matmatch.com/

5.3. Final assessment: opportunities and risks

Regardless of the model of choice, digital platforms exploit a number of advantages, including though not limited to: established and accessible networks; high user engagement, including recurrent users with a high level of fidelity to the platform; digital marketplaces that seize a large enough share of the market enjoy high margins; successful marketplaces generally dictate the fees of service, including increasing fees over time; and digital infrastructures facilitate the collection of consumer data, which can be used to expand into new industries and undermine competition.

On the other hand, constraints and risks include: the cost of the technology, advertising, and labour needed to establish the platform; revenue may be slow to come at first; marketplaces for larger items and fewer purchases are liable to become dependent on other platforms such as Google or Facebook for attracting buyers; considerable competition in the early stages; platforms must invest in and regulate the sellers they host in order to maintain quality and potentially build logistics networks to facilitate delivery.

(Duch-Brown, 2017) assessed the competitive landscape of multi-sided markets by identifying forces driving it and this is where opportunities can be found. **Indirect network effects** are beneficial for multisided marketplaces as user numbers have to be increased on all sides. Thus, one needs to grow consumers and providers equally strong, as the buyers want to see new/different offers to come back for more. The providers are expected to start a healthy competition with their peers and try to outdo them on the offering. **Economies of scale** should be reachable for a multisided marketplace very soon since the costs of developing and operating a platform are independent of the volume of transactions between sellers and consumers. The platform owners have to investigate appropriate pricing models for both sellers and buyers to keep them happy. **Capacity constraints** are to be considered if **listing** is the business model of choice – paid listings are advertised on the top results in a website and the usage of handhold devices permits even less of advertising space. Hence, if platforms are smart and can enable personalised searches, relevant listings maybe displayed and the small space can be filled with most relevant listings. **Differentiation** will be important with respect to other platforms so, by targeting specific niches for customers, a marketplace can attract new customer segments. Interestingly, some consumers may choose similar platforms which is referred to as "**multi-homing**", for example, streaming services. Some of them produce their own movies or series and a consumer may want to watch them all. The streaming services offer subscriptions for a shorter time in the knowledge that consumers will come back at some point. These forces are present on a marketplace and its providers have to decide which of those they want to dominate or keep subtle balance.

6. Marketplaces serving industrial R&D

In the following section we want to discuss how this e-commerce and online marketplace phenomenon can be harnessed to serve Materials Modelling and enable more innovation by offering people, software, hardware, data, and foremost knowledge to everyone who requires it in one place. Some established and emerging marketplaces (Goldbeck, Mogni, & Simperler, 2021) will be introduced here.

6.1. Expertise and knowledge

IdeXlab[36], an open innovation platform, was introduced by its co-founder and CEO, Jean-Louis Liévin. They bring together people who seek to find information and people who can provide it. It takes less than 24 hours to establish a contact. They can offer around 10 m experts on any topic and they serve many industry sectors, e.g., Telecom, Health. Constructions, etc. Their platform is simple to use and hosts a richness of information and also scientific publications and patents can be searched. This search is metadata driven but may require the user to purchase publications if they are not open access. Their web search is based on smart algorithms.

The idea to manifest this platform emerged in 2010 and a first release happened in 2017. IdeXlab used consulting to better understand the market they are serving and in 2021 they optimised their services even more. A customer can explore, validate idea, recruit experts and there are also sources to look into business intelligence, marketing, etc. Subscription service may start form €50-€200/month and experts can be hired on a pay-as-you-go scheme. IdeXlab sees knowledge as an asset and encouraged experts to charge an appropriate fee. Marketing is key for the platform and the advent of new services can lead to even more international interest in their service. Seed funding requires the presentation of clear KPIs to relate opportunities to investors.

*Table 1: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **IdeXLab***

PBM Type	DMBM Type	Revenue Model
Collaboration Matching	Peer-to-peer offline services	Subscription

Kolabtree[37] is a platform, where freelance scientists can offer their services and a transaction fee is charged. Over 6,000 freelance scientists from 131 countries have registered with Kolabtree. These freelancers offer a broad range of advanced services, including data analytics, scientific writing and experiment design, to provide small businesses and research organizations with the specialized skills and experience required for their projects. Based in London and established in 2015, Kolabtree has supported a total of 2,400 projects which, in many cases, resulted in the development of a new innovative product or arrival a reliable research conclusion.

*Table 2: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **Kolabtree**.*

PBM Type	DMBM Type	Revenue Model
Collaboration Matching	Peer-to-peer offline services	Commission

[36] https://www.idexlab.com/
[37] https://www.kolabtree.com/

QuestPair [34] is an online platform that is offering a more holistic approach to a wide range of businesses that require scientific input to bring in new ideas and creativity. QuestPair aim to pair business with scientific expertise (consulting), equipment, data and materials. This idea found the favour of the European Commission, as they were awarded funding via the SME instrument Phase I funding[38] from the European Union's Horizon 2020 research and innovation programme. This grant was used to support a feasibility study to implement a new online platform for bringing together companies and organisations with scientific experts within universities or research centres for consultancy and contract research projects.

