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Interdisciplinary integrative capabilities as a catalyst of responsible technology-enabled innovation: A higher education case study of Design MSc dissertation projects

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Abstract
It has been acknowledged that global challenges are in the way of delivering responsible innovation, as reflected in the Sustainable Development Goals – a set of strategic objectives formulated by the United Nations General Assembly, to promote environmentally, societally, and economically-sustainable development. Design higher education has an important role to play in equipping the next generation of professionals with knowledge and skills for tackling pressing system-level challenges. Sustainable design research and ways of integrating emerging technologies in future design higher education curricula have, separately, attracted significant interest in recent years. However, comparatively little effort has concentrated on the role that a broader range of technologies can play in shaping the design higher education provision with system-level sustainability challenges in mind. This article presents an analysis of 180 Design MSc dissertation projects, implemented at a UK higher education institution between 2019 and 2022, focusing on research challenges of societal and industrial relevance. The data set includes a mapping of dissertation projects to relevant technologies, industry sectors, and Sustainable Development Goals. Data analysis suggests a balanced distribution of projects across a range of sustainability goals, although under-represented thematic areas have also been highlighted. The methods adopted for this study, based on a systematic study of relational patterns reflecting associations of dissertation projects with technologies, industry sectors, and sustainability goals, provide a blueprint for future data-driven research on the role played by technologies within student projects in design higher education, with an emphasis on their relevance to sustainable innovation challenges.

Keywords Design higher education · Technologies · Industry sectors · Sustainable Development Goals · Network analysis

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Introduction

It has been recognised that major global challenges, including those underlying the United Nations Sustainable Development Goals (SDGs) (UN SDGs, n.d.) are inherently complex and, as such, can often only be tackled effectively from a systems design perspective (Chen et al., 2021; Maier et al., 2022; Reynolds et al., 2018).

A visual representation of the 17 UN SDGs and their main purposes from (Leal Filho et al., 2022) is provided in Fig. 1.

The increasing degree of attention that interdisciplinary research methodologies and practices have received in recent years reflects, in part, this demand for innovation across traditional epistemological and methodological silos (Ashby & Exter, 2019; Body & Habbal, 2016). "Healthcare, climate change, food security, energy, financial markets and quality of life are just a few examples of issues that require scientists and academics to work in a crossdisciplinary way" (Menken et al., 2016).

Fig. 1 Visual representation of the UN Sustainable Development Goals and their main purposes (Leal Filho et al., 2022)

This has implications for design higher education, which has increasingly focussed on developing knowledge and skills across discipline boundaries over recent years, so that future graduates can be equipped for addressing challenges requiring the adoption of system-level strategies (Menken et al., 2016). Broader scope of interdisciplinary dialogue has been advocated with reference to research training programmes (Tobi & Kampen, 2018), combined with stronger links between academic and industry stakeholders towards the solution of well-defined problems (Mainzer, 2011). The fast-paced change to the role that design has been playing in the research and innovation landscape is highlighted by the evolution of the field from an initial emphasis on product and service design to a focus on socioeconomic challenges such as those associated with delivering equitable healthcare provision and addressing climate change (Khayal & Farid, 2021; Lawrence et al., 2020; Ceschin & Gaziulosoy, 2016). As a result, design has grown into an interdisciplinary field of enquiry and locus of academic and industrial innovation. The field is therefore in a privileged position for shaping graduate profiles to address future workforce requirements, particularly considering the critical role played by user-centred and system-level design in research and innovation (Kumar, 2009). Considering the extent of recent technology development, especially in relation to information technology and computing, it has also been argued that polymathic thinking, i.e. the ability to establish connections and to examine "the intersection of ideas to understand how different 'trades' link, overlap, impact or depend upon one another", building on "proficiency and expertise across multiple fields" (Manoharan, 2019), is needed for tackling contemporary challenges (Rodgers, 2007).

Whereas interdisciplinarity in design research has been praised as often essential for tackling complex societal challenges, a close relationship between interdisciplinary academic research and industry practice has been recognised as an important source of competitive advantage, which further highlights the value of interdisciplinarity in design as a catalyst of innovation (Hacklin & Wallin, 2013). This underlines the value of design higher education programmes that rely on an overlap of multiple theoretical and methodological lenses for tackling concrete design research challenges of relevance to private sector organisations. Successful design interdisciplinary programmes in higher education, with an emphasis on project-based integration between design and engineering skills (Self et al., 2019; Voûte et al., 2020), illustrate the value of "an intertwining of education, research, and practices in the industrial and wider societal context" (Voûte et al., 2020).

Considering the potentially-disruptive opportunities associated with the adoption of emerging technologies including Artificial Intelligence (AI), immersive technologies such as Virtual Reality and Augmented Reality, and the Internet of Things, it has been recognised that design higher education programmes can benefit from innovation, if future graduates are to be prepared to tackle the above-mentioned system-level challenges effectively. Increased breadth and depth of interdisciplinary collaboration as well as strengthened connections across design researchers, practitioners, and stakeholders including third-sector and clinical organisations, have been advocated with a view to "addressing real problems and attempting to craft more sustainable futures" (Voûte et al., 2020).

It has been observed that "new insights and better answers to complex problems" often originate from "contrasting, connecting, adding and adapting concepts, theories and methodologies from different disciplines" (Menken et al., 2016). This underlines the importance for the design higher education provision to embed interdisciplinary skills development in their programmes and to facilitate student exposure to multiple perspectives around well-defined design challenges across a range of stakeholders, including universities, research institutions, and private organisations (Voûte et al., 2020).

This priority, in turn, requires academics to be familiar with research cultures and methodologies across discipline boundaries, beyond their core areas of expertise and across multiple research and innovation contexts, so that students can be exposed to a range of methods across disciplines and professional practices and learn how to bring them together.

