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Review

Linking Business Ecosystem and Natural Ecosystem Together—A Sustainable Pathway for Future Industrialization

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Abstract: China has emerged as the second largest economy in the world during the globalization in the last forty years. However, in the last decade, Chinese manufacturing has also demonstrated its dark side causing wide range of concerns globally and directly jeopardize people's health because of serious pollutions. How could the world keep its industrialization yet without damages to the natural environment? The paper proposes a new framework entitled 'IE^3' by integrating three domains of knowledge—Industrial Entrepreneurship, Industrial Engineering and Industrial Ecology. The IE^3 model provides a potential answer to the future development pathway for industrialization, changing from pursuit of quantity to quality via considering resources efficiency and ecology efficiency. The novelty of the research lies in incorporating three originally separated theories into a comprehensive system.

Keywords: business ecosystem; industrial ecology; innovation and entrepreneurship

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1. Introduction

China has emerged as a superpower with the 2nd largest GDP and 1st highest Gross Industrial Output after its forty-years of economic revolution, opening and development. If it is globalization that has fed and grown China's manufacturing sector over the past four decades, then the current China's manufacturing sector is trying to expand the connotation of global manufacturing and assuming the responsibility of a great nation. In this paper, we conduct a preliminary discussion on the sedimentation of China's manufacturing industry in the past and its future-oriented expansion. It is argued in this paper that the core experience and core advantage of China's manufacturing development over the past four decades lie in the formation of an "effective business ecosystem." This ecosystem can integrate and absorb social resources, rapidly form a highly efficient industrial system and ultimately provide with competitive products and services.

However, everything comes at a price but particularly painful in China. Along with these advantages—great scale and fast speed—come the serious damage that manufacturing does to the natural environment. The greater the advantage, the greater the damage and environmental and ecological crisis has become one of the biggest challenges to China's continuous development. Therefore, we strong believe the current industrial system models no longer be able to play sustainable role for further development and propose an upgrade from an "effective business ecosystem" to a "healthy business ecosystem." In fact, the experience of business ecosystems is still instructive in solving natural ecological problems. This paper explains how to add new elements to the lessons learned and how to use business ecosystem thinking to solve natural ecological problems.

This paper and its behind thoughts are the results from a very long term longitudinal observations of Chinese manufacturing evolutions in the last forty years. Particularly in the last 25 years, intensive and very frequent fieldwork has been conducted in the Chinese manufacturing hotspots, such as Pearl River Delta (PRD) region, Yangtze River Delta (YRD) region, Pan Bohai Bay region and some key industrial areas in the middle China by scholars and various kinds of students. In this paper, it is very difficult to provide detailed empirical research data to demonstrate the model's traceability because case studies have been dominantly adopted in the fieldwork, company visits and factory tours. Instead, we focus more on the new industrial system design framework and its principal logic arguments, seeking to tackle the emerging challenges that not only China but all human beings are facing.

The rest of the paper has been divided into four parts. After the demonstration of the paradox between industrialization and environmental damages in the Chinese manufacturing evolution, this paper argues, in Section 3, that we need to explore a more integrated pathway to achieve industrialization through the IE^3 (Industrial Entrepreneurship, Industrial Engineering and Industrial Ecology) model. In the Section 4, the detailed IE^3 framework is illustrated. And the final section discusses the new framework's potential impacts and contributions.

2. Two Ecosystems behind the Rise of Chinese Manufacturing: A Paradox Metaphor

When looking back at the evolution of Chinese manufacturing, it can be found that the following milestones formed the current structure and also patterns of Chinese industries: The 'Three-plus-one" trading mix (custom manufacturing with materials, designs or samples supplied and compensation trade), which started around late 1970s and early 1980s at the Pearl-River-Delta area in the South-East China, efficiently leveraged the individual competitiveness of Hong Kong, Dongguan at Shenzhen, China's national foreign trading system and currency system to form an extrovert value chain. It has bridged the demand from oversea and manufacturing capability inside China, forming the fundamental industry infrastructure of China's extrovert economic development. Stepping into 1990s, after over a decade's development, China's companies have progressed, from primitive manufacturing stage—importing whole production line and producing simple components, to the stage of synergizing the supply chain and further to manufacturing complex components and outsourced modules and eventually OEM (Original Equipment Manufacturer) and ODM (Original Design Manufacturer). Along this journey, Chinese firms began with labor-intensive processing, gradually moving towards high-end, complex products and capital-intensive, technology-intensive manufacturing. World-known companies emerge including Haier, Midea, Lenovo and Huawei. After new millennium, China joined World Trade Organization and this further stimulate the potential of China's manufacturing sector. Firstly, the extrovert value chain has become mature, the pioneer firms change the role from copy-cat to innovation, at the same time speed up their globalization. Secondly, the strategy of 'market for technology' starts to work, high-end manufacturing industries, for example, high-speed train, power generation equipment, had made their breakthrough. Thirdly, 'Shanzhai' phenomenon (Grass-root manufacturing) rapidly develops and expands in global markets. The 'Shanzhai' phenomenon showcase the deposit of three-decades' China's manufacturing sector, demonstrating not decent but unique patterns of its model. In recent years, this development model continues to evolve and focuses on the first and second routes above-mentioned, making an larger impact not only in China but also globally. Especially, merged with the waves of digitalization and innovation/entrepreneurship, this model has nurtured representative companies including Xiaomi, Dajiang and so forth.