*Table 3: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **QuestPair**.*

PBM Type	DMBM Type	Revenue Model
Collaboration Orchestration Matching	Peer-to-peer offline services	Commission

6.2. Marketplaces for R&D outsourcing

A report from 2014 revealed that the pharmaceutical and biotech industries had the highest levels of R&D outsourcing across hi-tech industries (PwC, 2014). At that time, the pharma industry suggested that 40% of their R&D would be outsourced to 3rd parties. This is indeed, a very good prospect for a marketplace that could offer the required R&D provisions. Two marketplaces who offer this are Science Exchange and Scientist.com.

Science Exchange[39] is a marketplace for scientists to list, discover, access, and pay for scientific services from any institution in the world. It brings together researchers (academia and industry) with specialist contract research providers who offer research expertise and services. The company was founded in 2011 by Elizabeth Iorns, a New Zealand scientist, and raised interest and thus, funding by investors (Konrad, 2017) (Tansey, 2017). Their website advertises that 2,500+ different service providers are using the website, including specialized research infrastructure and expertise at top research institutions. A big asset is that Science Exchange vets the providers on their marketplace and forms contracts with them through a standardized agreement. Also, there are pre-established contracts in place to protect customers' intellectual property and confidentiality, so terms and conditions are covered. This, however, makes it difficult if bespoke services are sold as a uniform set of terms and conditions is often not sufficient in such cases. However, a support team of research consultants called "concierge service" can assist customers with bespoke problems, a similar role to that of EMMC[40] Translators (Hristova-Bogaerds, et al., 2019).

[38] https://clustercollaboration.eu/open-calls/h2020-call-proposals-sme-instrument
[39] https://ww2.scienceexchange.com/s/
[40] European Materials Modelling Council, www.emmc.eu

*Table 4: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **ScienceExchange**.*

PBM Type	DMBM Type	Revenue Model
Collaboration Orchestration Matching	Peer-to-peer offline services	Commission

Scientist.com[41] (formerly known as Assay Depot) is a network of public and private e-commerce marketplaces that connects buyers to sellers of scientific research services. In 2020, it saw a 55% increase in orders from last year and they earned the #1 Fastest-Growing Company in San Diego [42] . The company was founded in 2007 by Kevin Lustig, Chris Petersen and Andrew Martin, and launched its first public research marketplace in September 2008. Similarly to Science Exchange, it provides a powerful tool for R&D outsourcing of all sorts with: strong operational support, 24/7 research consulting services, as well as the administrative and legal contracts needed for a seamless business interaction. Scientist.com focuses primarily on the R&D area of life sciences, with a majority of service providers and buyers being from pharmaceutical and biotech industries. The website users include some of the world's leading biopharma brands and reports having 17,500+ research service providers. In 2017, Scientist.com was selected by VWR International [43]—an industry leader in the life science consumables and reagents space—as its exclusive provider of custom research services. In the same year, Scientist.com was selected by the US National Institutes of Health to create an outsourcing marketplace for researchers at more than 20 major government research institutes[44]. On the Scientist.com network, all suppliers are vetted and a proprietary compliance platform is used whenever a service provision has to be regulated.

*Table 5: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **Scientist.com**.*

PBM Type	DMBM Type	Revenue Model
Collaboration Orchestration Matching	Peer-to-peer offline services	Commission

[41] https://www.scientist.com/

[42] https://ocbj.media.clients.ellingtoncms.com/news/documents/2020/12/24/SDBJ_Fastest_Growing_Large_Companies_2020.pdf

[43] https://vwr.com/5F16712EC0614B3887106D0A34219233.htm

[44] https://www.businesswire.com/news/home/20170719005225/en/Scientist.com-Expands-Research-Marketplace-for-US-National-Institutes-of-Health-NIH

6.3. Marketplaces more specific for materials

Compared to life sciences the materials modelling sector is more in the fledgling stages when it comes to widely operational marketplaces. Many undertakings are referred to as a forum, in its second meaning "forum – an event or medium where people can exchange opinions and ideas on a particular issue" (Dictionary F. , 2021).

Science Exchange does offer "Computational Modelling" services and there are some offers for materials modelling hidden in a plethora of life science offers. When we looked through the order history it became clear, that modelling specific for biosciences attract more customers.

A noteworthy effort is "The **MaterialDigital** platform" [45] driven by the German government's research facilities which started on July 1st, 2019. The aim of their project is to develop a sustainable platform that brings together and supports interested parties from industry and academia in the sustainable implementation of digitalization tasks for materials. MaterialDigital is thus not a marketplace but a collaboration forum (platform) for research institutes.

A marketplace with a focus on the actual materials is **Matmatch**[46]. It is dedicated to discover, compare and evaluate over 31,000 materials, and was founded in Germany in 2017. They offer to their users a comprehensive database and provide them with the best materials for their goals. Hence, it can be seen as a modern version of the more traditional supply chain marketplace.