Education for sustainable development (Kioupi & Voulvoulis, 2022), design for sustainability (Ceschin & Gaziulusoy, 2016), research into the potential of design for addressing the UN SDGs (Chou, 2021), and strategies for embedding emerging technologies such as Artificial Intelligence, Big Data, and the Internet of Things in future design higher education curricula (Self et al., 2019; Voûte et al., 2020) have, separately, attracted significant attention in recent years. However, a comparatively-smaller body of research has focused on the role that technologies can play in design higher education with reference to the UN SDGs. CERN IdeaSquare, an innovation space with access to technology and expertise from the European Organization for Nuclear Research, has been facilitating initiatives towards radical innovation capable of addressing societal needs (Thong et al., 2021). However, the emphasis is on 'deep technologies', namely technologies with potential for disruptive change that "demand significant intellectual and economic capital to pursue" (Siegel & Krishnan, 2020). Despite the recognition of a need for additional investment in technologies and infrastructures towards achieving the UN SDGs (Leal Filho et al., 2022), little research has concentrated on the role that a broader range of technologies can play in design higher education, with a view to equipping future design professionals with knowledge and skills for tackling system-level challenges.

This article contributes to filling this gap by reporting and analysing data from 180 Design MSc dissertation projects completed at Brunel University London between 2019 and 2022. The aim is to generate objective representations of the role played by a range of technologies in the students' work, with reference to sustainable design research themes reflected in the UN SDGs.

The objectives of the study are listed below:

- *Objective 1.* To assess how balanced the distribution of dissertation projects is across technologies, industry sectors, and UN SDGs;
- *Objective 2.* To identify areas for improvement to the MSc programme, with a view to encouraging a more balanced distribution of dissertation projects across the SDGs.

Following a discussion of the methods adopted for this study (Section "Methods"), results are presented (Section "Results") in the form of network graphs, made available online for interactive exploration, providing a visual representation of relational patterns relevant to associations of dissertation projects with technologies, industry sectors, and sustainability themes. The manual annotations of individual dissertation projects, identified by custom keywords reflective of project scope, are provided as part of the results with reference to technologies, industry sectors, and sustainability themes. A discussion of the results from data analysis is presented (Section "Discussion"), followed by conclusions and recommendations towards further development (Section "Conclusions and recommendations").

Methods

A Design MSc dissertation module at Brunel University London was used as a case study to assess the extent to which technologies, industry sectors, and UN SDGs are represented across student projects. Dissertation projects provide students with an opportunity to pursue a piece of interdisciplinary research driven by a contemporary design challenge. The projects, implemented each year over a period of five months, address design challenges of societal and global relevance.

As part of their dissertation work, students research and evaluate well-formulated specialist integrated design research questions, based on review of published academic research and other information available in the public domain, and through engagement with research participants following approval by the Brunel Research Ethics Committee. Students can demonstrate appropriate use of methods relating to digital design, design and innovation management, and product design simulation and manufacture, as appropriate depending on project scope, aim, and objectives. The projects require integration of knowledge, methods, and skills across user-centred design (Blessing & Chakrabarti, 2009), established systems engineering principles (Albers et al., 2005), and product engineering design methodology (Pahl & Beitz, 2013), depending on project scope.

The project specifics are the outcome of a consultation process involving students and academics. Where projects are proposed by (and implemented in collaboration with) UK businesses, the specifics of the work are defined jointly by students, academic supervisors, and business representatives. The primary goal behind this decision is to achieve alignment of the design research with the relevant business development strategies, while at the same time ensuring compliance with academic requirements.

Data about 180 Design MSc dissertation projects implemented at Brunel University London over three academic years (2019–20, 2020–21, 2021–22) were analysed, following a categorisation of projects by relevant technologies, industry sectors, and sustainability themes. The categorisation was performed manually by the authors based on the full dissertation reports submitted by the students. Technologies were extracted from the World Intellectual Property Organisation (WIPO) Technology Classification (Schmoch, 2008). A list of industry sectors was obtained from the Industry Classification Benchmark (ICB) (FTSE Russel, n.d.). Custom keywords were employed for highlighting sustainability and more general design research themes of relevance to individual dissertation projects. The assignment of technologies, industry sectors, and design research themes to dissertations was iteratively refined following review by all authors. All 17 UN SDGs were considered, with a view to assessing the degree to which the dissertation projects are relevant to individual sustainability themes without enforcing any a-priori selection.

A total of 102 dissertations were associated with one or more WIPO technology fields, 90 with one or more ICB industry sectors, and 134 with one of more UN SDGs. Out of 134 projects deemed relevant to one or more UN SDGs, 121 were associated with at least one technology or industry sector. The remaining student projects addressed design research topics that were not relevant to any WIPO technologies or ICB industry sectors or did not directly address any of the UN SDGs. Examples include design of inclusive support services for parents, children, and pet owners, design for reduced levels of occupational stress and increased workplace productivity, and design of innovative solutions for the retail sector.

The academic team comprised 23 supervisors, with core expertise spanning user-centred design, design for manufacture, computer-aided design, design for sustainability, emerging technologies and innovation, inclusive design, immersive technologies, robotics, product and furniture design, industrial design, narrative design, electronics and sensors, design innovation, design history, graphic design, and healthcare design innovation. Academic supervisors had 5+to 40+years of professional experience, with research and innovation profiles often spanning academic research and industry practice. The broad spectrum of expertise of the academic team facilitated allocation of individual dissertation projects to a suitable academic for supervision. Each project was assigned a second supervisor in a supporting role, typically with complementary expertise to the first (or primary) supervisor. Second supervisors played an important role during assessment of the dissertations, as they were less significantly involved in the implementation of the projects.

The WIPO technology classification adopted for this study (Schmoch, 2008) was developed with the aim of facilitating cross-country analysis of international patent records. It is based on International Patent Classification (IPC) codes and builds on a previous classification, namely ISI-OST-INPI, proposed by Fraunhofer ISI and by the Observatoire des Sciences et des Technologies (OST) with the French patent office (INPI) in 2005. The 2008 WIPO technology classification covers 5 technology areas and 35 technology fields. Technology fields cover electrical engineering, audio-visual technology, telecommunications, digital and computer technology, control systems, and medical technology, among others. A full breakdown by technology areas and technology fields is reported in Table A1 (FTSE Russel, n.d.).