It is realized that there is a unique industry development pattern in China's manufacturing sector. The uniqueness of this model does not lay in its success but in its ability to extensively absorb external factors, rapidly repeat iteration and evolution, similar to a biological metabolism system. In this research it is named as 'business ecosystem' demonstrating in Figure 1.

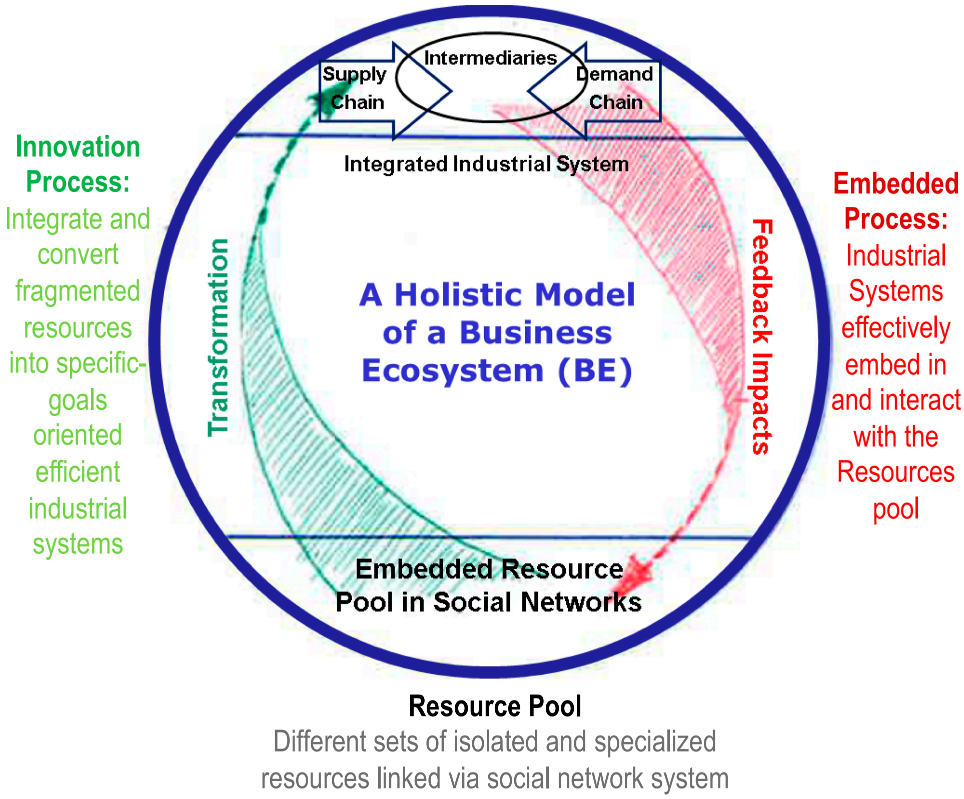

Figure 1. Whirlwind Model of Business Ecosystem.

Whether it was a 'Shanzhai' manufacturer back then or a well-known manufacturer like Xiaomi today, the support behind the development comes from the fact that China's continuously growing and maturing business ecosystem, from design to equipment, from component production to total integration of system and service, from initial idea to financial support and eventually industrialization. The system is constantly incorporating new factors that are ready and willing to contribute their specific expertise to the new enterprise.