*Table 6: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **MatMatch**.*

PBM Type	DMBM Type	Revenue Model
Matching	Efficient product transactions Product community	Listing Model

Materials and manufacturing companies may be interested in 3rd party equipment and knowledge and this will be enabled by the two H2020 projects Market 4.0[47] and WeldGalaxy[48], respectively. Market 4.0 works on enabling production equipment and service providers to connect and work together with manufacturing companies. At a later stage, materials modelling may find a place under their Simulations provision. Market 4.0's revenue is not officially in place yet, but could be in the form of a commission for products sold via the platform (e.g., buying access to an app) and in the form of a subscription for suppliers that opt to sell products via peer-to-peer IDS apps.

WeldGalaxy is a niche marketplace that aims to connect global buyers with the EU sellers of welding equipment for arc welding and related consumables. They would like to go beyond the core equipment and the materials, and also safety equipment, life cycle management, or information about the carbon footprint of the welding process.

[45] https://www.materialdigital.de/
[46] https://matmatch.com/
[47] http://market40.eu/project/concept/
[48] https://cordis.europa.eu/project/id/822106

*Table 7: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **Market 4.0***

PBM Type	DMBM Type	Revenue Model
Matching	Efficient product transactions	Commission
Collaboration	Online services	Subscription
	Peer-to-peer	
	Offline services	

*Table 8: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **WeldGalaxy**.*

PBM Type	DMBM Type	Revenue Model
Matching	Efficient product transactions	Subscription
	Product community	Free of charge

Further marketplaces in this field can be found within an organisation, such as Dassault Systèmes, who offer "On demand Manufacturing"[49] They enable a customer to upload their design, get an instant quote, choose their manufacturer and receive their parts. On offer are 3D Printing, CNC Machining, Sheet Metal, Cutting and Injection Molding.

Examples in the field of engineering and materials modelling include vendor specific App stores such as the Ansys Store[50].

6.4. Marketplaces for Modelling and Simulation as a Service (MSaaS)

Similar to borrowing a car or a dwelling, there is an appetite to borrow software and hardware on demand. Users are not interested in buying software or infrastructure to run it on, but would rather borrow somebody else's. Infrastructures such as high-performance computers (HPCs), often needed for materials modelling calculations, are expensive. It is not only the purchase costs but also the physical place where the machines are hosted, their electricity bill, and the cost of employing skilled personnel. On top of this, the user would have to pay for software licenses. This demand was satisfied by HPC centres who would offer hardware, infrastructure, and staff sponsored with national or EU finding and buying special software licenses for a whole country. Some well-known examples are PRACE[51], ARCHER[52] in the UK, CINECA[53] in Italy, CINES[54] in France, and many more. Especially researchers of these respective countries could apply for grants to use software and hardware in these

[49] https://www.3ds.com/3dexperience/marketplace/
[50] https://catalog.ansys.com/
[51] https://prace-ri.eu/
[52] https://www.archer.ac.uk/
[53] https://www.cineca.it/en
[54] https://www.cines.fr/en/

facilities. The only thing these researchers needed was a reasonable personal computer and a decent internet connection.

HPC infrastructure is typically subject to some restrictions, such as a queuing system, how much space one can occupy, and potential down-times due to malfunction and servicing. In this context, cloud computing is a game changer because it offers access to this state-of-the-art supercomputing hardware and software without the need to acquire expensive in-house data-centres and server facilities. Further, the resources are available 24/7 and there will be always a provider in the cloud that offers a service (Kiss, Dagdeviren, Taylor, Anagnostou, & Fantini, 2015). Using cloud computing, simulation software vendors and providers can offer simulation applications to their end-users through their cloud-based platform, thus allowing the user to "consume" simulation services without necessarily having to install or maintain the simulation software locally. This type of user interface, supported by cloud-based online systems, is referred to as Modelling and Simulation as a Service (MSaaS).

Cloud Computing even caught the attention of NATO, which has carried out a significant amount of research and development with respect to their technical, governance, security, business model and conceptual perspectives. Subsequently, NATO has proposed "the Allied Framework for Modelling and Simulation (M&S) as a Service as a permanent service and cloud-based M&S ecosystem for use by NATO and partner nations" (Hannay & van den Berg, 2017)

Most computer-aided engineering (CAE) software owners were and still are not ready to fully embrace the cloud and many customers remain wary of it (Wong, 2013). The software owners must make their software fit for the cloud while also worrying about their licensing. On the other hand, software users worry about their proprietary and sensitive data. In recent years, the EMMC[40] has hosted several meetings that were attended by modellers based in the materials and manufacturing industry. When asked about the cloud, they seemed overall to be positive about it. Especially, for SMEs the cloud could be a way to access modelling without having to invest in infrastructure. We find automotive, aerospace, and defence/government organisations most reluctant to join the cloud as they often have excellent in-house facilities and are daily users of software which makes annual licences and maintenance viable.