Whereas ISI-OST-INPI reflects an international trading landscape driven by a small number of countries at an advanced stage of industrialisation, the update to the 2008 WIPO classification was driven by a need to include emerging countries. Key requirements in the development of the 2008 WIPO technology classification were (i) to cover all IPC codes, (ii) to select technology field size in such a way that numbers of international patent applications could be evened out across technology fields, and (iii) to ensure an appropriate level of differentiation in order to avoid excessive detail blurring general structures (Schmoch, 2008). Whereas it was acknowledged that a degree of heterogeneity within technology fields can hardly be avoided, experience with ISI-OST-INPI and with prior classifications highlighted that introducing specific technology fields on grounds of topical interest is ultimately of limited usefulness, as topicality is often short-lived. The 2008 WIPO classification was designed to operate at a higher aggregation level towards longer relevance as the technological landscape evolves. Moreover, the area of information technology is associated with a higher number of technology fields than in ISI-OST-INPI, therefore providing a higher degree of granularity. The MSc dissertation topics covered in this study were selected based on relevance to current challenges in design research and design industry practice, and there is no requirement on dissertation projects to cover a range of technologies. For this reason, not all WIPO technology areas and fields are represented in the MSc dissertation projects analysed in this study.

Table 1 summarises the scope of the 2008 WIPO technology fields relevant to the MSc dissertations reported in this article, and provides additional information about the corresponding dissertation topics.

For this study, industry sectors were obtained from the Industry Classification Benchmark (ICB) (FTSE Russel, n.d.). The ICB classification was designed to aid international comparison of companies and is based on four levels, namely ‘Industry’, ‘Supersector’, ‘Sector’, and ‘Subsector’. To illustrate the level of detail associated with the different levels, information from the ICB classification for ‘Industrials’ is given in the Appendix (Figs. A1, A2, A3, A4 and A5). Whereas ICB is used for allocating businesses to Subsectors based on revenue sources, the classification was not used with reference to individual businesses in the context of this study. Instead, Design MSc dissertation projects were associated with relevant industry sectors based on project scope, aim, objectives, and nature of the outputs. Considering the topics of the design dissertations analysed for this study, ICB information at the Sector level was deemed appropriate for mapping dissertation projects to industry sectors.

Table 1 Scope (Schmoch, 2008) of the technology fields relevant to the MSc dissertations analysed for this study, with additional information about dissertation topics

WIPO technology	WIPO description	Examples of relevant MSc dissertation topics
IT methods for management	Data processing software systems and methods for administrative, commercial, financial, managerial, supervisory or forecasting purposes	Online crowdsourcing systems; systems for increasing space utilisation efficiency in urban households; online educational systems; e-commerce platforms augmented by immersive technologies; software services in support of 3D and 4D printing workflows; software services based on immersive technologies to augment user experience in cultural institutions; software systems for remote control of agricultural machinery; software services in support of clinical workflows; immersive digital environments for physical rehabilitation and inclusive access to healthcare services by disabled users; assistive services within immersive digital environments (e.g. for users affected by memory impairment); digital services to aid management of sleep disorders; digital healthcare services for ageing populations; assistive software systems for travellers; services based on machine learning and immersive technologies for arts performers; data-driven digital systems in support of medical training; online services for enhanced civic engagement; digital services for streamlining communication between clinicians and patients; technology-enhanced services for wellbeing in domestic settings
Digital communication	Transmission of digital information	Crowdsourcing systems integrating mobile networks and augmented reality; communications-based innovations for improved parenting experience; technology-augmented inclusive innovations for urban spaces, personal health, and wellbeing; networking-enabled innovations for remote control of agricultural machinery; deployment of autonomous vehicles; inclusive interconnected domestic appliances
Medical technology	Medical technology, whether relying on advanced technology or not	3D printing of solutions for adjuvant treatment of early arthritis; products to support individuals with lower-limb injuries; sanitation for public transport; inclusive healthcare self-management systems and post-partum care services; cryotherapy for soft tissue injury; machine learning in support of clinical decision making; personalised solutions for management of type-1 osteoporosis; audio technology to support management of sleep disorders; customised walking aids for individuals with limited mobility; educational tools to augment medical training for diagnosis of skin conditions; inclusive healthcare services for ageing populations; products to facilitate rehabilitation of individuals with spinal cord injury; inclusive telemedicine applications; AI-assisted patient data visualisation interfaces

Table 1 (continued)

WIPO technology	WIPO description	Examples of relevant MSc dissertation topics
Control	Control of electrical and non-electrical systems	Control systems for 3D and 4D printing workflows; systems enabling remote control of agricultural machinery; systems enabling control of connected autonomous vehicles; control systems for household appliances with embedded computational capabilities; audio control systems to facilitate management of sleep disorders; control of domestic healthcare systems for ageing populations; control systems for digital tools facilitating communication between clinicians and patients; digital control systems for enhanced civic engagement; control of digital systems to improve individual wellbeing
Furniture, games	The main parts of consumer goods in terms of the number of patent applications	Domestic space optimisation; humanisation of technology; games design for senior citizens' wellbeing
Other consumer goods	Consumer goods not associated with furniture and games	Mobility assistive devices; personalised products to promote wellbeing, including footwear accessories and smart textiles; self-defence products; products to promote medication self-management and adherence; environmentally-sustainable and technology-enabled luxury goods; home entertainment products; dedicated devices in support of visually, mobility, and memory-impaired individuals; domestic appliances designed for inclusivity; products for management of social anxiety symptoms; products based on upcycled aluminium

Information about ICB Sectors relevant to the MSc dissertations considered as part of this study, adapted from (FTSE Russel, n.d.), is provided in Table 2. Dissertation projects deemed relevant to industry sectors in Table 2 were not necessarily implemented in collaboration with an industry partner, but rather reflect the relevance of dissertation work to selected industry sectors.

Network graphs were generated from the data, in order to provide interactive visual representations of how individual dissertation projects are positioned with reference to technologies and industry sectors. The data were processed using Python 3.6.9 custom scripts relying on the following libraries: NetworkX 2.5.1, Pyvis 0.1.9, VisJS 4.16.1. Interactive network graphs were generated, providing access to keywords reflecting themes relevant to individual dissertations as well as labels from the manual annotation process based on the WIPO Technology Classification (Schmoch, 2008), the Industry Classification Benchmark (ICB) (FTSE Russel, n.d.), UN SDGs, as well as custom keywords reflecting design research themes, extracted from the body of the student dissertations.

