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ORIGINAL PAPER

Industrial Symbiosis to Circular Economy: What Does the Literature Reveal for a Successful Complex Industrial Area?

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Abstract
We observe that some industrial areas thrive, whilst others under-perform, and that the competitive potential of an enterprise located within an industrial area is impacted by a range of non-apparent characteristics related to the particular location. A dynamic industrial area is a better place for an industrial enterprise to be located than one that on the face of it seems lack-lustre—the 'dynamism' of the industrial area seems not that well understood or described. The goal of the literature review was to determine to what extent researchers have gone beyond the traditional view that industrial symbiosis (IS) is singularly focused on the symbiotic relationships that are responsible for the beneficial outcomes associated with product, by-product, and utility exchanges. We attempted to expose other forms of symbiotic relationships that might also contribute to the improved economic outcomes of companies located within complex industrial areas. Our findings confirm there are additional interacting factors contributing to the relative success (dynamism) of a given complex industrial area. We posit that an industrial area will exhibit varying degrees of success or failure, depending on the extent to which its creators have given thought to how it will operate to contribute to the international competitive advantages of its industrial inhabitants. We identified four contributing factors that contribute to this dynamism, and these align with an emerging four-dimensional framework for IS which the author is describing as the KIC4 dimensions of industrial symbiosis.

Keywords Industrial symbiosis · Kwinana Industrial Area · KIC4 · Four dimensions of industrial symbiosis · Circular economy

Abbreviations

AMC	Australian Marine Complex
CE	Circular economy
IS	Industrial symbiosis

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IE	Industrial ecology
KIA	Kwinana industrial area
KIC	Kwinana Industries Council
KIC4	Kwinana Industries Council four dimensions (as devised by the author)
LIPS	Local industrial production systems
RIZ	Rockingham Industry Zone
S	Sustainability
TBL	Triple bottom line
WTC	Western Trade Coast

Introduction

Throughout the world, governments have sought to plan for and establish industrial areas where enterprises can be co-located in precincts in close geographical proximity to transport hubs such as ports and major overland freight routes. Reasons for creating these precincts may be varied, and can rightly include improving the economic efficiency of the individual actors and improved sustainability through better environmental and social outcomes, and there may be a range of other factors that also influence governments in identifying the locations for their future industrial areas. So why is it then that some industrial areas succeed and some are unable to attract new enterprises? Why do some languish for years or just simply fail to gather momentum, even when governmental incentives are made available? It is therefore reasonable to consider the degree to which unidentified influences are impacting on the success or otherwise of a given industrial area. The process an enterprise engages to determine where to locate itself subjectively considers known or apparent factors, but there is no objective pathway that facilitates analysis of factors that are unknown. Based on extensive direct observation of industry at work over two decades in the Western Trade Coast (WTC) industrial area located in Western Australia (WA), and in great detail for the Kwinana Industrial Area (KIA) precinct within the WTC, it has become apparent that there seem to be several impacting factors that individually and collectively determine the competitive ability of this industrial precinct and its industrial inhabitants. Anecdotal evidence is that there is a multi-dimensional locational decision to be made by a prospective industrial enterprise to identify a suitable industrial precinct within which to locate.

The authors seek to develop a theoretical framework to describe seemingly influential characteristics of industrial areas to be based on empirical evidence through the research. The potential for this framework was identified by Oughton et al. [1] where the presence of four dimensions of IS emerged to explain to some extent the variability of industrial area performance using current two water-based circular economy (CE) case studies which were both located in the KIA. The framework is further elaborated in this paper incorporating an extensive literature review that provides the broader context for the framework. To achieve this, the paper is structured into four sections. The first is providing explanatory information about the KIA itself because this is the industrial area which is used to contextualise the findings and to outline the motivation for the research. The second section is a comprehensive systematic literature review which is structured to track the expansionary research that has occurred in relation to IS, and we provide observations about this throughout. The third section relates to the methodology engaged and the results reported, with the final section presenting concluding statements.

For clarity, throughout this paper, we use a hierarchy of terms to describe industrial activity. The higher-order term we use is 'industrial area'. This refers to the overall geographic expanse within which all of the industrial activities are located. Stepping down a level, we refer to 'precincts' which are where characteristically themed enterprises have been co-located. One might think of these as industrial suburbs within a broader industrial area. Finally, at the local level, we refer to 'hubs' which relate more specifically to a type of activity, for example, freight logistics or fuel storage and distribution.

Motivation for the Research

Internationally, and over decades, much scholarly research has been focused on highlighting the characteristics of major industrial areas around the world. This international research focus by Neves et al. [2, 3] has resulted in a number of industrial areas being the subject of scholarly research, thus achieving a position of higher reputational prominence than others. It follows that these beacons may then be used to illuminate design considerations for bespoke industrial areas, or toward optimising existing industrial precincts, or even for the purpose of reinventing under-performing precincts.

The focus of this paper is on the also well-studied and documented KIA, located in Perth, WA, by several academic scholars [4–8], including Neves [2, 3].

The KIA was established in the early 1950s as a major heavy industrial area, located 30 km south of Perth's central business district, and with good deep water port access. In 1991, industry representatives located in Kwinana collectively incorporated their own industry association, called Kwinana Industries Council (KIC), which was established to act in the collegiate interests of its industry members and continues this focus to this day, some 30 years later. Amongst the many achievements of KIC was the establishment of its eco-efficiency committee in the late 1990s, with its purpose being to identify opportunities for the exchange of products and by-products. The committee continued on until 2009 and was largely responsible for the identification and establishment of the extensive IS exchanges associated with the KIA [9].

The KIA is a mature industrial precinct, producing many industrial, agricultural, and mining chemicals and refined materials, for national and international markets. It has entered another expansionary phase, with significant interest from new enterprises related to the new energy metals value chain industry, and from within the renewable energy sector. Today, the KIA (Fig. 1) [10] is but a part of a larger industrial area referred to as the Western Trade Coast (WTC).

For context, the WTC has four industrial precincts as shown within the circle (https://kic.org.au/industry/) in Fig. 2 [11], these being the KIA which is the traditional heavy industrial core shown with the yellow background, the Rockingham Industry Zone (RIZ), the Australian Marine Complex (AMC), and Latitude 32. There are around 30,000 industrial workers (direct and indirect) who attribute their employment to the WTC, and 65% of them live within 15–20 km of their place of employment. The economic contribution of the WTC is around $16Bn to the WA State economy annually, and it occupies approximately 6000 ha, with only 2000 ha currently developed [12–14].

- The AMC is depicted by the orange area at the top of the circle. This area focuses on ship building and maintenance, defence industries, and specialist resource fabrication and sub-sea engineering.

Fig. 1 Western Trade Coast within the Perth Metropolitan Area (KIC, 2020a)

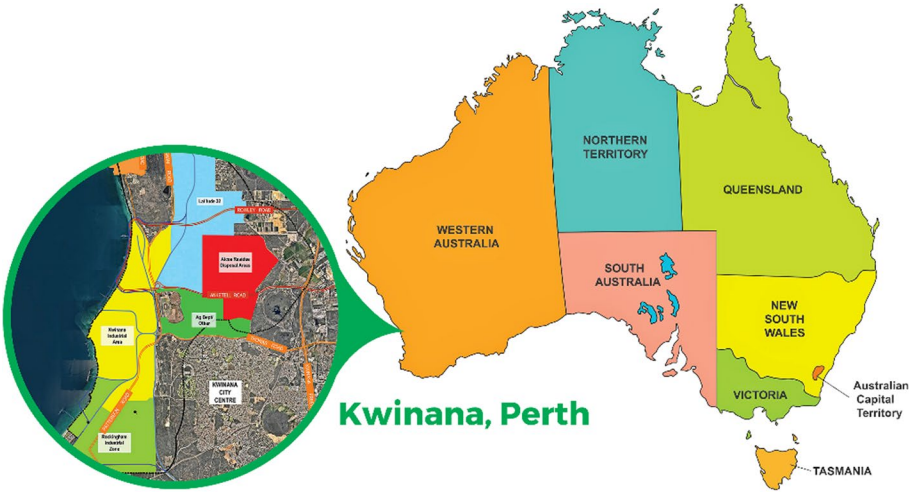

Fig. 2 Industrial precincts within the Western Trade Coast

- The RIZ is the area shaded in light green. It is a mixture of heavy and general industry zones and is the main location hosting the emerging 'Lithium Valley' industries producing cathode and anode materials.
- Latitude 32 is shown in blue. This area is largely undeveloped, but is likely to become the place where an expansion of the heavy and general industrial precinct will occur in the future.