In 2011, **Rescale** [55] was founded in San Francisco to develop a cloud computing simulation platform. However, there are a number of platforms and solutions such as Simscale[56] and UberCloud[57] in this space, but we will discuss here just a small selection. On demand, users can access software from big players such as ANSYS[58], Siemens[59], MSC Software[60], COMSOL[61], CD-adapco[62], Dassault Systemes[63], and many more. On their webpage, Rescale reports having over 8m servers and 1400 PFLOPs of

[55] https://www.rescale.com/
[56] https://www.simscale.com/product/simulation-features/
[57] https://www.theubercloud.com/how-it-works
[58] https://www.ansys.com
[59] http://www.siemens.com/
[60] http://www.mscsoftware.com/
[61] http://www.comsol.com/
[62] http://www.cd-adapco.com/
[63] https://www.3ds.com/

processing power and they support 650+ enterprise HPC simulation applications, which were optimised for HPC in the cloud.

*Table 9: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **Rescale**.*

PBM Type	DMBM Type	Revenue Model
Orchestration	Online services	Commission

SAMSON[64] has thousands of registered users and developers, both in academia and industry, who offer software which is geared to bio/chemistry modelling. However, there are some tools useful for materials sciences as well such as GROMACS, some UFF atomistic models and some builders. The software providers are advised how to link their software to Samson and the users can pay a monthly or annual subscription to access a visualiser and some software tools.

*Table 10: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **Samson**.*

PBM Type	DMBM Type	Revenue Model
Orchestration	Online Services	Subscription

7. Materials Modelling Marketplaces

As has been discussed in many historical and current examples, marketplaces work well whenever they bring together a wide range of otherwise dispersed actors, goods and services, creating value by easing the access and use, as well as by fostering interactions between stakeholders and thereby building communities. All of these factors play a significant role in the materials modelling field, which consists of many disparate sub-domains, each with their own academic backgrounds, terminologies and different modelling approaches. There have been significant advances in bringing these communities together, widening participation and collaboration.

Arguably the forerunner of materials modelling marketplaces has been nanoHUB.org[65] which offers a free platform for computational research, education, and collaboration in nanotechnology, materials science, and related fields. Consistent, long term US grant funding has enabled development of an easily accessible and usable platform that has led to a massive increase in access to and utilisation of materials modelling (Goldbeck, 2012). While the emphasis has been more on education than on advanced academic and industrial research, nanoHUB is a clear demonstration of the potential of a marketplace type environment in the field. nanoHUB taglines is “Making Data and Simulation Pervasive” nanoHUB reports to be serving 1.6+ million visitors and provides cloud simulation services to over 16,000 users annually.

[64] https://www.samson-connect.net/
[65] https://nanohub.org/

*Table 11: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **nanoHUB***

PBM Type	DMBM Type	Revenue Model
Collaboration	Product community	Free of charge
Creation	Online services	(Grant funding and donations)

In Europe, the creation of a more integrated materials modelling community in general and the marketplace idea in particular has been spearheaded by EMMC and expressed in its roadmaps[66], which fed into the EU's Horizon 2020 NMBP Work Programmes. Notably, the call H2020 NMBP-25-2017[67], *Next generation system integrating tangible and intangible materials model components to support innovation in industry*, specifically asked for the establishment "*of a web-based marketplace linking various activities and databases on models, information on simulation tools, communities, expertise, course materials, lectures, seminars and tutorials for at least two manufacturing sectors of the European industry*." Two projects, MarketPlace[68] and VIMMP[69], were awarded funding and embarked on the development of digital marketplaces for the field of materials modelling at the beginning of 2018. In particular, they aim to overcome current barriers to a model-driven R&D in materials industries as a means of accelerating innovation.

At the time of writing this paper, both projects are in the final year of developing online digital platforms that are able to incorporate the entire materials modelling community and its wide range of models, software and expertise. In particular, activities on translation (Hristova-Bogaerds, et al., 2019) play a key role, as well as improving access to all aspects regarding models, i.e., software, data as well as expertise, and supporting complex simulation workflows utilising open simulation platforms. By integrating the diversity and richness of materials modelling resources into a state-of-the-art marketplace and collaboration platforms, they aim to transform a currently highly fragmented landscape of software, data and knowledge from a wide range of providers into a coherent system.

Integration is achieved by building on the foundations of a terminology, classification and metadata established by the Review of Materials Modelling and the related CEN Workshop Agreement. Further formalisation of the semantics has led to sets of ontologies[70] supporting key functions of the marketplaces. Advanced semantic knowledge services are utilised to provide connections between marketplace clients looking for software, data, translators and experts and relevant providers much more efficiently and effectively. Hence, the marketplaces offer substantial value to both providers and users by reducing barriers and overheads of a fragmented market. Indeed, the materials modelling market (Goldbeck & Simperler, 2020) is dominated by a large number of small enterprises (up to 50 employees) making up about 76.4 % of the players, and most business located in the €1m to €5m range, both for discrete and continuum modelling. There are also providers of free and open sources

[66] https://emmc.eu/emmc-roadmaps/
[67] https://cordis.europa.eu/programme/id/H2020_NMBP-25-2017
[68] https://cordis.europa.eu/project/id/760173, https://www.the-marketplace-project.eu/
[69] https://cordis.europa.eu/project/id/760907, https://www.vimmp.eu/
[70] https://github.com/emmo-repo/OIE-Ontologies , https://zenodo.org/record/4411422

software (FOSS) which is often limited to highly skilled users; hence, industrial use may require substantial additional investment in expertise and training which could be provided on a marketplace.