Results

A full anonymised list of dissertation projects with the corresponding manual annotations (technologies, industry sectors, UN SDGs, and design research themes) is provided in Table A2. Information relevant to individual dissertation projects can also be accessed interactively via the network graphs.

Figure 2 displays a network graph showing the mapping of individual student projects (red nodes) to technologies according to the 2008 WIPO classification (blue nodes). Technology node labels are displayed in the graph. An edge between a red and a blue node indicates that the corresponding technology was relevant to the dissertation project. The size of the blue nodes is proportional to the corresponding number of edges. Larger blue nodes therefore relate to technologies relevant to a higher number of dissertation projects within the dataset analysed in this study. Nodes were positioned using the Barnes Hut force-directed layout algorithm (Díaz et al., 2002), whereby connected nodes are brought closer together and a trade-off with repulsion between nodes leads to a surveyable layout. Individual node locations ultimately reflect the relational embedding of each node in the context of the entire network as opposed to local properties exclusively. This results in nodes with a higher number of edges and a higher degree of 'topological importance' within the network being positioned towards the centre of the graph, which in turn improves the interpretability of the visual representation.

A network graph displaying a mapping between dissertations and ICB industry sectors is displayed in Fig. 3. Red and blue nodes correspond to individual dissertations and to industry sectors, respectively. Key industry sectors are labelled in the graph, the four unlabelled smaller network fragments corresponding to 'Waste and Disposal Services', 'Travel and Leisure', 'Retailers', and 'Gas, Water and Multi-utilities'. Edges between red and blue nodes indicate which dissertations are relevant to which industry sectors. As in Fig. 2, blue node size is proportional to the corresponding number of edges. The network graph shows a hierarchical arrangement of clusters, with 'Health Care Providers', 'Technology Hardware and Equipment', 'Software and Computer Services', 'Industrial Engineering', and 'Household Goods and Home Construction' forming a larger cluster distinguished from smaller and often isolated clusters. It is worth noting that node position in the network graphs is determined by graph layout algorithms and reflects local relational patterns as well as global network

Table 2 Information about ICB Sectors relevant to the MSc dissertations included in the analysis, including examples of relevant types of businesses, adapted from (FTSE Russel, n.d.)

Industry	Sector	Examples
Technology	Software and Computer Services	Providers of computer-system design, systems integration, network and systems operations, cloud computing, distributed ledger technology, consulting and integration, data management and storage, repair services and technical support. Publishers and distributors of computer software for home or corporate use. Companies involved in digital platforms that primarily generate revenue from advertising, content delivery and other virtual products for consumers
	Technology Hardware and Equipment	Producers and distributors of semiconductors and other integrated chips. Companies involved in the application of high-technology parts to finished products, including printed circuit boards
Health Care	Health Care Providers	Owners and operators of primary healthcare property, community hospitals, retirement homes, nursing homes, and related medical businesses. Companies and government programmes offering managed health care benefits and services. Companies providing specialised disease management services to healthcare professionals
	Medical Equipment and Services	Manufacturers and distributors of medical devices such as MRI scanners, prosthetics, pacemakers, X-ray machines and other non-disposable medical devices. Manufacturers and distributors of medical supplies used by health care providers and the general public
Consumer Discretionary	Automobiles and Parts	Companies that provide assistance to individual vehicle owners. Makers of passenger vehicles, including cars, sport utility vehicles (SUVs) and light trucks. Excludes makers of heavy trucks and makers of recreational vehicles (RVs and ATVs)
	Consumer Services	Companies that lease automobiles, appliances, electronics or furniture to consumers. Consumer Services companies that are not categorized in the Education Services, Funeral Parlors and Cemeteries, Printing and Copying Services, Rental and Leasing Services, Storage Facilities or Vending and Catering Services categories
	Household Goods and Home Construction	Constructors of residential homes, including manufacturers of mobile and prefabricated homes intended for use in one place. Manufacturers and distributors of furniture, including chairs, tables, desks, and office furniture. Companies that manufacture and market household electrical appliances. Companies that manufacture and supply household products
	Leisure Goods	Companies involved in the application of technology and electronics to the consumer discretionary sector. Companies that design, manufacture and market video game software and related elements. Manufacturers and distributors of toys, including such toys and games as playing cards, board games, stuffed animals and dolls. Manufacturers and distributors of recreational equipment including musical instruments. Companies that design, manufacture and market recreation vehicles (RVs), motorcycles or passenger boats. Companies that produce and/or market professional and/or personal imaging products including digital cameras and film cameras
	Personal Goods	Manufacturers and distributors of clothing and related accessories, footwear, luxury items, and cosmetics
	Retailers	Retail outlets and wholesalers offering a range of products including clothing, shoes, jewellery, sunglasses and other accessories, and home improvement products. Specialty retailers and wholesalers
	Travel and Leisure	Companies providing passenger air transport. Companies providing travel and tourism-related services. Providers of gambling and casino facilities. Operators and managers of hotels and motels. Providers of leisure facilities and services, including fitness centres, amusement parks, concerts and sports/e-sports event promotion. Operators of restaurants and bars

Table 2 (continued)