The business ecosystem is simply made up of four subsystems. At the top is the classical 'industrial system,' responsible for efficient production of products needed at the marketplace; at the bottom is the 'resource pool' that relies on the social network which integrates fragmented resources and provides resource reserves and foundation for industrial system above; the bottom-up arrows on the left is the innovation process through which a particular factor is transformed from the resource pool into one particular industrial system; the top-down arrows on the right indicate that the forested industrial system feeds back into the social network system to achieve resource embedding process. To a large extent, this feedback takes place in the form of externalities. It is clear that the mission of business ecosystem is to support the creation, development and upgrading of industrial systems in a dynamic way that continually deconstructs and reconfigures value factors, while promoting synergistic evolution between factors and between systems. China's manufacturing industry has developed rapidly since then, with its agility, flexibility and resilience attracting global attention, providing the world with a new option for industrial development. According to the above whirlwind model, we propose the general busines ecosystem definition as: an interdependent and interactive relationships between a group of diversified business communities and a business-focused and integrated industrial system, as well as their supporting infrastructures.

However, while China's manufacturing industry benefits from the macro-level business ecosystem described above, the shortcomings at the meso and micro levels are largely obscured. Although using this model achieves the time efficiency of industrial system, total labor productivity in production and operation process and even the utilization rate of production equipment, as well as the short delivery cycle and high order fulfillment efficiency, the model has not given due attention to the energy efficiency and raw materials efficiency of industrial system. The resulting negative externalities, especially to the natural ecological environment, have shown a momentum that is difficult to reverse. For example, the pollution problems of China's air, water and soil have received widespread attention. In dealing with these problems, China has invested significant resources, possibly partially offsetting the manufacturing advantage that already established. The aggressive emulation of the most populous developing nations could put a high strain on existing planetary resources. The world has witnessed China's economic leap forward but it has been consciously or unconsciously overlooked that predicated industrialization is achieved based on sufficient energy and resources consumed or transformed by this industrial system. Based on the input-output efficiency behind current industrial model, the total amount of energy and resources on the globe is likely to be difficult to support sustainable economic development.

In summary, the development of China's manufacturing industry over the past four decades can be summarized into two ecology systems—a business ecology that supports its success, a natural ecology that takes its toll. This paradoxical metaphor inspires us to explore the future path of manufacturing on a new level and also develop the business ecosystem model with sustainable purpose.

3. New Path for China's Manufacturing: The Fusion of Industrial Ecology, Industrial Engineering and Innovation & Entrepreneurship (IE^3)

In response to the issues analyzed, we attempt to integrate the three major research areas: natural ecological protection, resource gradient exploitation & utilization and rapid construction of industrial systems, to proposed a new trinity thinking/disciplinary frameworks, called IE^3, which is consist of Industrial Ecology, Industrial Engineering and Innovation & Entrepreneurship. This session starts from a brief literature review and then details on the IE^3 framework.

3.1. A Brief Literature Review

To tackle the gradually serious contradiction between economic development and environmental protection, industrial symbiosis or its extended version–circular economy, has stepped into the center of researchers' focus [1]. Researchers have been explored different aspects of implementing industrial symbiosis. The participating industries are varies, including chemical [2], manufacturing [3,4], waste management [5] and oil & gas [6] and so forth. The impacts of industrial symbiosis are also frequently discussed, with focus on environmental benefits [7], economic benefits [8] and social benefits [9].

On the other end, industrial engineering researchers come to understand the importance of full value in products and leveraging it. Dinis-Carvalho et al. [10] explores using typical operations management tool—value stream mapping to identify potential value in waste. Similarly, frameworks and tools are developed to value assessment from used resources and waste [11,12]. Solutions in specific industries are also explored, for example, biodiesel industry [13], cement production [14].

While the interaction between industrial symbiosis and industrial engineering is relatively well studied, the motivation and mechanism of engaging large firms and small and medium enterprises (SMEs) into industrial symbiosis/circular economy are not clear to researchers and practitioners. Velenturf [15] has used industrial park in Humber region of UK as example to demonstrating the process of promoting industrial symbiosis. Henry et al. [16] categorize newly established firms which establish circular business models into five types, namely design-based, waste-based, platform-based, service-based and nature-based. There are more observations on stimulating industrial symbiosis/circular economy from the policy perspective [17–19]. The business ecosystem theory is expected to cover the above-mentioned aspects and serve as an overall framework to illustrate this dynamic process.

Applying the ecosystem concept to business and sustainability study has been explored by the open innovation research community for some time. Choi [20] proposed that the fourth-industrial technological innovation should be accompanied with social innovation. Tolstykh et al. [21] discussed three models in as well as proposing a method to evaluate ecosystems' actor using AHP (Analytic Hierarchy Process) approach. From the aspect of building ecosystem for sustainable purpose, Liu and Stephens [22] generated a conceptual framework linking innovation ecosystem and sustainability. The framework studied key players for example, companies, universities, industrial associations and NGOs, as well as the potential sustainable innovations, for example, product, service, business model and business network. Svirina et al. [23] started to look at innovation models (open innovation and traditional close innovation) of the business which particularly aim for social benefits. In their review paper of innovation system, Egbetokun et al. [24] also discuss the innovation commencing on network level. In general, though the business ecosystem concept has been mentioned and emerged in innovation research, it is still in early stage especially considering sustainable agenda.