Users of marketplaces will be able to access modelling tools and solutions via an App and Workflow store, whereby Apps are understood to be applications that fulfil a specific single purpose as opposed to applications that are multipurpose. Workflows involving linking of models to address complex R&D challenges are of increasing importance for industrial R&D. These workflows typically involve a range of discrete and continuum models from different providers and require deployment on HPC resources for execution. The pains for industrial end users in constructing and using these workflows include a range of issues such as: identifying simulation platforms that can support and easily integrate such a wide range of models, difficulties in changing software for a particular model from one provider to another, requiring specific additional functionalities in a software implementation that are not available off the shelf, requiring input and/or validation data, requiring particular expertise not available in-house etc. Marketplaces are able to bring together the capabilities and expertise to address all of these issues. It highlights the collaborative aspect of marketplaces, hence both projects include a range of open and secure collaboration environments between actors on the marketplace. VIMMP and MarketPlace are in close collaboration regarding a common understanding on issues such as interoperability, semantics and ontologies. (Horsch M. T., et al., 2020) (Horsch M. T., et al., 2021)

Also, the importance of Open Simulation Platforms (Ghedini, 2019) and its interoperability concept is evident. Such platforms will enable the seamless integration of existing materials modelling solutions and materials data from disparate databases into advanced materials modelling workflows, covering electronic, atomistic, mesoscopic and continuum models. Integration of existing platforms includes AIIDA[71] and AixViPMaP® (Koschmieder, et al., 2019) in the MarketPlace project and Salome[72] in VIMMP. Deployment of workflows in HPC resources via dockerised containers is also supported. There are ongoing efforts to achieve OSPs with full semantic interoperability based on the EMMO[73] ontology.

Hence, marketplaces develop and provide an open cloud system enabling collaboration and exchange of information for translators, modellers, manufacturers, and R&D in academia and industry. Users can explore existing as well as create new knowledge by integrating and executing workflows online. The expected benefits are lowering risk of adopting new workflows, less upfront cost, greater speed and agility of deploying materials modelling and realising the wide range of demonstrated economic impacts.

Application fields in the marketplaces include formulation and processing of consumer-packaged goods, polymer nanocomposites for tire applications and functional coatings for corrosion protection in VIMMP and additive manufacturing of super-alloys, simulation of a screen-printing process, nanomaterials for catalyst applications, ceramic injection moulding for medical applications, printing of photovoltaic thin-film, and 3D printing of metals and alloys for powder metallurgy in MarketPlace. The applications and related models, data, software solutions and expertise required to address these challenges served to guide the development and test the applicability of the marketplaces to a wide range of industries.

[71] https://www.aiida.net/
[72] https://salome-platform.org/
[73] EMMO – European Materials and Modelling Ontology https://github.com/emmo-repo/EMMO

As they prepare to enter into exploitation, these projects stand to benefit from the trend towards digitalisation of marketplaces in general, and the increasing readiness of businesses to use online and cloud-based services.

*Table 12: Categories of platform business model, Digital Market Business Models and Revenue Models applicable to **VIMMP and MarketPlace**, subject to further developments and choice of specific business models.*

PBM Type	DMBM Type	Revenue Model
Collaboration	Online services	Commission
Orchestration	Peer-to-peer	Subscription
Creation	Offline services	Listing
Matching	Efficient product transactions	Free of charge/Freemium
	Product community	

8. Conclusions and Outlook

The emerging landscape of digital marketplaces in business-to-business interactions has been reviewed in general and with a particular focus on R&D solutions. The macro environment is positive for wider and wider adoption of marketplaces as a way of overcoming fragmentation and offering highly efficient and effective ways for providers and consumers to interact. Successful examples in the R&D space have been discussed, including examples from R&D outsourcing in pharma, science and technology expertise and knowledge marketplaces and materials provider/data solutions.

This favourable landscape offers a space for the MarketPlace and VIMMP solutions for the materials R&D field, as no other solution offers the completeness of products and services around materials modelling. Of importance is their work regarding interoperability of tools and data which makes them less of a competitor to existing businesses but enables a symbiotic relation with the latter.

Materials modelling marketplaces can provide excellent solutions to customers who would like to "borrow" goods, services and infrastructure rather than purchase them. Materials modelling marketplaces can hence contribute to a much wider use of modelling as customers can access software that otherwise would not due to them just needing modelling too rarely, or due to a lack of budget for large scale software and hardware solution. Also, more complex modelling workflows involving several models that are often needed to industrial research solutions can be accessed more easily via marketplaces, in terms of interoperability, software, data and expertise required.

Software owners, even though they have successful ways to reach their customers, would also profit as the marketplaces could give shelf space to new solutions as well as multiscale workflows which they developed in EU projects but are not ready to be digested into their portfolio. Another interesting business opportunity is to offer Apps that can more easily be used by non-experts.