Industry	Sector	Examples
Consumer Staples Industrials	Beverages	Manufacturers and shippers of cider and malt products. Producers, distillers, vintners, blenders, and shippers of wine and spirits. Manufacturers, bottlers, and distributors of non-alcoholic beverages
	Food Producers	Companies dealing with farming, fishing, ranching, and plantations. Food producers, including meatpacking, snacks, fruits, vegetables, dairy products, and frozen seafood
	Personal Care, Drug and Grocery Stores	Food retailers and wholesalers. Drug retailers. Makers and distributors of toiletries and personal-care and hygiene products, including deodorants, soaps, toothpaste, perfumes, diapers, shampoos, razors, condoms, and feminine-hygiene products. Non-durable Household Products
	Construction and Materials	Companies that provide construction and infrastructure development services to private and/or public-sector clients. Companies that provide capital project planning and solutions, including engineering contracts, infrastructure development, bid preparation, interior enhancement designs and architects. Companies that design, manufacture, market and/or install air conditioning, heating and/or refrigeration systems. Companies that provide materials to the building and construction industry, excluding air-conditioning, cement, heating, plumbing, roofing, and wall boards
	Industrial Transportation	Companies that provide commercial trucking or mass public bus services. Companies that design, develop, manufacture, and distribute light, medium and heavy-duty trucks and vans. Companies that operate railway systems for transporting goods and mass public rail services. Companies providing services to the Industrial Transportation sector, including companies that manage airports, train depots, roads, bridges, tunnels, ports, and providers of logistic services to shippers of goods. Includes companies that provide aircraft and vehicle maintenance services
Energy	Alternative Energy	Companies that produce alternative fuels such as ethanol, methanol, hydrogen, and bio-fuels that are mainly used to power vehicles, and companies that are involved in the production of vehicle fuel cells and/or the development of alternative fueling infrastructure. Companies that develop or manufacture renewable energy equipment utilizing sources such as solar, wind, tidal, geothermal, hydro and waves
Utilities	Gas, Water and Multi-utilities	Companies that engage in multiple utilities that have no dominance over one another. Distributors of gas to end users. Companies providing water to end users, including water treatment plants
	Waste and Disposal Services	Providers of pollution control and environmental services for the management, recovery, and disposal of solid and hazardous waste materials, such as landfills and recycling centres
Real Estate	Real Estate Investment and Services Development	Companies that provide services to real estate companies but do not own the properties themselves. Includes agencies, brokers, leasing companies, management companies and advisory services

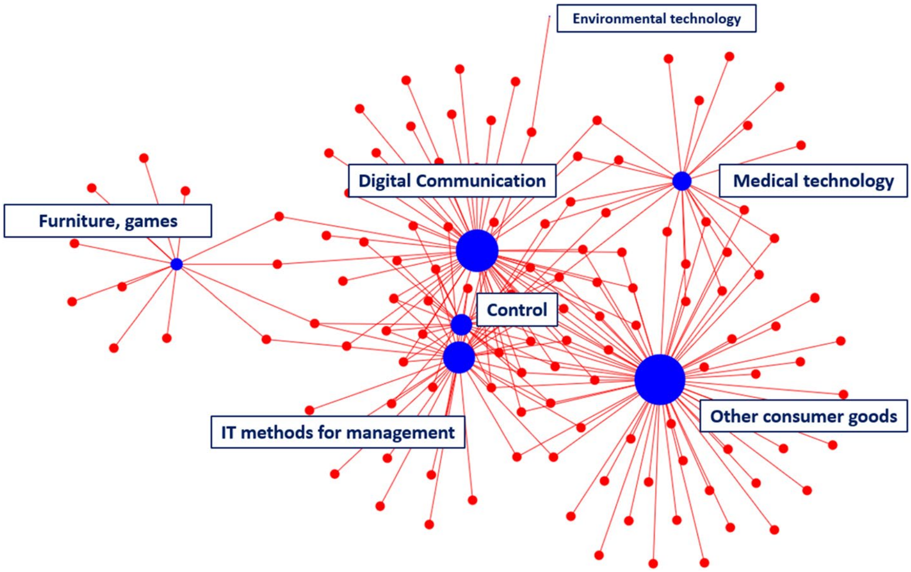

Fig. 2 Network graph showing individual MSc dissertation projects (red circles) and the technologies relevant to them (blue circles). Technologies have been labelled in the graph

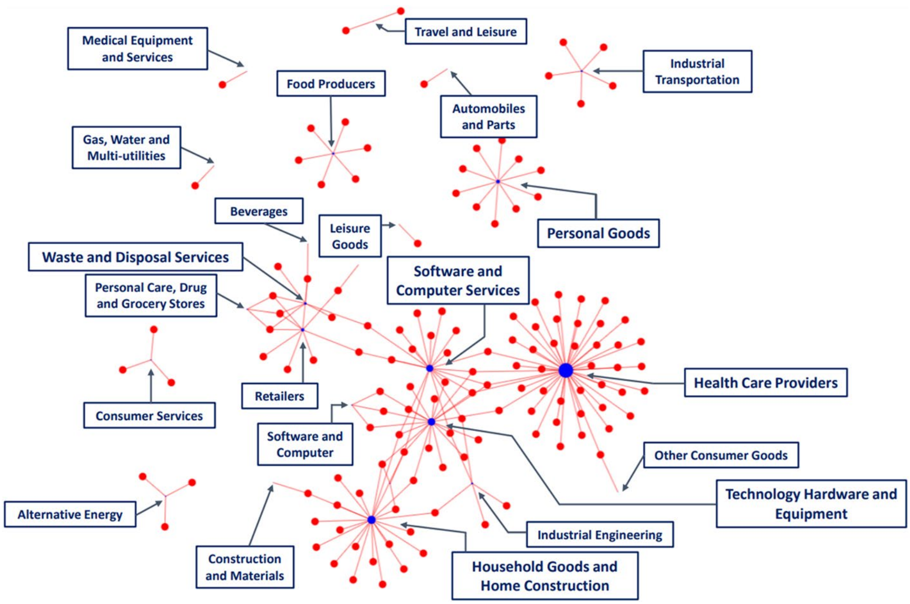

Fig. 3 Network graph showing individual MSc dissertation projects (red circles) and the Industry Classification Benchmark industry sectors relevant to them (blue circles). Industry sectors have been labelled in the graph