Many of the potential new entrant enterprise representatives who have availed themselves of the KIC's 'drive-through' interpretative tour of the WTC prior to their locational decision reach a point where they favour the Kwinana industrial precinct over others because they realise that the multi-dimensional interrelationships that are evident enable them to:

- Identify and access product and by-product exchange opportunities
- Source their future employees from the large and established skilled workforce
- Contract with, for example, the constructors, fabricators, and specialist engineering workshops that are located nearby
- Collaborate with the established government-departmental managers who are responsible for transport infrastructure, pipeline corridors, industry and environmental regulation, statutory land-use planning, etc.

We posit that these relationships are all dimensional aspects of IS, and that the significance of this phenomenon becomes clear with the realisation that this novel approach can be applied to any planned or existing industrial area, and by prospective industrial new entrants who are progressing toward their locational decision.

Objectives of the Study

There are a number of objectives of this literature review:

1. Identify factors, beyond the degree to which traditional IS is available to an enterprise, that additionally contribute to the relative success of an industrial area or precinct when compared to others.
2. Review the literature of IS in order to find a sound theoretical basis to assist in evolving the understanding of IS toward a multi-dimensional framework that encompasses not previously considered facets of symbiotic industrial relationships.
3. Identify knowledge gaps in the historical literature of industrial ecology that verifies the need for a broader understanding.
4. Identify leading contemporary research to improve the theoretical basis of IS so that it may be applied to improve proposed new industrial areas, and those existing ones that may be underperforming.
5. Through a raised awareness about critical success factors for an industrial precinct which provides insights:
6. For prospective new entrant enterprises to assist them with their locational decision process.
7. For those parties who locate, build, and bring to market industrial areas for development.

The Significance of the Study

Surprisingly, there has never been a formal strategic plan for the development of the KIA, one of the world's most successful integrated industrial complexes [8]. The responsibility for the KIA falls across numerous government departments, and it is well understood that their traditional silo-structured approach has resulted in the evolutionary creation of a number of avoidable constraints on the Kwinana precinct's enterprises, and collectively on industrial development.

For 15 years as the Director of KIC, the Principal Author has advocated in the collegiate interest of the association's members. Extensive tailored guided tours of the WTC have been provided over the past 6 years for parties with an interest in understanding more about (predominantly) the KIA. Almost invariably, the direct feedback from participants, some of whom were politicians and senior bureaucrats, has been that people simply had no idea how extensive, complex, constrained, and integrated the KIA was. Representatives from potential new industries are drawn to Kwinana's traditional product/by-product/utility exchange IS story, which often features as the most prominent factor in their locational choice when they establish in Kwinana. Over the years, it has been observed that there is much more to the characteristics of an industrial area than simply the traditional IS relationships that are vital in an enterprise's quest for international competitiveness. In the context of industry being as competitive as it can be, it became clear that there were a number of aspects of relationship that must deliver sustainability outcomes for individual industrial enterprises. The relationship between a sender of a by-product and a receiver, for example, is necessary to create a successful exchange. Just as this is so, relationships must exist between the cluster's primary industries and their collective workforce, and between the primary industries and the lower tier enterprises that provide the goods and services that are needed. Furthermore, there must be relationships between the 'primaries' and the government departments that deliver the policy environments and state infrastructure within which the cluster operates. The novel approach is that for industry to be as sustainable as it can be, positive synergistic relationships across a number of dimensions (facets) are at the core of that success.

Industrial Symbiosis Research and the KIA

The KIA is well documented for its IS materials exchanges and exhibits a strong inclination toward closing cycles across water, energy, and materials [5, 6, 8]. It is often referred to in scholarly research papers in reference to the maturity and extent of its product, by-product, and utility synergies, and is widely regarded as one of the world's best practice examples of IS at work [2, 3, 5–7]. The synergy exchanges between the different KIA companies were researched and re-mapped in 2013 and reported in the SKM Western Trade Coast Integrated Assessment 2014 report. The schematic representation of the exchanges identified more than 150 product, by-product, and utility exchanges. This report was the fourth in a series of reports, each of which mapped the synergy exchanges [12–16], and they represent a 30-year formal chronological history of the development of IS in Kwinana. The 2013 schematic was reviewed in 2020 [17] and confirmed the IS exchanges have expanded to a total of over 170, with over 30 firms participating. The PDF of the schematic is available to download from www.https://kic.org.au/industry/synergies [16].

The KIA and RIZ precincts have become the preferred location for the new energy metals (electric battery) value chain industry, and for many of the associated renewable energy or green fuel industry proponents in Western Australia. This interest will increase the new product outputs and resulting by-products generated from the KIA which will inevitably increase the visibility of the role of IS as a business sustainability solution and for providing opportunities to tackle challenges such as decarbonising an economy [1, 18].

Literature Review

Overview of the Literature Review

As far back as the post-World War II era, scholars were interested in the social and technical inter-relationships between people and technology, and how these can be optimised for improved production and organisational performance [19]. The field of IS can be said to exhibit similar goals, and it is interesting, therefore, that one can postulate that there has been an evolutionary set of frameworks that take socio-technical systems theory from that post-war, enterprise-centric era to modern times, where circular economy (CE) is an expression of a new and far broader theoretical framework, but one not with a dissimilar intent. This literature review steps through this evolution of frameworks and in doing so illuminates the emergence of gaps in the research, which are only possible to observe with the advantage of hindsight. It is through the identification of these gaps that the opportunity to, in a practical sense, re-cast the theoretical encapsulation of IS emerges. The novel idea is that the traditional definitions of IS [20] fall into but one dimension of what we view as being multi-dimensional industrial relationships [1]. Lombardi and Laybourn [21] brought in aspects of enterprise eco-innovation, and culture change, seeing the emerging thought as leading to other less definable aspects of IS, and broadening the worldview of IS perhaps into aspects not yet considered. Branson [22] in his paper entitled 'Reconstructing Kalundborg: the reality of bilateral symbiosis and other insights' concluded that "Research also on this issue (achieving eco-industrial sustainability) would be useful in 'crystallising what does, actually, constitute industrial symbiosis", and "Irrespective of theoretical perspectives, ultimately what happens in practice, is what determines sustainability."

> Observation: A portal through which the idea that the traditional view of IS and its sustainability orientation may be expanded into areas as yet not associated with IS has potentially been presented.