3.2. Overview of IE^3

Industrial ecology focuses on the interaction between industrial development and its natural environment and attempts to provide methodological guidance and fundamental theories for circular economy and environmental friendliness. The takeaway in this area is that by-products from one production process can be valuable raw materials for another, the so-called Industry Symbiosis. The weakness of this approach is that it is based solely on sustainability considerations, which is often difficult to commercialize. Industrial engineering, on the other hand, has its root in the 'scientific management' movement of early industrialization in the United States, where a set of methodologies was proposed to optimize the efficiency of factory processes and individual productivity. The take-away from this area is that a strong focus on efficiency can be grounded in a well-designed protocol of workable processes. Where it falls short is in the neglect of resource and energy efficiency and the lack of a holistic approach to system sustainability. Innovation & entrepreneurship is an area that focuses on the development of ideas to eventual commercialization, leading to regional competitiveness and economic prosperity. The insight from this area is that innovation ecosystems are critical for individual firms and regional development, as our previous analysis has shown. Its weakness is that, at least in China, economic value is the main objective function and is less integrated with social and environmental values. The IE^3 framework is proposed because it is realized that China's manufacturing industry's past experience in developing business ecosystems can be fully complemented by industrial ecology and industrial engineering to address the aforementioned challenges in harmony.

3.3. Insights from Industrial Ecology: Waste as Misplaced Treasure

Although industrial ecology's relentless efforts for environmentally friendly action have won praise from various sectors of society, business managers still generally believe that it will bring a burden of investment and operating costs and usually shelve proposals from the field. A classic example of the "industrial symbiosis" is the Mulberry Fish Ponds promoted in southern China in the late Ming and early Qing dynasties. However, in modern manufacturing, companies are often required to set up new supply chains to convert by-products or waste from main business processes. In this way, the enterprise's traditional main business supply chain will generate other supply chains, so called "industrial symbiosis" or symbiotic/nested supply networks. To illustrate this idea, the example of a symbiotic network built by British Sugar (Figure 2) is demonstrated.

British Sugar purchases all the sugar beet grown in the UK for its sugar production. The company is unique in that it not only produces table sugar but also converts almost all of the by-products into income-generating goods. For example, beet washing residue soil is sold under the separate brand called Topsoil. The limestone used for purification is used to form a lime material that regulates soil acidity to enhance soil quality. And this business become main source of British agricultural lime. It even makes use of the highly concentrated CO^2 and waste heat generated during production process, which are fed into the greenhouse and contributed to make most suitable conditions for tomatoes grow. This alone inadvertently makes the factory the second largest supplier of tomatoes in Europe. These initiatives have created significant economic value. On one hand, new revenues are generated and on the other hand, huge waste disposal expenditure is significantly avoided. Take the example of its Wissington plant near Cambridge, which processes 3.5 million tons sugar beet per year, ultimately requiring landfill of waste less than 100 tons. This is no easy task, as building a supply chain outside main business is a huge challenge for most companies. Also, the economic model is constrained by the size of main business and the volatility of market.