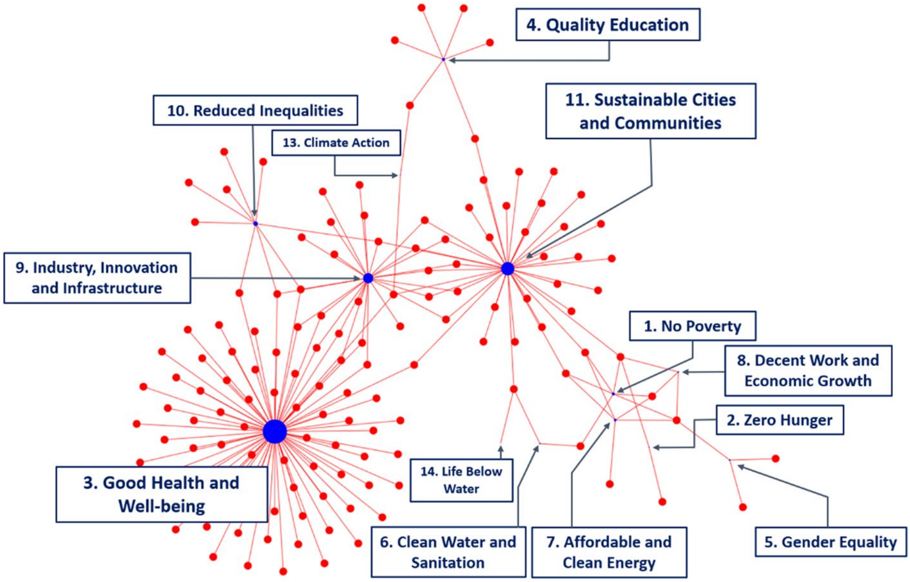

Fig. 4 Network graph showing individual MSc dissertation projects (red circles) and the UN SDGs relevant to them (blue circles). SDGs relevant to a higher number of dissertations have been labelled in the graph

connectivity. For example, 'Health Care Providers' being closer to 'Technology Hardware and Equipment' and 'Software and Computer Services', and farther from 'Household Goods and Home Construction', carries information about 'Health Care Providers' having higher thematic similarity with 'Technology Hardware and Equipment' and 'Software and Computer Services' than 'Household Goods and Home Construction', as reflected in the data. Smaller clusters disconnected from the rest of the network correspond to industry sectors that have been discussed in one or more dissertations in isolation, i.e. without reference to any other industry sectors. Examples are 'Food Producers', 'Personal Goods', 'Industrial Transportation', and 'Alternative Energy'. The presence of such isolated clusters highlights an opportunity for encouraging dissertation topics and projects of relevance to multiple industry sectors, which is expected to increase further the economic and societal relevance of the student dissertations. The corresponding network graph showing associations between dissertation projects (red nodes) and UN SDGs (blue nodes) is displayed in Fig. 4.

The network graphs displayed in Figs. 2, 3 and 4 are available online and can be explored interactively via the following links: technologies network graph, industry sectors network graph; UN SDG network graph. Text containing additional information about individual nodes can be accessed by hovering over the nodes of interest. All personal identifying information (relating to both students and academic supervisors) was removed from the data for the purpose of publication.

Discussion

Given the nature of the layout algorithm employed for node positioning, the position of each node in the graphs displayed in Figs. 2, 3 and 4 reflects the corresponding relational patterns with other nodes, considering not only local connections but also the topology of the graph in its entirety. As a result, nodes connected via edges to a higher number of other nodes across the network tend to be positioned more centrally in the graph. Such network graph features are useful for visualising complex relational patterns and have been relied upon in a range of studies across research domains such as bibliometrics, focusing on statistical analysis of publications including academic literature and patents (Glänzel, 2012), and social network analysis (Meghanathan, 2017), among others.

Key technologies of relevance to the MSc dissertation projects analysed in this study stand out in Fig. 2 as having a higher number of edges connecting them to individual projects, and therefore correspond to blue nodes with larger size. Whereas some (red) project nodes cluster around one single (blue) technology node, e.g. with reference to environmental technology and medical technology, others are connected to more than one technology node and are therefore visualised as nodes positioned more centrally in the graph. These include projects relying on Information Technology as well as on technology relevant to systems control and digital communication.

The graph displayed in Fig. 3 shows dissertation projects clustering around industry sectors, most projects being relevant to a single sector. A smaller number of projects, primarily relevant to hardware equipment and software services – in some instances in relation to healthcare provision – have more than one industry sector relevant to them. This often reflects broader research interests of students and academics.

Regarding pertinence of the dissertation projects to the UN SDGs, a prominent number of projects is relevant to sustainable cities and communities and to health and wellbeing, as shown in Fig. 4. Most projects tend to cluster around a single SDG, although some span more than one sustainability theme. This minority of projects which span more than one SDG, including health and wellbeing, sustainable cities and communities, and reduced inequality, again reflects the range of interests of the students and of the academics involved.

It should be noted that there is currently no academic requirement for dissertation projects to span multiple technologies, industry sectors or UN SDGs, and the relational pattens highlighted in Figs. 2, 3 and 4 reflect the students' design research interests and the supervisors' research expertise. On the other hand, it can be argued that a more balanced distribution of dissertation projects across SDGs could be a desirable feature of the MSc teaching provision. To achieve this in future, students and supervisors could be encouraged to address a broader range of design research themes relevant to sustainable innovation.

Conclusions and recommendations

This analysis of 180 Design MSc dissertation projects implemented at Brunel University London from 2019 to 2022 has highlighted relevance to a range of technologies, industry sectors, and sustainable design research themes. A good degree of project diversification was observed across the UN SDGs. Technologies relevant to digital communication, systems control, and data processing software, as well as medical technology, were found to be pertinent to a higher number of dissertation projects in the dataset analysed. Regarding industry sectors, a significant number of student projects were relevant to healthcare provision, household goods and home construction, personal goods, as well as software and computer services. Approximately 20 dissertation projects were implemented in close collaboration with a UK-registered business qualifying as a Small and Medium Enterprise. In those instances, the project briefs were initially proposed by the businesses, primarily operating in the healthcare, software and computer services, and household goods sectors, and refined in collaboration with Design academics. Industry partners contributed to the projects with a varying degree of involvement, typically by providing feedback on design concepts and additional guidance to the students. Planned improvements to the Design MSc provision include enhancing the number and scope of such collaborative projects in the future, to increase further the economic and societal relevance of the student dissertations.

The results hold potential for informing future revision of the Brunel Design MSc provision at module and programme level. A current minority of dissertation projects, often corresponding to nodes positioned outside graph relational cores, were found to be relevant to multiple technologies and sustainable design research themes. It is argued that conditions could be put in place for such projects, complementing others addressing a single technology or SDG, to play a more prominent role in future, with a view to encouraging students to develop broader skillsets. The analysis also suggests that academic supervisors with broader knowledge and more pronounced integrative capabilities, often but not always reflecting a higher number of years in professional practice including experience outside academia, can be equally well suited to supervision of dissertation projects around contemporary design challenges as are those with more specialised academic profiles.