The Broad Evolution of Terms—for Context

Scholarly research shows that IS was neither a beginning nor was it an end, rather that it is an evolving theme or manifestation of something bigger. This research has promoted and tracked the establishment of principles and practices associated with the course of evolutionary thinking which has taken the collective of 'industry' from producer of products and wastes through to conserver of scarce resources. The 'sustainable development' thinking emerged in the 1980s. Novel terms were introduced over the next three decades to describe the implementation, understanding, and evolution of sustainable development. During the latter years of the 1990s and into the new millennium, the emphasis moved to IS. Academic research expanded the thinking into the yet broader concept of industrial

ecology. The IS phenomenon was retained as a key aspect, as opposed to being replaced by some new descriptor. Later in that first decade the notion of a 'green economy' emerged to continue the expansionary thinking and evolution of a societal theme needing to have less impact on the planet. Within the past 10 years, we observe further expansionary thinking, with the emergence of the term 'circular economy'. None of this evolution of more broadly encompassing terms has replaced earlier expressions; this has been a 'building upon' process and is a reflection of the academic thinking that is evolving toward greater understanding of the desire or need to minimise society's impact on its environment.

Observation: This perspective is much less focused on the commercial sustainability of the business actor than it is on the environment of the planet.

A Focus on Industrial Symbiosis

It was in the late 1980s when writers were publishing papers on what was then referred to as industrial ecology (IE) arising along with the sustainability thinking in relation to industrial areas described this as "industrial metabolism" and a system for the transformation of 'wastes' into raw materials [23]. At the 1992 Earth Summit, the World Business Council for Sustainable Development presented its publication entitled "Changing Course", thus endorsing "eco-efficiency" as a new way for business to implement Agenda 21. The acceptability of industry as a system that evolves, much like the natural ecological system does, was gathering momentum. Wallner and Narodoslawsky and Wallner et al. [24, 25] went on to propose, from their two articles, that industry's movement from unsustainable production to sustainable production was an evolutionary process. Supporting this thinking, only a year later, the natural environment, or ecology, was used as a metaphor for industrial ecology [26]. During the first years of the new millennium, 'eco-efficiency' was a term commonly used to describe industry's quest to drive internal production costs lower. Industrial symbiosis evolved from the domain of the sustainability movement [20, 27] where a 'natural (environmental) ecology' was used as a metaphor for industry's material exchanges [22]. Chertow cites the model of industrial symbiosis as being notably expressed in the eco-industrial park at Kalundborg, Denmark. In her publication, she presents an exchange model involving ten companies and 14 materials exchanges.

Prior to this in the late 1980s, writers were publishing about IE. In 1989, Frosch and Gallopoulos [28] described IE where "the consumption of energy and materials is optimized and the effluents of one process … serve as the raw material for another process". At the same time, Ayres described places where industrial ecology was evident as "systems for the transformation of materials", and "industrial metabolism" [23]. In 1996, Wallner and Narodoslawsky and Wallner et al. [24, 25] were part of the momentum behind the sustainability movement, proposing that industry progressing from unsustainable to sustainable production was an evolutionary process taking industry toward "islands of sustainability".

Since those times, much research documenting this evolution has been published, more especially in recent years. In a paper by Neves et al. [2], a comprehensive review of IS was undertaken where some 584 publications on the subject were reviewed. The aim of the work was to "trace the trend of IS research and to map the existing case studies around the world, with a critical analysis of its impact". Their findings exposed a dominance (70%) of the research articles on IS being written from 2007 onwards, and continuing to increase, with their publication being predominantly in two journals (*Cleaner Production* and *Industrial Ecology*), the main type of content being "theoretical" (48%), the economic activity category (manufacturing) representing 62% of

published case studies, rising to 78% with the addition of the water/wastewater management activities. Several formal studies over time have mapped the development of the symbiotic exchanges between the companies located within the KIA [12–15]. Harris [7] focused attention on the project, process, and platform levels as shown in Fig. 3, positing that these are required to be present in order to develop and establish symbiotic (material) exchanges between industries.

Literature, and indeed its practical application, indicates that the internationally accepted understanding of IS is that it contemplates the exchange of products, by-products, and utilities (usually) within a complex industrial cluster. This appreciation appears to focus on the associated aspects of the broader value (social, economic, environment, etc.) that IS creates [4, 21, 29]. Since 2000, the academic community outside of Australia has tended to define IS on the basis of experiences primarily collected from Kalundborg and was thus described by Chertow as:

> Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials,

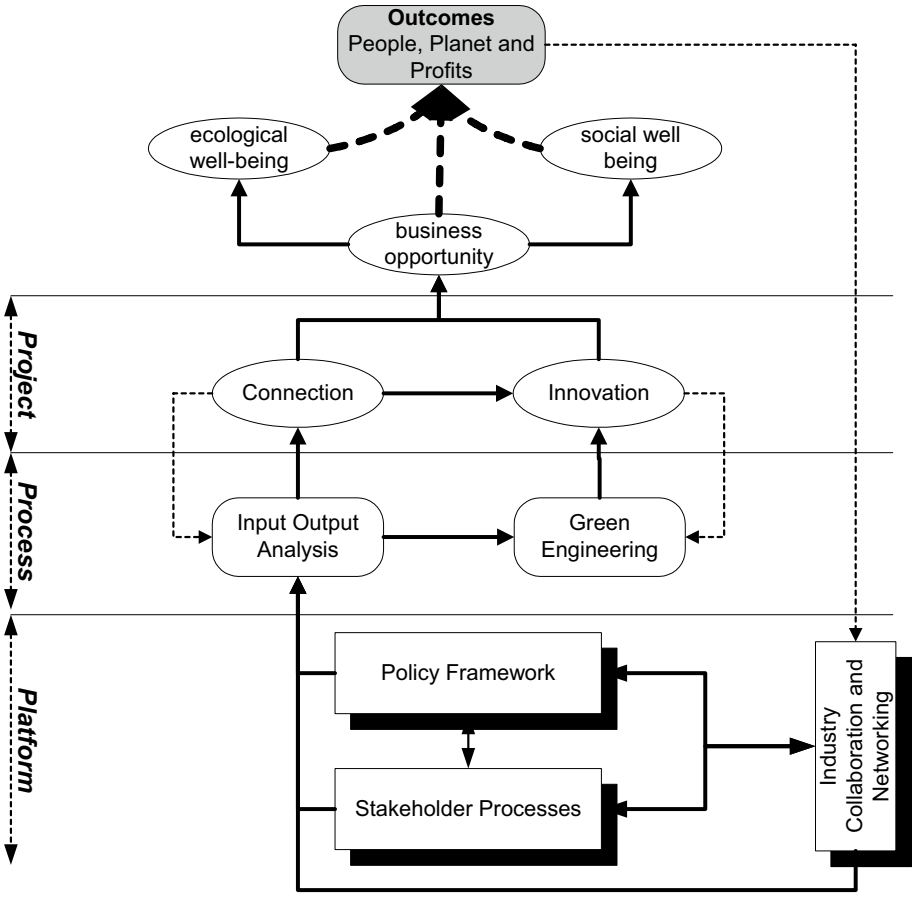

Fig. 3 Descriptive model for realisation of regional resource synergies (source: Harris 2008)

> energy, water, and/or by-products. The keys to IS are collaboration and the synergistic possibilities offered by geographical proximity [20].

One is able to draw out some important aspects of IS from this quotation: Separate industries collectively pursuing competitive advantage through collaboration, noting the reference to a geographic location, and the limitation to the exchange of materials. Chertow [20] further developed the definition in association with her colleagues by adopting the approach that as a minimum, there needs to be at least three independent entities engaged in the exchange of more than two materials to qualify to be regarded as IS. This was referred to by Chertow as the 3–2 heuristic mode. What this does is extend a reference to IS beyond a mere linear relationship where a material is exchanged between two entities, to multiple exchanges within complex relationships. Jensen [30] and Velenturf and Jensen [31] in these papers discuss the importance of geospatial industry diversity—a range of different enterprises in one larger geographic location, and the role of those diverse enterprises being located together in an industrial complex. These elements, geoproximity and geospatial diversity, are clearly an applicable characteristic within the KIA. Because of the experiences they encountered from the National Industrial Symbiosis Programme (NISP) a decade later, practising consultants and the facilitators from the UK further extended the definition:

> Industrial symbiosis engages diverse organisations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes [21].