Regardless of the specific application, the main asset of the materials modelling marketplaces will be that they can open vast amount of knowledge to any person that wants it - no matter who they are and where they are.

Acknowledgement

This study has received financial support from the EU H2020 projects MarketPlace GA n. 760173 and VIMMP GA n. 760907. The authors thank Prof. em. Herbert Knittler of University of Vienna, for his contribution to the section on historical markets in Europe. They also thank Dr. Konstanze A. Knittler, an art historian and specialist in Chinese ceramics, for her section on the Chinese porcelain trade. The authors are also grateful to Otello Roscioni, Davide Di Stefano and Ilian Todorov for helpful comments and revision of this article and to Raimund Bröchler for his information on Market 4.0.

Disclaimer

Goldbeck Consulting Ltd is not endorsing any mentioned marketplaces/companies or functions as their broker/dealer. Links are provided for the sole purpose of underlining the thoroughness of our research. All statements of fact, opinion, or analysis expressed in the report are those of Goldbeck Consulting Ltd. The information used and statements of fact made are not guarantees, warranties or representations as to their completeness or accuracy. With the exception of Market 4.0, the categories of Platform Business Model, Digital Market Business Models and Revenue Models applicable to named market places were assigned by Goldbeck Consulting Ltd using available information in the public domain but may not reflect how the respective businesses would categorise themselves. Goldbeck Consulting Ltd assumes no liability for any short term or long terms decision made by any reader based on analysis included in this report. In many cases, the opinion expressed in the reports is our current opinion based on prevailing trends and is subject to change.

Glossary of Terms and Abbreviations

API – Application Programming Interface

BBC – British Broadcasting Corporation

BC – before Christ

CAD – Computer Aided Design

CAE – Computer Aided Engineering

CEO - Chief Executive Officer

CFD - Computational Fluid Dynamics

DFT – Density Functional Theory

DMBM - Digital Market Business Models

EMMC – European Materials Modelling Council

EMMO – European Materials and Modelling Ontology

EDI - Electronic Data Interchange

EPA - European Union Payment Area

EU – European Union

FEA – Finite Element Analysis

FOSS – Free and Open-Source Software

H2020 – Horizon 2020 is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness. (2014-2020)

HPC – high performance computing

IMF - International Monetary Fund

iOS - (formerly iPhone OS) is a mobile operating system created and developed by Apple Inc.

MSaaS – Modelling and Simulation as a Service

NATO - North Atlantic Treaty Organization

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

PBM – Platform Business Model

PFLOPs - petaflops. A measure of computing speed equal to one quadrillion floating-point operations per second.

OECD - Organisation for Economic Co-operation and Development

OSP – Open Simulation Platform

SME – Small and Medium Enterprises

WTO – World Trade Organisation

References

Atticus. (2014, June). *Price comparison website: Consumer market research.* Retrieved from Financial Conduct Authority: https://www.fca.org.uk/publication/research/price-comparison-website-consumer-research.pdf

BBC. (2010, May 8). *History of Harrods department store*. Retrieved from BBC news: https://www.bbc.co.uk/news/10103783

Bloomenthal, A. (2020, Nov 24). *Electronic Commerce (e-commerce)*. Retrieved from Investopedia: https://www.investopedia.com/terms/e/ecommerce.asp

Bourke, A., & Rendall, J. (2010). *A Lion called Christian.* New York: Broadway Books.

Cave, R. C. (1965). *A Source Book for Medieval Economic History.* Biblo & Tannen Publishers.

Cramer-Flood, E. (2020, Jun 22). *Global Ecommerce 2002*. Retrieved from eMarketer: https://www.emarketer.com/content/global-ecommerce-2020

Dictionary, A. (2021, accessed 27th April). *APP Meaning in the Cambridge English Dictionary.* Retrieved from https://dictionary.cambridge.org/dictionary/english/app

Dictionary, F. (2021, accesed 28th April). *Definition of forum noun in Oxford Advanced Learner's Dictionary.* Retrieved from https://www.oxfordlearnersdictionaries.com/definition/english/forum?q=forum

Duch-Brown, N. (2017). The Competitive Landscape of Online Platforms. *JRC Digital Economy Working Paper*.

Edwards, J., & Ogilvie, S. (2011). What lessons for economic development can we draw from the Champagne fairs? *CESifo Working Paper No. 3438*.

Erikson, E. (2014). *Between Monopoly and Free Trade: the English East India Company, 1600- 1757.* New Jersey: Princeton University Press.

Ghedini, E. (2019). *Update recommendations for the Review of Materials Modelling, in particular regarding the reference architecture for metadata based semantic interoperability.* Zenodo. https://doi.org/10.5281/zenodo.6038364.

Goldbeck, G. (2012). *The economic impact of molecular modelling.* Zenodo. https://doi.org/10.5281/zenodo.44359.