Except for a minority of dissertation projects that were directly initiated by students based on own research ideas, most project briefs were based on preferences expressed by students across a range of design research themes and topics suggested by academics. Raising academic supervisor awareness of how dissertation projects have been associated with technologies, industry sectors, and sustainable design research themes in recent years, and encouraging academics to consider a broader range of technologies and UN SDGs when presenting dissertation project ideas to the students are therefore expected to be beneficial with a view to promoting a more balanced distribution of future projects across SDGs. More generally, the methods employed in this study provide a blueprint for future data-driven analyses of the role played by a range of technologies in the context of student projects in higher education, with an emphasis on their relevance to sustainable design research themes. Insights generated from such analyses can, in turn, inform interventions to strengthen further the design higher education provision, with a view to empowering future design professionals to become catalysts of responsible technology-enabled innovation over the course of their careers.

Appendix

Table A1 provides a breakdown of the 2008 WIPO technology classification by technology areas and fields. The relevant IPC codes are included. The hash symbol in the right-most column is used to indicate all IPC codes starting with the relevant string. Parentheses are used in conjunction with logic NOT operators where ambiguity could otherwise arise. Commas in the right-most column correspond to logic OR operators.

Table A1 Technology areas and fields in the 2008 WIPO classification. Source WIPO IPC Technology Concordance Table (Schmoch, 2008)

Technology area	Technology field	IPC codes
Electrical engineering	Electrical machinery, apparatus, energy	F21#, H01B, H01C, H01F, H01G, H01H, H01J, H01K, H01M, H01R, H01T, H02#, H05B, H05C, H05F, H99Z
	Audio-visual technology	G09F, G09G, G11B, H04N-003, H04N-005, H04N-009, H04N013, H04N-015, H04N-017, H04R, H04S, H05K
	Telecommunications	G08C, H01P, H01Q, H04B, H04H, H04J, H04K, H04M, H04N001, H04N-007, H04N-011, H04Q
	Digital communication	H04L
	Basic communication processes	H03#
	Computer technology	(G06# not G06Q), G11C, G10L
	IT methods for management	G06Q
	Semiconductors	H01L
Instruments	Optics	G02#, G03B, G03C, G03D, G03F, G03G, G03H, H01S
	Measurement	G01B, G01C, G01D, G01F, G01G, G01H, G01J, G01K, G01L, G01M, (G01N not G01N-033), G01P, G01R, G01S; G01V, G01W, G04#, G12B, G99Z
	Analysis of biological materials	G01N-033
	Control	G05B, G05D, G05F, G07#, G08B, G08G, G09B, G09C, G09D
	Medical technology	A61B, A61C, A61D, A61F, A61G, A61H, A61J, A61L, A61M, A61N, H05G

Table A1 (continued)

Technology area	Technology field	IPC codes
Chemistry	Organic fine chemistry	(C07B, C07C, C07D, C07F, C07H, C07J, C40B) not A61K, A61K-008, A61Q
	Biotechnology	(C07G, C07K, C12M, C12N, C12P, C12Q, C12R, C12S) not A61K
	Pharmaceuticals	A61K not A61K-008
	Macromolecular chemistry, polymers	C08B, C08C, C08F, C08G, C08H, C08K, C08L
	Food chemistry	A01H, A21D, A23B, A23C, A23D, A23F, A23G, A23J, A23K, A23L, C12C, C12F, C12G, C12H, C12J, C13D, C13F, C13J, C13K
	Basic materials chemistry	A01N, A01P, C05#, C06#, C09B, C09C, C09F, C09G, C09H, C09K, C09D, C09J, C10B, C10C, C10F, C10G, C10H, C10J, C10K, C10L, C10M, C10N, C11B, C11C, C11D, C99Z
	Materials, metallurgy	C01#, C03C, C04#, C21#, C22#, B22#
	Surface technology, coating	B05C, B05D, B32#, C23#, C25#, C30#
	Micro-structure and nano-technology	B81#, B82#
	Chemical engineering	B01B, B01D-000#, B01D-01##, B01D-02##, B01D-03##, B01D041, B01D-043, B01D-057, B01D-059, B01D-06##, B01D-07##, B01F, B01J, B01L, B02C, B03#, B04#, B05B, B06B, B07#, B08#, D06B, D06C, D06L, F25J, F26#, C14C, H05H
	Environmental technology	A62D, B01D-045, B01D-046, B01D-047, B01D-049, B01D-050, B01D-051, B01D-052, B01D-053, B09#, B65F, C02#, F01N, F23G, F23J, G01T, E01F-008, A62C

Table A1 (continued)

Technology area	Technology field	IPC codes
Mechanical engineering	Handling	B25J, B65B, B65C, B65D, B65G, B65H, B66#, B67#
	Machine tools	B21#, B23#, B24#, B26D, B26F, B27#, B30#, B25B, B25C, B25D, B25F, B25G, B25H, B26B
	Engines, pumps, turbines	F01B, F01C, F01D, F01K, F01L, F01M, F01P, F02#, F03#, F04#, F23R, G21#, F99Z
	Textile and paper machines	A41H, A43D, A46D, C14B, D01#, D02#, D03#, D04B, D04C, D04G, D04H, D05#, D06G, D06H, D06J, D06M, D06P, D06Q, D99Z, B31#, D21#, B41#
	Other special machines	A01B, A01C, A01D, A01F, A01G, A01J, A01K, A01L, A01M, A21B, A21C, A22#, A23N, A23P, B02B, C12L, C13C, C13G, C13H, B28#, B29#, C03B, C08J, B99Z, F41#, F42#
	Thermal processes and apparatus	F22#, F23B, F23C, F23D, F23H, F23K, F23L, F23M, F23N, F23Q, F24#, F25B, F25C, F27#, F28#
	Mechanical elements	F15#, F16#, F17#, G05G
	Transport	B60#, B61#, B62#, B63B, B63C, B63G, B63H, B63J, B64#
Other fields	Furniture, games	A47#, A63#
	Other consumer goods	A24#, A41B, A41C, A41D, A41F, A41G, A42#, A43B, A43C, A44#, A45#, A46B, A62B, B42#, B43#, D04D, D07#, G10B, G10C, G10D, G10F, G10G, G10H, G10K, B44#, B68#, D06F, D06N, F25D, A99Z
	Civil engineering	E02#, E01B, E01C, E01D, E01F-001, E01F-003, E01F-005, E01F-007, E01F-009, E01F-01#, E01H, E03#, E04#, E05#, E06#, E21#, E99Z