Key elements in this definition tend to link Jensen's geospatial diversity to Chertow's materials reuse to enhance cost competitiveness. Lombardi was beginning to bring in aspects of industrial eco-innovation and culture change.

> Observation: The emergence of Lombardi's thinking seemed to be taking the traditional basis of IS toward other facets of the business world, to ones that would otherwise bear no discernible attachment to the traditional roots of IS.

Lombardi's definition of IS referred to diverse organisations, or an industrial area, where the presence of commercial stand-alone transactions is characteristic, and where the exchanges of inputs and outputs are agreed between a sender and receiver to improve business outcomes. Scholarly papers [20, 21, 30, 31] gave witness to the evolution of the traditional 'product/by-product/utility exchange' view of IS to a recently emerging consideration of other less definable, or esoteric, aspects of IS as related to the East Sicily Industrial Park. It was concluded that the mere existence of the opportunity for IS alone did not deliver actual IS outcomes for new, appropriately aligned industries, even though these industries demonstrated an appropriate alignment of their business sustainability, the skill sets of their people, and their interaction within the broader environment as identified by Oughton et al. [1]. Luciano [29] makes reference to the diversity of enterprises as part of the creation of IS benefits in addition to the usual materials exchanges. He concludes that something else beyond "the mere existence of opportunity" leads to improved competitiveness.

> Observation: Without explicitly saying it, Luciano leads the reader to consider what else is therefore needed to improve "business sustainability". The reference

to skill sets of the workers and "additional" benefits of IS are indications that something else beyond traditional IS material exchange is occurring.

Other scholars have developed a range of models that look further than the mere exchange of materials. Kurup's [5] 'Six Capitals' model explores the broader economic, social, and environmental impacts of these IS exchanges, continuing the broadening the contextual framework of the single-dimensional view of IS. Undoubtedly, this work has contributed to the body of knowledge through a greater understanding of the benefits of a functional industrial symbiosis that finds its base limited to IS material exchanges.

Observation: The traditional headline field of IS expanded in its scope, indicating a deepening understanding of its value and impact.

A model by Golev et al. [32] in a study into another of Australia's major heavy industrial areas, Gladstone, focused on the development of an IS 'Maturity Grid'. This model was developed in the recognition that there can be a range of factors limiting the development of IS, including environmental regulation, poor trust and cooperation between industries, and lack of information and economic barriers. The use of the model provides an insight into the degree to which the maturity of the IS collaborations has evolved.

Observation: Golev's work broadened the traditional conceptualisation of IS into areas that were beyond the mere exchange of materials, etc.; regulation, trust, economic barriers.

Does Sustainability Theory Contribute?

In her Triple Bottom Line (TBL) paper, Kurup [4] looked into regional sustainability and concluded that it was a commonly held view that the full potential of IS was not being realised. She identified that there were problems with quantifying economic benefits for companies, and in allocating those benefits across a TBL (economic, social, and environmental) accounting model, even at the regional synergy level. This indicated that a company's sustainability is reliant on more than better TBL performance across external factors.

Observation: The take-away is that a company itself must be sustainable before wider benefits can flow.

Company Sustainability

Sustainability theory [33] has evolved from idealism around zero waste and cleaner production to the establishment of environmental and industry balance. Even in the context of competitive positions getting harder for industry to achieve without harming the environment, it is possible to simultaneously achieve environmental and economic development. Achieving this balance radically changes businesses and the broader approach to (doing) business according to Yazan and Fraccascia [34]. Alakas et al. and Boix et al. [33, 35] highlighted that the IS and sustainability literature focuses on the environment within which the enterprises operate. Much of the research [35–40] rounds up on the provision of eco-industrial parks for optimum IS and potential maximation. Yazan made the observation that "no studies have been found" that have qualitative and quantitative evaluation processes to assist companies to achieve and remain in a competitive environment. Whilst this is at odds with Kurup's work, it is a subtle point that is made. Yazan was reversing the

nexus of sustainability—the company's sustainability must come first. Alakas concluded that the main criterion for sustainable IS is the management criterion, where a business management philosophy for management and employees is actioned. The economy criterion was also identified as being important, it being about industrial assets delivering return on investment, regional GDP, financial contribution through taxes to the government sector, and increasing employment. Importantly, Alakas concluded that companies operating within the same market can have inconsistent success in forming the necessary partnerships for sustainable operations and suggested further investigation into why this is so.

> Observation: The thinking was turning toward sustainability of the company being a higher order priority than environmental sustainability. Writers were introducing the effects of governmental influences and a suggestion for further investigation into what other factors were behind inconsistent success for companies operating in the same market. What role then does corporate sustainability have, and indeed, what defines corporate sustainability?

Through a quantitative survey, Renato et al. [41] identified a series of 29 criteria held within six dimensions to preponderantly define corporate sustainability. In their order of relevance, the dimensions were (i) corporate governance; (ii) general; (iii) economic and financial; (iv) nature of product; (v) environmental; and (vi) climate changes. Developing this theme, where broader industrial sustainability comes from within individual enterprises, Schrippe [42] examined criteria for corporate sustainability by interviewing sixty large Brazilian companies that were committed to sustainability and reported "a list of eighteen preponderant corporate sustainability criteria, with respective components and dimensions."

In summarising the conclusions of the study, a strong finding was that top management commitment to corporate strategy and governance were essential instruments in achieving corporate sustainability. Schrippe also found, surprisingly, "the three classical dimensions of corporate sustainability (being Environmental, Social, and Economic), are not enough in this modern era to define corporate sustainability". Again, surprisingly, there was no social dimension criterion preponderant in the study. The focus had moved to two more recent dimensions, being corporate governance and climate change. This is aligned to a reasonable degree with Renato et al.'s criteria, although somewhat simplified it.

> Observation: New relationship-based 'dimensions' were emerging from the research, where symbiosis is based on relationships and improved outcomes.

Industrial Ecology

White [43] provided a broad definition of IE, it being "the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory and social factors on the flow, use and transformation of resources". The descriptive boundaries of industrial ecology (IE) are indistinct, and emerge from the narrower definition of IS, which occurs at the process level and at the inter-firm level. According to Ayres [44], IE emerges as a geographic higher order of IS, at the district or sector level and even beyond this at the regional, national, or global levels. They broke White's older definition down into key themes. The first was the biological analogy [45], where IE is applied at the levels of facilities, districts, and regions. It uses notions borrowed from the ecosystem ecology which include flows, and the recycling of materials, nutrients, and energy, and this theme is then

likened to the relationships between processes and enterprises. The second was the systems perspective for environmental analysis and decision making, and the use of life cycle perspective, energy and materials flow analysis, systems modelling, and multi- and inter-disciplinary research and analysis. The third is related to technological innovation and change to solve environmental problems, providing a conspicuous path for pursuing the achievement of environmental goals [46]. The fourth theme is related to the role of companies and is seen by many as a means to escape from the reductionist basis of historic 'command and control' approaches [47, 48].