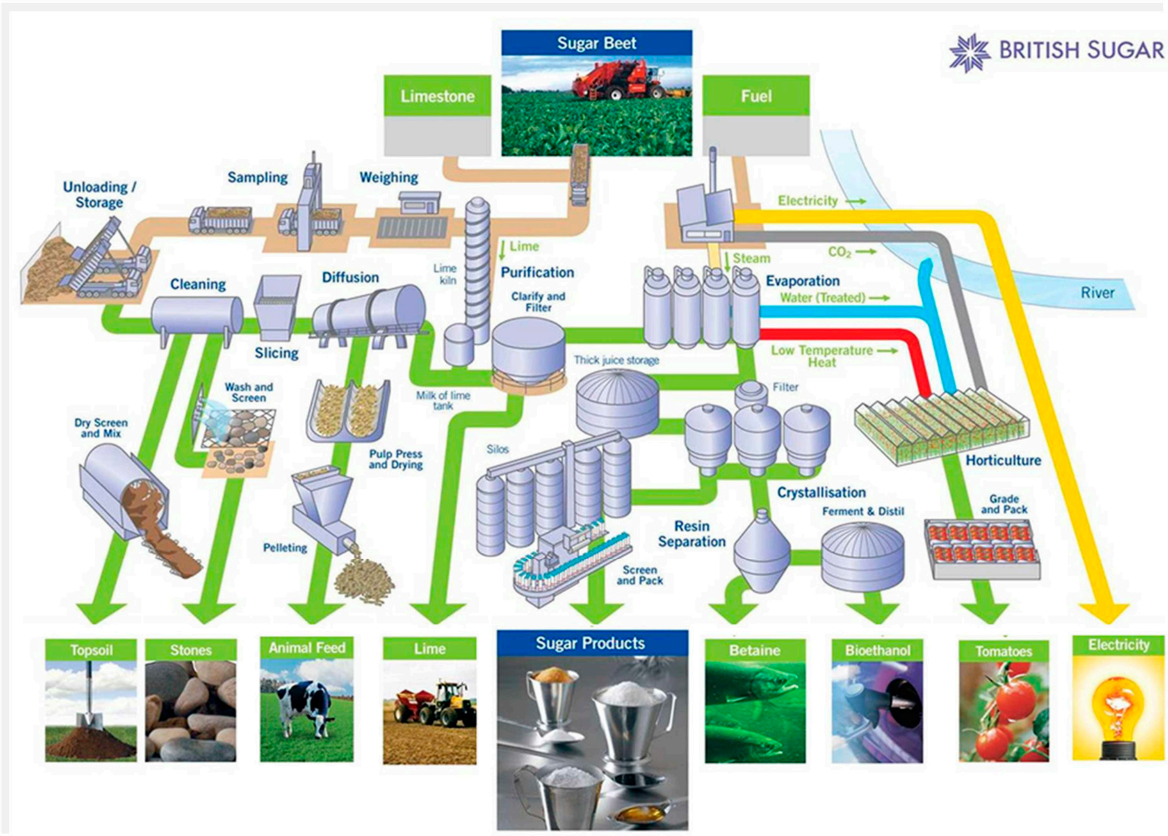

Figure 2. Symbiotic Network in a factory of British Sugar.

But the biggest inspiration from industrial ecology is that waste or intermediate by-products are likely to be misplaced treasure with intrinsic economic and social value. When assessing the attractiveness of an industry, whether or not the potential value of its intermediate by-products is taken into account, may lead to entirely different conclusions. Regarding to how to extract this value, it can be drawn on the wisdom from other field, beyond the British Sugar model.

3.4. Expanding Industrial Engineering Approach: Design for Resource-Efficiency

Although industrial engineering has studied labor efficiency in detail, it has largely ignored the issue of resource efficiency. If different ways of maximizing resource efficiency could be studied in the same detail as Taylor's study of scientific management, with a consideration to labor productivity, work flow efficiency and resource efficiency, it would be the most promise for providing practical advice on how to disrupt China's manufacturing sector. This goes beyond the framework of industrial ecology, as it is not limited to digesting the by-products produced within companies but takes a more commercial approach to business potential of all resources and the efficient release of these value. This goal presents as two interrelated issues.

3.4.1. Design Resource Utilization Scenarios to Achieve Higher Value Creation and Acquisition

In Hsinchu, Taiwan, Wu's family operates a glass recycling business. His father founded Chunchi Glass in the 1960s and has since built a glass recycling logistic system that can recycle 70% of all discarded glass in Taiwan, which made the family a pride for Taiwan. Six years ago, his son inherited father's business and aspired to break out from monotonous-cycle circular economy into multiple-cycle one, creating higher business value. The following are two case studies:

The problem with after-use new-type glass (TFT LCD) from mobile phone screens is that even if the company can efficiently recycle them, they are not willing to do so. For this reason, the Wu's son, in cooperation with National Cheng Kung University's researchers, has developed a glass-foaming production process, which can be used to produce a new lightweight building material which is high-temperature resistant, thermal and acoustic insulated. This not only creates a brand-new product for building materials but also sets up a role model of circular economy without going back to original source.

In terms of recycling conventional glass, he discovered that his home town Hsinchu is a hub for Taiwanese glass artisans, which consumes a lot of raw glass. Borrowing from the concept of sharing economy, he opened up his glass furnace to the artists who are creative but ill-equipped and offered them the diverse range of recycled glass products. In this way, not only entrepreneurial and innovative vitality has been stimulated but also makes the rebirth of waste glass into fine arts. It is very amazing to have the leap of value.

3.4.2. Design Recycling Path to Optimize Overall Value through Multiple Recycle Times

For example, in winter there is a demand to burn charcoal for heating and the owner of the forest can make a steady profit by cutting down trees but long-life potential of the wood only burns out in a few hours. If taking into account the finite nature of the resource and pay great attention to its usage efficiency, it can be imagined that the same woods are harvested and made into furniture which would allow people to enjoy for decades. Then it can be made into paper, which will work for a few more years before being turned into fuel. The same resource can achieve multiple times of value if a better circular path is designed. This hypothetical case is obviously overly idealistic but the scope for value multiplication is clearly worth considering for environment-protection entrepreneurs.