Goldbeck, G., & Simperler, A. (2020, Sept 5). *Materials Modelling Software Market.* Retrieved from Zenodo: https://doi.org/10.5281/zenodo.4016089

Goldbeck, G., Mogni, G., & Simperler, A. (2021, June 11). *Workshop on Business Models of R&D Digital Marketplaces.* Retrieved from Zenodo: http://doi.org/10.5281/zenodo.4926400

Hannay, J. E., & van den Berg, T. (2017). The NATO MSG-136 Reference Architecture for M&S as a Service. *NATO Modelling and Simulation Group Symp. on M\&S Technologies and Standards for Enabling Alliance Interoperability and Pervasive M&S Applications (STO-MP-MSG-149)* (pp. MP-MSG-149-03). Lisbon, Portugal: STO/NATO.

Harrods. (2020). *Media Opportunities 2020-2021.* Retrieved from Harrods Partnerships: https://www.harrodspartnerships.com/media/4208.pdf

Hayes, A. (2019, June 25). *Dotcom Bubble*. Retrieved from Investopedia: https://www.investopedia.com/terms/d/dotcom-bubble.asp

Heiss, A. G., Jakobitsch, T., Wiesinger, S., & Trebsche, P. (2021). Dig out, Dig in! Plant-based diet at the Late Bronze Age copper production site of Prigglitz-Gasteil (Lower Austria) and the relevance of processed foodstuffs for the supply of Alpine Bronze Age miners. *PLoS ONE 16*, e0248287.

Holleran, C. (2012). *Shopping in Ancient Rome: The Retail Trade in the Late Republic and the Principate.* Oxford University Press.

Horsch, M. T., Chiacchiera, S., Seaton, M., Todorov, I., Šindelka, K., Lísal, M., . . . Schiffels, P. C. (2020). Ontologies for the Virtual Materials Marketplace. *Künstl Intell 34*, 423–428.

Horsch, M. T., Chiacchiera, S., Seaton, M., Todorov, I., Toti, D., & Goldbeck, G. (2021). *Introduction to the VIMMP ontologies.* Zenodo. https://doi.org/10.5281/zenodo.4411422.

Howard, D. S. (1974). *Chinese Armorial Porcelain.* London: Faber and Faber Limited.

Hristova-Bogaerds, D., Asinari, P., Konchakova, N., Bergamasco, L., Marcos Ramos, A., Goldbeck, G., . . . Schmitz, G. J. (2019, Nov 25). *EMMC Translators Guide.* Retrieved from Zenodo: http://doi.org/10.5281/zenodo.3552260

Jahn, S., Nierobisch, T., Toporowski, W., & Dannewald, T. (2018). Selling the Extraordinary in Experiential Retail Stores. *Journal of the Association for Consumer Research 3*, 412-424.

Kerr, R., Mengoni, L. E., & Wilson, M. (2011). *Chinese export ceramics.* London: V&A Publishing.

Kim, S.-H. (2017). *London's traditional markets: managing change and conflict in complex urban spaces.* Retrieved from Doctoral Thesis - University College London: https://discovery.ucl.ac.uk/id/eprint/1546153/

Kiss, T., Dagdeviren, H., Taylor, S., Anagnostou, A., & Fantini, N. (2015). Business Models for Cloud Computing: Experiences from Developing Modeling & Simulation as a Service Applications in Industry. *Winter Simulation Conference (WSC)* (pp. 2656-2667). Huntington Beach, CA, USA: IEEE.

Knittler, H. (2019). *Städte und Märkte.* Berlin, Boston: De Gruyter Oldenbourg.

Köbler, G. (1995). *Deutsches Etymologisches Wörterbuch.* Tübingen: Mohr.

Konrad, A. (2017, June 29). *Science Exchange Takes On $28M To Help Companies Outsource R&D.* Retrieved from Forbes: https://www.forbes.com/sites/alexkonrad/2017/06/29/science-exchange-takes-on-28m-to-help-companies-outsource-rd/?sh=168e65643907

Koschmieder, L. H., Altenfeld, R., Bami, Y., Haase, C., Lin, M., Vuppala, A., . . . Schmitz, G. (2019). AixViPMaP®—an Operational Platform for Microstructure Modeling Workflows. . *Integr Mater Manuf Innov 8*, 122-143.

Lambert, B. (2016). Merchants on the margins : fifteenth-century Bruges and the informal market. *Journal of Medieval History 42*, 226-253.

Loranger, D., & Greene, M. (2020). The 'store of the future' in popular culture: Trends in press coverage of experiential retailing. *Fashion, Style & Popular Culture 7*, 313–329.

Maradin, D., Malnar, A., & Đipalo, E. (2020). The market structure of the smartphone operating systems industry in the EU. In M. Tomljanović, *Contemporary Challenges of the EU, the Republic of Croatia and the Western Balkan Countries* (pp. 209-222). Rijeka: University of Rijeka, Faculty of Economics and Business.

Mehdipour, A., & Rashidi Nia, H. (2013). Persian Bazaar and Its Impact on Evolution of Historic Urban Cores. *The Macrotheme Review 2*, 12-17.

Mesenbourg, T. (2000). *Measuring the Digital Economy.* Retrieved from United States Census Bureau: https://www.census.gov/library/working-papers/2001/econ/mesenbourg-01.html

Mitterauer, M. (1980). *Markt und Stadt im Mittelalter: Beiträge zur historischen Zentralitätsforschung.* Stuttgart: Hiersemann.