Susur et al. [49] provided a contemporary conceptional framework for IE and contextualised this in a case study based on a regional industrial centre in Catalonia. Their research question was "How can industrial symbiosis initiatives contribute to the emergence of regional industrial ecosystems for sustainability transitions of local industrial production systems (LIPS)?". The United Nations Industrial Development Organisation [50] identified LIPS as being agglomerations of industries in specific locations, with this phenomenon being a common theme in the formation of regional development strategies. Susur posits that IS exchanges can, if aggregated, contribute to the emergence of regional industrial ecosystems. Furthermore, that as interlinked exchange initiatives from a given region add up over time, a regional ecosystem emerges. A salient point is made: "If (an) emerging regional network provides support and protection for new initiatives (IS exchanges), a regional culture change can be realised to achieve (the) sustainability transition of local industrial production systems employing closed industrial production loops." How transitions into industrial ecosystems occur comes from within the sustainability transitions field of research. Authors Gibbs and Adamides and Mouzakitis [51, 52] viewed this as having not been properly addressed. Susur et al. [49] sought to fill this gap through study into the transition from the development of (traditional) industrial parks to the development of regional eco-industrial parks, where the principles of industrial ecology form the basis of their development. Susur revealed an important point: this being that each individual symbiosis exchange contributed to a greater or lesser extent to regional niche building processes. Regional specialisation (industrial thematic) emerged as a feature of successful eco-industrial areas, with niche industrial ecosystems appearing to exhibit characteristics including shared visions and expectations, shared rules and a network of enterprises that are geo-located. Of note in the research was the point that it was generally industry that fitted itself into the LIPS and that some parties were relatively disengaged and inflexible. These parties tended to be government related and not integrated into the industrial ecosystem—"the tax regime, environmental regulations, or market mechanisms that could facilitate changes in the cognitive and normative frames of the LIPS".

Industrial ecology (IE) researchers have provided insights into the agglomerative richness added by the presence of regional champions or coordinating bodies to a LIPS [53, 54]. Susur, in referring to the work of these authors, posited that the presence of such bodies, although absent, could have been of assistance in the continuing development of Catalonia's industrial ecology. Finally, the research concluded that planned industrial ecosystems can be prescriptively established using the proposed conceptual framework, and this was an outcome supported by other authors. Doing so requires the active participation of industrial organisations, entrepreneurs, universities and research institutes, local champions, managing/coordinating bodies, and the local community [55, 56].

Observation: The IE research has suggested a movement to a higher order than where IS situates itself, where a whole industrial area can be viewed as an ecosystem. It is noteworthy that with this geographic uplifting, the introduction of third-party entities

into industrial governance roles could be useful in achieving the creation and management of planned industrial ecosystems.

Dimensions and Industrial Symbiosis (Definitions and Applicability to Business)

Throughout the more contemporary literature, the word "dimension" is used in the context of phenomena to describe aspects of composition. The Cambridge Dictionary [57] lists meanings where a dimension may be a part or feature or way of considering something; for example, a person's personality has several dimensions. Additionally, a dimension might be a part or quality of a thing or situation that has an effect on the way one thinks about it; the new script gave the story a psychological dimension. To break it down, (from https://www.universetoday.com/48619/a-universe-of-10-dimensions/) [58], dimensions are simply the different facets of what we perceive to be reality. Wikipedia adds to the thematic that dimensions are more than something that can be quantitatively used to define an object, for example height, length, and mass. A dimension is a structure that categorises facts and measures in order to enable users to answer business questions. Commonly used dimensions are people, products, place, and time. Thompson [59] has published in this area. His 'Dimensions of Business Viability Model' provides a benchmark framework for measuring the viability of a business concept. The model expresses business viability using six of the core dimensions, these being market, technical, business model, management model, economic and financial model, and exit strategy. Productive Flourishing, a Web-based business development firm, writes about the internal dimensions of a single, typical business (https://www.productiveflourishing.com/the-four-key-dimensions-of-business/, accessed 12 April 2021) [60]: the dimensions being strategy, operations, marketing, and finances. They are described as distinct dimensions and as being heavily interrelated. Productive Flourishing broadens this intra-enterprise scope to bring in the notion that the external business environment itself contains various forces, or dimensions, that affect how an enterprise performs. These are described as the economic environment, and the social, legal, technological, and political dimensions.

Numerous research papers have explored various aspects of business performance and strategy. An analysis of medium and large, high technology, industrial manufacturing enterprises utilised six dimensions in a comparative construct in an attempt to find a relationship between strategic orientation and business performance [61]. It is observed that decision making about IS can be one-dimensional [62], based on the economic criteria alone, in essence a comparison on the basis of costs, and inherently implying that no other criteria are of sufficient relevance. Jacobsen (2006) [63] identified that at Kalundborg in Denmark, wider economic arguments and environmental considerations were employed in order to evaluate IS exchanges, and led to better social, economic, and environmental outcomes. Posch et al. [62] concluded that a one-dimensional model "will probably lead to the wrong conclusions and sub-optimal decision-making". Ehrenfield [64] observed that there is an implied need for management or, more broadly, governance of all relevant stakeholder groups, and this is on the basis that cooperation can be a significant factor in an IS network environment. Again, Posch summarises in concluding that the level of cooperation required only emerges if there are benefits (primarily economic, but not exclusively) accruing to all participating parties. In doing so, it is put that successful relationships of this type must cross into other dimensions, including those of trust and cooperation. In positing that IS development in a network is a change process, Posch observed that intervention by third parties, such as a regional authority or a focal institution, assisted with raising awareness

about a network, but the presence of an authority injects a requirement for participation, be this through regulatory or other means. These approaches tend to indicate the presence of a governance dimension in successful IS establishment. Building on the previous author's views on the roles of overarching authorities, other authors like Ashton [65] believe this role to be imperative beyond the individual enterprise, and positively on the environment and society more broadly.

> Observation: The use of the word 'dimension' to describe facets of business activity is commonplace. The description 'one-dimensional' is a term used by an author to describe the economic role of IS. The writers are supporting the theme that there are additional dimensional roles contributing to IS, such as, for example, a 'governance' dimension.

Governance and IE

The industrial ecologist, according to Graedel and Allenby [45] in their contribution to *The handbook on industrial ecology* (Ayres and Ayres, 2002, Industrial ecology: governance, laws and regulations, p.60), needs to be, obviously, not only comfortable with the basic disciplines of the field, but also willing to consider these within the overlay of the cultural and legal contexts. They refer to these contexts as dimensions and note their inter-relatedness to other contexts including the economic and policy dimensions. The important point to draw out here is that governance, as a dimension, assists in the description of IE. It has been shown that IS is a subset of the broader geographical context of IE. Yet, in IS, governance has a role. Velenturf (a) [66] stated in her abstract, "the effects of governance on the implementation of IS have remained under-explored". She proceeded to recommend strengthening regulatory integration and flexibility, regulators building stronger relationships between the tiers of government, and investment in the upskilling of regulatory actors. In an earlier paper, Velenturf and Jensen (b) [31] concluded that the promotion of IS by governments was limited and, in Europe, under-developed. This conclusion was based on their study of the Humber region where the governance (framework) was delivered through the policy support of regional governance actors for the conversion of 'biowaste-to-resource'. They suggested that strengthening could be achieved by (i) increasing integration and flexibility of the regulatory 'landscape' across governmental departments; (ii) building better connections between national- and regional-level governmental organisations as well as within the Humber region itself; and (iii) investing in knowledge and skills as well as the operational capacity of regional governance actors. The authors suggested that these recommendations should contribute to restoring the balance between regional capacity and the national ambitions to promote biowaste-to-resource innovation. Quantitative research in the policy (governance) field from the perspective of the firm produced a model to assist with the development of efficient policy support mechanisms [67] that lead to better IS outcomes. Again, this supports the idea that policy (being an aspect of governance) is being thought of as a component part of IS.

> Observations: The contemporary research appears to be increasingly accepting of the idea that IS is multi-dimensional, and is moving beyond the original concept of material exchanges. The presence of a strong overarching governance role in respect to an industrial complex is seen as a necessity, and it has been described in the context of a dimension.