3.5. Convergence of Innovation & Entrepreneurial: Business Ecosystem to Solve Natural Ecological Challenges

Industrial ecology can make manufacturing enterprises aware of the potential value of by-products and the expanded industrial engineering can design an ideal industrial system aiming to maximize resource value. The final parts in question are who and how to realize the system, which is precisely the focus of innovation & entrepreneurship.

The current situation faced by environmental protection activist in China may not be much better than the manufacturing sector in China 30 years ago. There are a number of lessons to be learned from the experience of China's manufacturing sector, which has grown from weak to strong. This experience has been summarized as a business ecosystem and depicted as a four-part tornado model in Figure 1. In the new context, the various waste and by-products of the production process should be brought into the resource pool at the 'bottom' of model and almost all manufacturing firms can be embedded in it, such as British Sugar. The expected circular industrial system that maximizes resource efficiency should emerge from the top part of model and could be led by professional environmental practitioners, such as Chunchi.

The diversity of resources at the model's bottom end may go beyond this simple description. British Sugar's integration model is actually a self-cycling tornado model within itself, with resources coming from itself by-products of other business processes.

A more typical scenario is resources are distributed fragmentally, provided by a group of manufacturing firms that do not have the capacity or the will to integrate. Then a firm similar to Chunchi step out to integrate with its expertise of leveraging resources. It is easy to see that the demand for resource pools is not limited to the resource (glass) itself but also includes glass artists of Hsinchu, the researchers of National Cheng Kung University. These are the factors or resources that resource pool is capturing. Likewise, it is likely that companies that with ability to operate industrial systems are not limited to professional environmental protection practitioners. For example, in China, the tomato business similar to British Sugar is likely to be run by professional tomato growers. In other words, British Sugar is simply a provider of CO^2 and waste heat resources. British Sugar is called upon or leveraged by a grower at the upper part of model. For this grower, it is not practicing environmental protection business but simply acquiring the raw materials needed for operation. As a result, many companies, even those far beyond the manufacturing sector, may become resource consolidators and be included at the top part of model. This simple analysis shows that in order to overcome environmental resource constraints, China's manufacturing industry calls on active participation of all sectors to build a cross-industry business ecology with widest-possible vision.

3.6. Summary of IE^3

Rome was not built in a day. The 'Shanzhai' phenomenon emerged after three decade of China's manufacturing development and ultimately drove China's mobile phone industry to become one of major global players. China has made many products, from electronic calculators and single-card cassette recorders in the late 1970s, to MP3s and MP4s, to VCDs, DVDs and Blu-ray DVDs, as well as modern smartphones, bitcoin miners and wearables devices and so forth. Many of them may only have a product life cycle of perhaps 3 to 6 months but the ability to design, tooling, product parts, to assembly and particularly to coordinate and orchestrate production, is slowly accumulated, rooted in different types and sizes of firms, culminating and nurturing the business ecosystem. Eventually this business ecosystem is strongly resilient and agilely react. We may not need, nor allow, to wait thirty distributed fragmentation of formation of an extensive green manufacturing business ecosystem. To accelerate this process, the left and right arrows in the model need to be started and iterated on quickly. There is a need for guidance and support from regional governments but more importantly, a close integration of industry, academia and research is of most pressing urgency, to provide knowledge and guidance necessary for 'chemical reaction' in such a complex ecosystem of different resources, to provide a foundation for maximizing commercial value of resources and to inspire a wide range of entrepreneurial activities as well as innovators. It is no doubt that integration of business values and social values is an important direction for most disciplines. That is also why this paper presents IE^3 from the perspective of disciplinary integration.

4. IE^3: An Integrated Framework for the Ecological Development of China's Manufacturing Industry

The IE^3 integrated process framework (Figure 3) consists of three functional modules: a resource gradient development process that focuses on raw material extraction, an industrial symbiosis process that utilizes waste/by-product in the production process and a business ecosystem process that mobilizes discrete social resources to build a new industrial system.

The first module—raw material resource mining and gradient development, takes re-examination and evaluation of raw material resources as starting point and analyzes the possibility for existing raw materials to generate multiple layers of value. It also looks at replacement solutions for these various raw materials. These solutions are then modified in terms of technical and economic feasibility to make decisions. Finally, through establishing raw-material gradient development project, companies start business model design and industrial system construction. This process is aimed at reducing the consumption of raw materials in natural ecosystem, that is, by selecting, as far as possible, those that have already been gradient-developed resources to use as raw materials.