Nesvit, A. (2021, Oct 13). *TOP 7 Online Marketplace Revenue Models in 2021.* Retrieved from Soloboda Studio: https://sloboda-studio.com/blog/online-marketplace-revenue-models/

OECD. (2012). *OECD Internet Economy Outlook 2012.* Retrieved from OECD Publishing, Paris: https://doi.org/10.1787/9789264086463-en

Packard, N. (2020). The ARPANET Into the Internet: A Tale of Two Networks. *Studies in Media and Communication 8(1)*, 37-49.

Pierson, S. (2019). Chinese porcelain, the East India Company and British cultural identity, 1600-1800. In T. H. Bentley, *Picturing Commerce In and From the East Asian Maritime Circuits, 1550-1800.* (pp. 275-292). Amsterdam: Amsterdam University Press.

PwC. (2014). *R&D outsourcing in hi-tech industries. A research study.* Retrieved from PwC: https://www.pwc.com/gx/en/pharma-life-sciences/assets/pwc-r-and-d-outsourcing-in-hi-tech-industries.pdf

Russon, M.-A. (2021, February 19). *Uber drivers are workers not self-employed, Supreme Court rules*. Retrieved from BBC: https://www.bbc.co.uk/news/business-56123668

ScienceExchange. (2019, January 1). *NASA's super-black carbon nanotubes developed through Science Exchange.* Retrieved from Customer Story: https://blog.scienceexchange.com/wp-content/uploads/2019/07/CustomerStory-Nasa011719.pdf

Shah, A. (2021, May 12). *Digital marketplaces: Examples, benefits, strategies.* Retrieved from The Future of Commerce: https://www.the-future-of-commerce.com/2021/05/12/digital-marketplaces/

Simakov, V. (2020). HISTORY OF FORMATION OF E-COMMERCE ENTERPRISES AS SUBJECTS OF INNOVATIVE ENTREPRENEURSHIP. *Three Seas Economic Journal 1(1)*, 77-83.

Solanki, V. (2020, Jan 30). *How mobile apps are reshaping the e-commerce industry*. Retrieved from Smart Insights: https://www.smartinsights.com/ecommerce/ecommerce-strategy/how-mobile-apps-are-reshaping-the-e-commerce-industry/

Stempel, J. (2020, Dec 10). *Apple is sued by rival over alleged App Store monopoly*. Retrieved from Reuters: https://www.reuters.com/article/us-apple-cydia-lawsuit/apple-is-sued-by-rival-over-alleged-app-store-monopoly-idUSKBN28K310

Tang, H. (2018). "The finest of Earth": The English East India Company's enamelled porcelain trade at Canton during the eighteenth century. *Artefact 8*, 69-88.

Tansey, B. (2017, June 30). *As Big Pharma Flocks to Science Exchange, Norwest Leads $28M Funding.* Retrieved from Xconomy: https://xconomy.com/san-francisco/2017/06/30/as-big-pharma-flocks-to-science-exchange-norwest-leads-28m-funding/

Täuscher, K. (2016). *Business Models for the Digital Economy*. Retrieved from Fraunhofer: https://www.imw.fraunhofer.de/content/dam/moez/de/documents/Working_Paper/Working_Paper_Digital_Marketplaces_final.pdf

Tian, Y., & Stewart, C. (2008). History of E-Commerce. In A. (. Becker, *Electronic Commerce: Concepts, Methodologies, Tools, and Applications* (pp. 1-8). IGI Globa.

Turner, M. (2007). *Nostalgia & Dionysus: The mystery of Sigmund Freud's final resting place.* Retrieved from Sigmund Freud's Collection: an Archaeology of the Mind:

https://web.archive.org/web/20140222133332/http://sydney.edu.au/museums/publications/catalogues/freud-catalogue.pdf

van Campen, J., & Eliëns, T. M. (2014). *Chinese and Japanese porcelain for the Dutch Golden Age.* Amsterdam: Zwolle : Waanders Uitgevers.

Van Gansen, K., Valayer, C., & Allessie, D. (2018, October 1). *Digital Platforms in public services.* Retrieved from European Commission: https://joinup.ec.europa.eu/sites/default/files/document/2018-10/330043300REPJRCDigitalPlatformsBM-D2.5FinalReportv051018.pdf

Verlag J.B. Metzler. (1999). *Lexikon des Mittelalters. Band. 6: Lukasbilder bis Plantagenet. .* Stuttgart, Weimar: Verlag J.B. Metzler.

Warnaby, G., & Medway, D. (2018). Marketplace icons: shopping malls. *Consumption Markets & Culture 21:3*, 275-282.

Wong, K. (2013, Sept 12). *SaaS Redefined: Simulation as a Service (or) Cloud-Hosted Simulation*. Retrieved from Digital Engineering 274: https://www.digitalengineering247.com/article/saas-redefined-simulation-as-a-service-or-cloud-hosted-simulation