Systems Theory and IE

Systems theory is not new. It is complex, and one might be forgiven for wondering what role it might play in this exploration of a new model of IS. Problem solving is the basis of systems theory. Systems engineering and design makes the distinction between the problem to be solved and the solution system that solves it [68]. The emerging concept of 'system of systems' [69] was being defined over 50 years ago. Ackoff [70] describes systems as a whole, derived from its parts (or properties), and its performance derives from the holistic relationship between the unified set of components (parts) of the system. Thus, total system performance is a reflection of the performance of the sub-systems. He describes a framework for systems (made up of systems), into which numerous types of systems can be placed, depending on the type of system. The basic types range from 'state-maintaining' to 'goal setting' to 'multi-goal-seeking' to 'purposive'. A goal-seeking system is responsive (not reactive) to internal or external events, whereas a purposeful system can even be an 'ideal-seeking' system, setting goals, achieving them, adapting, and re-setting new goals to take it toward its ideal state. Posch et al. [62] carried out research into the IS exchange of materials, waste, and energy with a view to a systems approach. In their research paper, they cited writers [69, 71, 72] who agreed that in the context of inter-organisational exchanges, the problems they encountered were more than "a mere technical problem". The emergence of IS networks relied on the accumulation of "profound knowledge" of the IS system and needed to take account of managerial decisions and social settings. In the interim, systems theory has evolved significantly, toward a more organic conception. Richmond [73] made the case for growth through interdependency rather than continuously trying to 'get smarter'. He colourfully concluded that "Without it (systems thinking and its interdependency) the evolutionary trajectory that we've been following since we emerged from the primordial soup will become increasingly less viable". Arnold and Wade [74] developed a systems approach to contemporary systems thinking following analysis of several pre-existing definitions. Their systems thinking model included having a clear goal or purpose, the presence of the elements or characteristics of the system, and the way in which the elements feed into or relate to each other—the interconnections.

> Observation: The interconnectedness of the dimensions of IS conforms to contemporary systems thinking and, in their totality, they would seem to conform to the framework of system of systems theory.

Circular Economy

Moreseltto [75] defined circular economy (CE) as an economic model aimed at the efficient uses of resources through waste minimisation, long-term value retention, reduction of primary resources, and closed loop of products, product parts, and materials within the boundaries of environmental protection and socioeconomic benefits. The volume of literature attempting to define CE is somewhat recent, significant, and growing [76]. The writers concluded from their surveying of enterprises (155 respondents) engaged in CE that there was a lack of clarity in understanding the differences between the more established (older) concept of sustainable development (SD) and CE. They drew two main conclusions: firstly, that sustainability was a higher-order concept than CE, both of which present pathways to sustainability. Secondly, that it was not considered a priority to the respondents what their pathways to a more sustainable world were (CE or SD), just that they were taking steps to strive toward it.

The European Union has provided a useful definition of CE and can be attributed with some credit for policy leadership. "In a circular economy the value of products and materials is maintained for as long as possible; waste and resource use are minimised, and resources are kept within the economy when a product has reached the end of its life, to be used again and again to create further value" [77]. The definitional 'boundaries' of CE became somewhat unclear as they extend into the business management and social dimensions. "The CE is an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output, to maximize ecosystem functioning and human well-being." [78]. In 2009, Chinese law promoting CE materials flows came into force, promoting circular, as opposed to the characteristically linear, movement via IS [79]. This provided considerable momentum to the emergence of scholarly research investigating this new field of study. Moreau et al. posited that whilst CE was gaining momentum in the promotion of closed materials cycles, product re-use, and the promotion of production and supply chains to improve resource efficiency, it does not extend into the higher level economic institutional (and social) dimensions. They illuminated the problem that CE does not venture into the labour and governance dimensions, and they ask who, beyond the enterprises, should bear the associated costs. The United Nations (2015) [80] adopted Resolution 70/1 in 2015. The intent of this resolution is worldwide sustainable development, and it itemised 17 Sustainable Development Goals, with associated targets. Cecchin et al. (2020) [81] in analysing the UN goals identified 7 goals where IS could make a contribution, further identifying the specific relevant targets that can be applied under 'IS'. In their conclusions, they group industrial ecology, ecological modernisation, and green economy within the higher-order circular economy framework, itself fitting within the sustainable development framework.

Strengthening the link between governance, IS, and CE, Alvarez and Ruiz-Puente and Moreau et al. [79, 82] observed that the European Union Data Centre on Waste was reporting reductions below policy targets and expectations. Efforts were being directed toward identifying new waste re-use policy (governance) targets and means by which these could be achieved. Continuing this theme, several obstacles [54] to the development of IS projects in Europe were identified. These included provision of weak economic incentives (IS exchanges are often low margin), geographic variations on incentives and drivers, varying policy frameworks (taxes and levies), and difficulty in navigating geographic boundaries (bureaucracy).

Referring again to Morseletto [75], it was suggested that the practice of governance was a common way, or requirement, in the transition to CE by way of the setting of policy targets.

> Observation: CE has emerged as the contemporary overlying framework, albeit still emerging, for IS and for several other frameworks. Whilst CE is considered to operate at a broader geographic scale, it is seen as not advancing as was anticipated. Several of the reasons for this can be attributed to the same issues that occur at the local geographic level where sustainability of current production patterns means a more likely achievement of long-term economic competitiveness.

The Emerging Future

In their review of the literature relating to the fields of CE and sustainability (S), Nikolaou et al. [83] identified there was significant and accelerating growth in the published material over the past decade. In their paper, they identified a growing connectivity between

the literature relating to CE and S, along with an increasing focus on activity at the macroeconomic level (over the micro- and mesolevels of research) where the implementation of governmental policy and projects has influence at the regional or national level. They further observed that whilst much of the literature was theoretical, science-based research from within the engineering and management scientific fields, the majority of the articles included in their research were to be found in the engineering/natural sciences fields of research. In their paper, they concluded that future research could be directed toward the links between CE and S at the micro-, meso-, and macrolevels of analysis, between CE and the social dimension, and a more multi-disciplinary focus which hones in on the intersection of the fields of engineering/natural sciences and the economic/management sciences.

Observation: The Nikolaou paper revealed that the more recent and emerging literature is moving society toward a future where CE and S are integrated fields of study and practice, and where the economic sustainability of an enterprise is interconnected to that of a cluster of enterprises which in turn is interwoven into the economic policies of a region or country. This future appears to be a new paradigm within which the evolutionary trajectory of IS falls into being simply a part of a much broader context where activity (human and corporate) aligns toward a replenishment focus. The KIC4 four-dimensional framework as described by Oughton et al. (2021) aligns within Nikolaou's conclusions, and it may, in addition to its assumed application at the local industrial area level, be an analysis tool with the potential to be applied at higher (regional, national, and beyond) economic levels to support industry's drive toward higher-order economic and environmental sustainability.

Methodology

The literature review for this paper was of the systematic type. The accumulation of evidentiary papers and their synthesis into a comprehensive account of the evolutionary nature of IS broadly followed the eight-step standardised methodology set down by Okoli [84]. Rather than the quantitative approach set down in that model, the review was more qualitative in nature. Rousseau et al. [85] posit that literature reviews can be a "comprehensive accumulation, transparent analysis, and reflective interpretation of all empirical studies pertinent to a specific question". This indicates that systematic research of the relevant literature can also be used to synthesise, assemble, analyse, and, importantly, interpret evidence gathered in a "highly reflective fashion". An additional category of literature review is referred to as 'standalone', which Fink [86] writes is distinguished by its scope and rigour leading it to become a reference point or a clear outline of the literature for researchers undertaking a new investigation. Standalone reviews are free-standing, summarising existing evidence, identifying gaps in current research, and providing a framework for positioning research endeavours. They are also valuable in informing policy and supporting practice [87].