Table A2 contains a full anonymised list of the MSc dissertation projects analysed for this study, including manual annotations (technologies, industry sectors, UN SDGs, and design research themes)

Figures A1, A2, A3, A4 and A5 illustrate the level of detail associated with 'Industry', 'Supersector', 'Sector', and 'Subsector' in the ICB classification with reference to 'Industrials' (FTSE Russel, n.d.).

Industry	Supersector	Sector	Subsector	Definition
50 Industrials	5010 Construction and Materials	501010 Construction and Materials	50101010 Construction	Companies that provide construction and infrastructure development services to private and/or public-sector clients.
			50101015 Engineering and Contracting Services	Companies that provide capital project planning and solutions. Includes engineering contracts, infrastructure development, bid preparation, interior enhancement designs and architects.
			50101020 Building, Roofing/Wallboard and Plumbing	Companies that design, manufacture, market and/or install non-climate control systems and related products such as siding, windows and water pipes.
			50101025 Building: Climate Control	Companies that design, manufacture, market and/or install air conditioning, heating and/or refrigeration systems.
			50101030 Cement	Companies primarily engaged in manufacturing and distributing cement and cement-derived products.
			50101035 Building Materials: Other	Companies that provide materials to the building and construction industry, excluding air-conditioning, cement, heating, plumbing, roofing, and wall boards.

Fig. A1 ICB classification with reference to 'Industrials': 'Industry', 'Supersector', 'Sector', 'Subsector'. (FTSE Russel, n.d.)

5020 Industrial Goods and Services	502010 Aerospace and Defense	50201010 Aerospace	Manufacturers, assemblers and distributors of aircraft and aircraft parts primarily used in commercial or private air transport. Excludes manufacturers of communications satellites, which are classified under Telecommunications Equipment Subsector.
		50201020 Defense	Producers of components and equipment for the defense industry, including military aircraft, radar equipment and weapons.
	502020 Electronic and Electrical Equipment	50202010 Electrical Components	Makers and distributors of basic electrical parts for finished products such as radios, televisions and other consumer electronics. Includes makers of cables, wires, ceramics, transistors, and electric adapters. Excludes communications-related equipment, which are classified under Telecommunications Equipment and makers of high-technology parts, which are classified under Electronic Components Subsector.
		50202020 Electronic Equipment: Control and Filter	Companies primarily involved in providing mechanical and electronic security and/or filtration systems.
		50202025 Electronic Equipment: Gauges and Meters	Companies that design, manufacture and market products used to measure electric, gas, water and other data for use in a variety of industries.

Fig. A2 ICB classification with reference to 'Industrials': 'Industry', 'Supersector', 'Sector', 'Subsector' (continued from Fig. A1). (FTSE Russel, n.d.)

		50202030 Electronic Equipment: Pollution Control	Companies primarily engaged in the production of pollution control equipment for purification of air and liquids. Also included are companies that provide services such as decontamination, solvent disposal management, used oil collection, vacuum truck services and recycling.
		50202040 Electronic Equipment: Other	Companies that specialize in the development and production of electrical devices/components marketed to business clients.
	502030 General Industrials	50203000 Diversified Industrials	Companies engaged in three or more industrial business activities, none of which is the dominant business line.
		50203010 Paints and Coatings	Companies that manufacture and distribute paint, material coatings, and resins.
		50203015 Plastics	Companies that manufacture and market plastic products or chemicals used to make plastic.
		50203020 Glass	Companies that manufacture various structural glasses such as float glass, architectural glass, delicacy glass, automotive glass, and other glass products. Excludes glass containers/bottles prepared for other markets.

Fig. A3 ICB classification with reference to 'Industrials': 'Industry', 'Supersector', 'Sector', 'Subsector' (continued from Fig. A2). (FTSE Russel, n.d.)

		50203030 Containers and Packaging	Companies that may produces a wide range of packaging products and packaging related materials, including cartons, plastic bottles, jars, glass bottles, aluminum cans, dispensing pumps, aerosol valves, etc.
	502040 Industrial Engineering	50204000 Machinery: Industrial	Companies that design, develop, manufacture, sell, and support general industrial machines and parts. This excludes all the other machinery Subsectors specified.
		50204010 Machinery: Agricultural	Manufacturers and distributers of a range of farming equipment for irrigation, harvesting, plowing and other processes.
		50204020 Machinery: Construction and Handling	Companies that design, manufacture and market large-size industrial equipment for construction and ports.
		50204030 Machinery: Engines	Companies that manufacture and distribute energy output devices and component parts, including diesel engines and gas engines.
		50204040 Machinery: Tools	Companies that manufactures and market value-adding equipment for various heavy industries.

Fig. A4 ICB classification with reference to 'Industrials': 'Industry', 'Supersector', 'Sector', 'Subsector' (continued from Fig. A3). (FTSE Russel, n.d.)

		50204050 Machinery: Specialty	Companies that design, manufacture and market a specific type or group of industrial machines and parts. This excludes all the other Machinery industries categorized in the Machinery Subsector.
	502050 Industrial Support Services	50205010 Industrial Suppliers	Distributors and wholesalers of diversified products and equipment primarily used in the commercial and industrial sectors. Includes builder's merchants and companies providing Maintenance/Repair services.
		50205015 Transaction Processing Services	Providers of computerized transaction processing services. Includes companies that engages in any aspects of global payment services such as routing of payment information and related data services that facilitate the authorization, clearing, and settlement of transactions.

Fig. A5 ICB classification with reference to 'Industrials': 'Industry', 'Supersector', 'Sector', 'Subsector' (continued from Fig. A4). (FTSE Russel, n.d.)

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