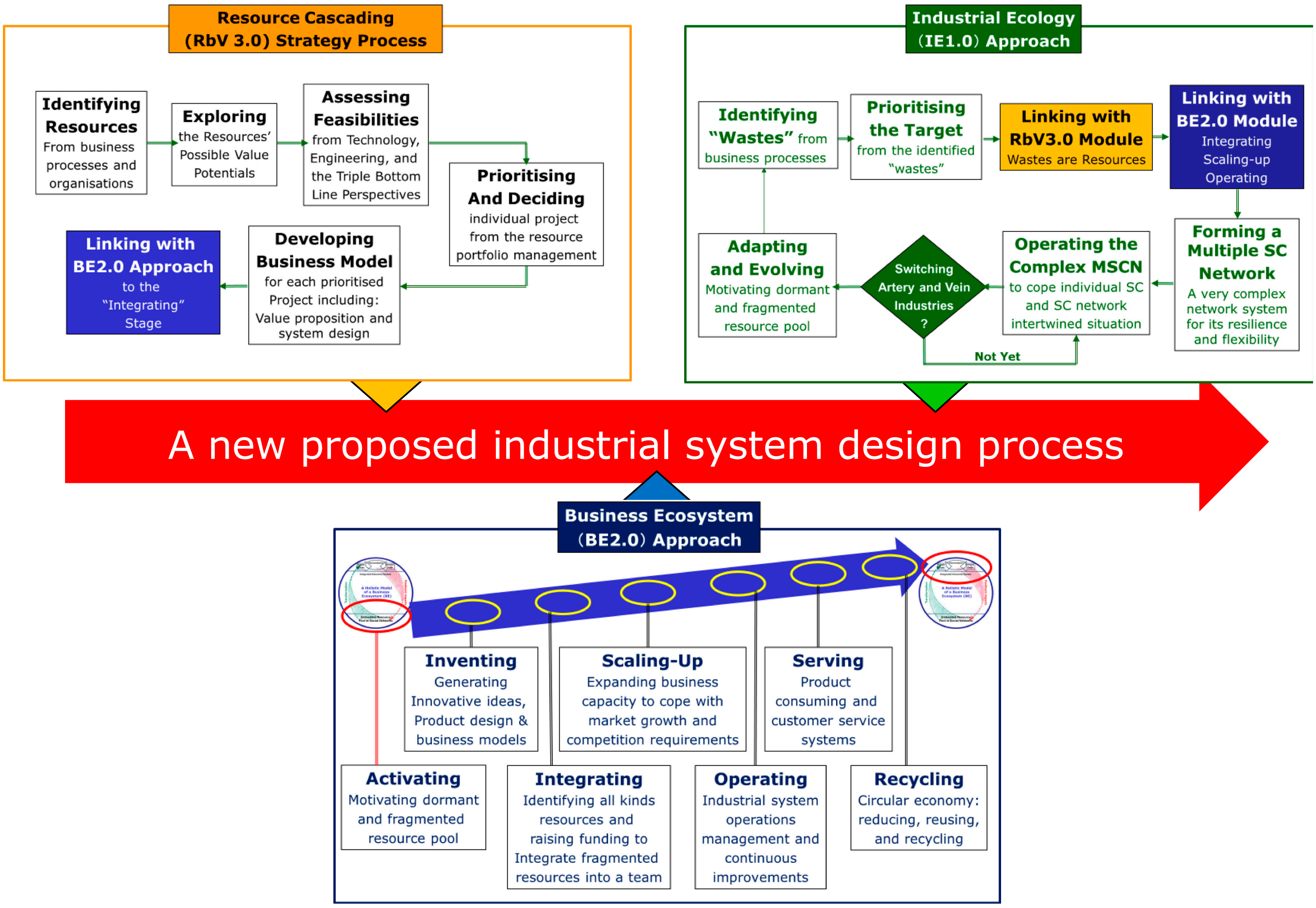

Figure 3. IE^3 Integrated Process Framework.

The second module, industrial symbiosis between a company's main business and waste/by-products, is in fact applying the resource gradient development process on waste/by-products. It differs from the previous module in that it starts with waste/by-products rather than raw materials. In fact, the by-products of Enterprise A may be the raw materials of Enterprise B, thus potentially linking two modules. The module tackles the question of how, for A, to manage the complex supply network between the main business and waste/by-products business. It is entirely possible that the waste/by-products business becomes the main business when it gets bigger and the focus of the module shifts to new waste/by-products, then so on and on.