Methods

On the basis that the literature review for this paper was systematic, qualitative, standalone, and reflective, it involved an extensive analysis of the scholarly literature through exploration of the evolution of the IS thinking and the various frameworks associated with this.

The review tracked the evolution of scholarly thinking from the socio-technical relationships and industrial ecology frameworks of 40 + years ago through to the CE framework that is the prevalent and substantially more encompassing characteristic of today's contemporary thinking as shown in Fig. 4. This tracking looked for emerging themes, sub-themes, and a confluence of ideas. It then sought to identify links in the literature that could connect to what has been observed in the KIA, and explored the extent to which the findings of the literature review could be applied to account for the success of the symbiotic relationships that can be observed there. The emerging KIC4 framework utilises contemporary CE approaches to IS and S, and builds on this by applying well-recognised business management techniques to conceptually advance the thinking around the objective locational placement of industrial enterprises where they can be best placed to contribute to our evolution toward a truly circular economy. There appears, up to the present time, to be no 'defined pathway' toward achieving this ideal.

Findings from the Literature

The key questions scholars have asked in relation to IS over the decades have been broadly directed toward the promotion of the benefits of the product, by-product, and utility exchanges that have characterised IS. The numerous published papers have been supporting IS through the presentation of arguments and models examining the benefits of IS and exploring how to encourage greater participation by individual companies, by industrial precincts, and by sovereign governments. Examination has extended into the economic, social, environmental, and productivity benefits for participating companies, to industrial enterprises located within a given precinct, to the environment, to the economy, and to society generally. More so latterly, researchers have turned attention toward understanding what limiting factors have been barriers to the greater expansion of IS practices. Thus, the research questions that this study addressed were:

- Why is it that some industrial areas thrive, whilst others stagnate?
- What are the locational characteristics that facilitate or enable the 'dynamism' and success of a given industrial estate over another?

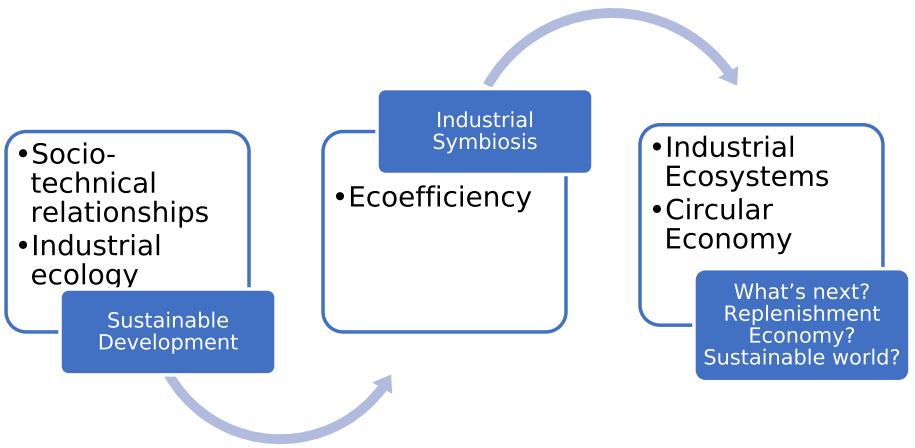

Fig. 4 Progression of the frameworks

The literature examined confirmed that IS has most often been focused on the movement of materials (including utilities) between enterprises within a complex industrial cluster on commercial terms. Aside from the broader environmental and social benefits derived as a result of the exchanges, it is clear that for their long-term sustainable operations, enterprises remain primarily focused on improving their competitiveness. This pragmatic view is pervasive and underlines their reason for being in business—to make a profit or to create wealth for their shareholders. Successful product and by-product material exchanges improve profitability, and from the perspective of business, if participation in IS can improve relative competitiveness, then it will be, and has been, embraced by industry. In the context that IS is good for business competitiveness and looking beyond the materials exchange context of IS, what else can or does IS then encapsulate? The research showed an expansion of the basic tenant of IS (the exchange of materials for mutual benefit) into deeper aspects of this, including, for example the social, capital, and environmental aspects. This is a linear expansion, with the literature examined referring at times to this phenomenon as additional 'dimensions' of IS. The more recent literature ventured well beyond this traditional understanding of IS. Novel aspects were considered in the context of S, IS, IE, and CE. These expanded the body of knowledge into areas such as government regulation and policies, government facilitation of industrial areas, and identification of prospective new industry entrants and 'anchor tenants', service industries, knowledge, innovation, and technology.

The literature confirmed that the concept of 'dimensions' (of something) is a familiar term used throughout the business world—the traditional economic, social, and environmental dimensions, for example. More recently, the technology, innovation, and motivational dimensions of business are also referred to. These emerging aspects, when combined, introduce a novel step in the continuing evolution of the IS phenomenon, and that they exist within the context of its evolutionary growth trajectory. Indeed, so much so that they may be regarded as dimensions of IS in their own right, thus expanding the current singular-dimensional traditional IS model. Furthermore, that contemporary 'system of systems' practice has the potential to directly influence IS practice in ways that sit well beyond product and by-product exchanges. Philosophically, this emerging dimensional broadening of IS exhibits an alignment with industry's focus upon maintaining relative competitiveness. To put this into context, we see in the research the emergence of three additional dimensions of IS beyond the traditional materials exchanges, these relating to the presence of a pool of skilled workers, the presence of an appropriate range of support industries, and a supportive governance regime. Figure 5 provides a visual interpretation of these dimensions. The literature review points to the possibility that there can be a dimensional theoretical framework for IS which brings the earlier frameworks together in a way that can deliver reliable information about strategies to increase the competitive potential of enterprises co-located within industrial precincts.

Results

The literature review has enabled the expansion of the definition of IS from its extensive traditional base of product, by-product, and utility exchanges, into a framework that encapsulates aspects of workforce, support industries, and governance fields of study. It has reflected this expansion by encompassing earlier research frameworks that are associated with a substantially broader context for industry. It explored each of these frameworks

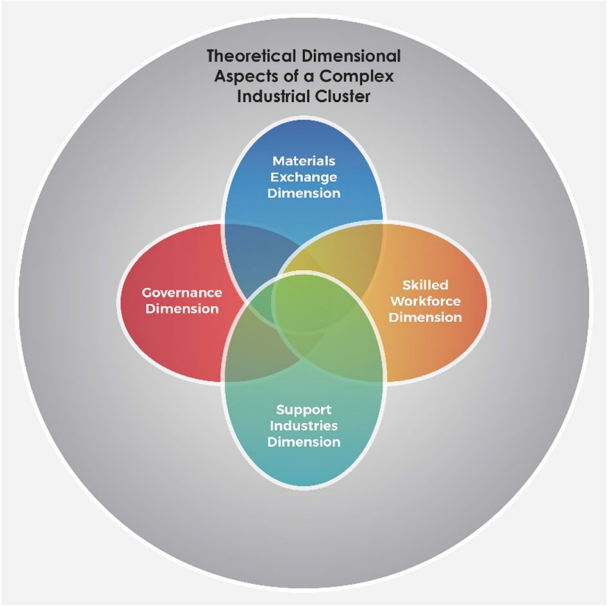

Fig. 5 Contextualising IS within CE and the interaction of the KIC4 dimensional framework

and highlighted their evolutionary influences on the growth of industry. Utilising the pre-existing, sound theoretical research, it indicated where the literature appears to stop short, or where there are gaps, and drew these frameworks together to illuminate and support the presence of three new dimensions of IS, thus precipitating the novel idea for a new field of research to be used to enhance the facilitation of successful industrial areas. Achieving this outcome will be entirely reliant on the posit that IS is far more than its traditional single-dimensional construct.

Discussion: an Emerging Conceptual Framework for Industrial Symbiosis

The presence of the four dimensions as originally posited by Oughton et al. [1] has been further consolidated in this literature review. There will be further development and study emanating from this work, and possibly further dimensions found as a result. So, to this end and for clarity, we provide an expansionary interpretation of the KIC4 framework building on the descriptions to provide a clear foundation for future researchers.

Materials Exchange Dimension

The product and by-product synergy is described as being the dimension of IS where the product, by-product, and utility exchanges occur. Activity in this dimension is essentially the traditional space within which IS operates. A vast amount of research has been published about IS in its various forms and its evolution over the decades, and this body of literature has included several papers about Kwinana. It is well known that an enterprise's competitive position is improved through participation in traditional industrial symbiosis relationships and materials exchange. Hence, this phenomenon, where an enterprise

is interacting with other enterprises within a given industrial precinct for the purpose of materials exchange, is a relationship that exhibits synergistic characteristics.

Skilled Workforce Dimension

The skilled workforce synergy refers to the 'human resource' (second) dimension of the model. In the WTC, it is reported that there are almost 30,000 skilled and experienced workers [14] that are directly and indirectly employed in KIA, and that approximately two-thirds of these live within 15 km of their workplaces. In a recent study (unpublished) conducted by KIC, this characteristic was reconfirmed, albeit that the distance from industry variable was adjusted to 15–20 km to reflect postcodes. There is anecdotal evidence that many of these workers are willing to make themselves available for engagement by other enterprises within the industrial cluster for career promotion or skill development. In effect what this means is that when a new industrial actor builds its plant in Kwinana, it can and does actively target and attract skilled workers from within the precinct. It can be said that an enterprise's competitive position is improved when it can employ from a pool of skilled workers because those workers bring their human capital in the form of local industrial knowledge and do not need re-location incentives to be attracted to the area. From the perspective of the enterprises located within the industrial area, maintaining the human capital supports the long-term sustainability of the enterprises collectively. To frame this in the context of IS, a collective of industries interacting with the precinct's aggregated workforce is a relationship that exhibits synergistic characteristics.

Support Industry Dimension

The support industry synergy refers to a dimension where the support industry enterprises that provide services into the broader industrial area have deliberately co-located close to the heavy or 'primary' industries. They provide the materials and services that the primaries require, and collaborate amongst themselves to be in a position to deliver these at competitive prices. The mere presence of these support enterprises and their interactivity with the larger industrial area improve the competitive potential of the precincts. These support enterprises have a business relationship with the primary industries, and they rely on them for their business sustainability. These enterprises include those which are the expert fabricators, constructors, engineering workshops, plant and labour hire suppliers, sand blasting and galvanising experts, the maintainers of specialist equipment, and the deliverers of services ranging from technical engineering design to waste management. They provide a training ground for entry into the cluster's workforce, hence interacting with the second (skilled workforce) dimension. Heavy industry has a strategic advantage in having the support industries it relies upon being located close by because an enterprise's competitive position is improved when it can rely upon ready access to the necessary range of support industry services that are required for business continuity, expansion, and development. The collective of support industries interacting with the cluster's major enterprises is a relationship that exhibits synergistic characteristics.

Governance Dimension

The governance synergy refers to a dimension where the industrial enterprises interact with government, from national to local. It refers also to the provision of a policy environment

(e.g. climate change policy), environmental and safety regulation, strategic land-use planning, provision of industrial land, facilitation and maintenance of common user support infrastructure (roads, rail, ports, pipeline, and utility corridors), planning and environmental approvals, and strategic business development. In any industrial area, there is a myriad of collegiate opportunities and issues that are largely outside the control of any individual enterprise. Opportunities, for example, might include improved enterprise competitiveness through the public sector provision of an efficient freight transport infrastructure network. Conversely, capacity-constrained transport common user infrastructure can diminish the potential for improved enterprise competitiveness. Thus, a favourable governance environment directly influences the competitive potential of the enterprises within the industrial area. An enterprise's competitive position is improved when the (public sector) governance functions are delivered efficiently and effectively. The interaction of the collective industries with the providers of policy frameworks and common use infrastructure is a relationship that exhibits synergistic characteristics.

We observe that none of the four individual dimensions described above operates in isolation within and of themselves. In their combined interactivity, they rely upon the functionality of all dimensions for the optimisation of the industrial area. It stands to reason then that a weakness in any given dimension translates into a compromised potential for the capacity of an enterprise to achieve and maintain international competitiveness or financial sustainability. As depicted in Fig. 5, the dimensions themselves exhibit a synergistic relationship with each other. On this basis, and as posited by Oughton et al. [1], it seems reasonable to assume that if a given dimension is identified as weak (presenting a constraint), it is then possible that the weakness can be strengthened to thus improve the ability of the industrial area to offer an environment that presents a greater opportunity for enterprises to achieve their desired sustainability profile.

Conclusion

The literature review has shown that the historical definition of IS has been evolving over many decades, and that the numerous and perhaps somewhat tenuous connections with other research fields can be wound together under the four-dimensional model we present in this paper. We suggest that doing so will open up a new and rich field for future research.

We observe that the presence of a favourable combination of the four dimensions of IS greatly enhances the broad sustainability of a given industrial area and precinct. It seems a reasonable extension then that, similarly, when the elements of the four dimensions are well understood by an individual enterprise proponent needing to make a locational decision from a range of industrial area options, and through a self-assessment process, they have the opportunity to profile their own unique dimensional characteristics, thus placing them in a far better position to identify the location of industrial area that best matches their own needs.

It follows then that not only does the sustainability of an industrial area rely on some combination of the presence of the four dimensions, but it also relies on those companies making a decision to locate there being a 'good fit'. Where a company is mismatched with an identified industrial area or precinct, in other words where its dimensional needs cannot adequately be met by the selected location, it has a higher risk of commercial failure as a result of its locational decision.

Our literature review has highlighted the following:

1. In addition to the exchange of materials and utilities referred to as IS, there are (at least) three other significant factors that contribute to the relative success of an industrial area or precinct.
2. A sound theoretical basis to a multi-dimensional framework has been demonstrated from the new streams of circular economy, sustainability, and systems theory.
3. The knowledge gaps identified in the historical literature of industrial ecology exist beyond the traditional exploration of IS. Whilst the understanding about traditional IS is strong, there is little investigation into the existence of other factors that might explain why some industrial areas are more successful than others.
4. Leading contemporary research to improve the theoretical basis of IS relevant to this study will be in the area of quantitatively defining the impact of the presence of the proposed four dimensions of IS.
5. A useful insight for a prospective new entrant enterprise considering entry into an industrial precinct is that there is a need to have awareness about the extent to which the location will provide a foundation for the success of their enterprise.

As a result of the process of review, we make the hypothesis:

A significant element in the development of a long-term competitive advantage to be enjoyed by an industrial enterprise relies on the extent to which the alignment of four key dimensions (of IS) match the defined dimensional characteristics of the actual industrial area within which the enterprise has chosen to locate itself.

The notion of the existence of these four dimensions, these inter-relational exchanges that contribute to the relative success of an industrial area, has emerged from discussions with industry and with industrial proponents, and through observation over many years. These dimensional relationships are symbiotic by their nature. They rely on the presence of two parties, a sender and a receiver; they appear to exist more predominantly within mature and complex industrial areas, with the traditional view of IS (product and by-product exchange) being just one of these.

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Code Availability Not applicable.

Declarations

Conflict of Interest Mr. Oughton (lead author) is employed as the Director of Kwinana Industries Council.

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