The innovation & entrepreneurship module serves as the basic enabling foundation that supports the building and realization of both above-mentioned modules. It is similar to conventional innovation and entrepreneurship process but the rich experience of China's manufacturing, that is, the practice of nurturing business ecosystems, is able to much effectively mobilize, identify and integrate efficient industrial system from the 'resource pool', according to objectives and business model design requirements.

Therefore, there is a mutual-embedded relationship between the three modules and it is essential to make flexible application and combinations as needed in practice. Therefore a refined definition of business ecosystems should not only include the business scope and its context that follows the classical model of the Figure 1 to reconfigure the resources into new industrial systems and adapt themselves based on the context requirements but also extend the business boundaries in order to reduce the negative impacts of the business to the natural environment and make both business and community more sustainable.

5. Implication and Conclusions

The IE^3 framework has not only enriched the intersection of three research areas: industrial ecology, industrial engineering and innovation but also created significant practical implications:

First, the three modules in IE^3 can individually provide functional solution to some of the cutting-edge problems. The industry entrepreneurship module helps to quickly build up industry systems which are needed. The industrial engineering module can assist on evaluating and exploring full value of raw material. Thirdly, the task of converting waste to valuable input can be achieved via industrial symbiosis module.

Second, there are fundamental sub-modules within the major three modules and these sub-modules can be shared and reused across the platform. The ease of modularity can help to improve system building efficiency and the robustness. Also creating these sub-modules as tools is building the basics for further academic investigation.

Third, the three modules can be used in many practical scenarios, such as: regional industrial system formation, waste-to-reuse for value creation, assessment to resources' potential values and so forth.

In summary, the framework proposed has not only theoretical value but also practical and policy implication.

After four decades of development, China's manufacturing industry has entered the stage from pursuit of quantity to quality and the emphasis on resource efficiency and eco-efficiency should be the proper goal for this stage. This paper argues that the development experience of China's manufacturing industry can be summarized as a business ecosystem (Figure 1), that is, an approach that rapidly integrates fragmented resources into a new highly efficient industrial system. This approach is still applicable to Chinese manufacturing industry in the new situation but it requires three areas: industrial ecology, industrial engineering and innovation & entrepreneurship. In this research they have been integrated and expanded to form a methodology that integrates environmental protection, resource utilization and industrial operations (Figure 3). We hope that this process will give China's manufacturing practice a broader vision and a more ambitious commitment, enabling it to make new contributions to the sustainable development of human society.

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References

1. MacArthur, E. Towards the Circular Economy. *J. Ind. Ecol.* **2013**, *2*, 23–44.
2. Mannino, I.; Ninka, E.; Turvani, M.; Chertow, M. The Decline of Eco-Industrial Development in Porto Marghera, Italy. *J. Clean. Prod.* **2015**, *100*, 286–296. [CrossRef]
3. Harris, S.; Pritchard, C. Industrial Ecology as a Learning Process in Business Strategy. *Prog. Ind. Ecol. Int. J.* **2004**, *1*, 89–111. [CrossRef]
4. Zhu, Q.; Lowe, E.A.; Wei, Y.; Barnes, D. Industrial Symbiosis in China: A Case Study of the Guitang Group. *J. Ind. Ecol.* **2007**, *11*, 31–42. [CrossRef]
5. Mirata, M.; Emtairah, T. Industrial Symbiosis Networks and the Contribution to Environmental Innovation: The Case of the Landskrona Industrial Symbiosis Programme. *J. Clean. Prod.* **2005**, *13*, 993–1002. [CrossRef]
6. Wang, Y.; Li, P.; Zhu, Z.; Liu, Z. The Evaluation of Eco-Efficiency of the Industrial Coupling Symbiosis Network of the Eco-Industrial Park in Oil and Gas Resource Cities. *Energy Sci. Eng.* **2019**, *7*, 899–911. [CrossRef]
7. Daddi, T.; Nucci, B.; Iraldo, F. Using Life Cycle Assessment (LCA) to Measure the Environmental Benefits of Industrial Symbiosis in an Industrial Cluster of SMEs. *J. Clean. Prod.* **2017**, *147*, 157–164. [CrossRef]
8. Cao, X.; Wen, Z.; Tian, H.; De Clercq, D.; Qu, L. Transforming the Cement Industry into a Key Environmental Infrastructure for Urban Ecosystem: A Case Study of an Industrial City in China. *J. Ind. Ecol.* **2018**, *22*, 881–893. [CrossRef]
9. Valenzuela-Venegas, G.; Salgado, J.C.; Díaz-Alvarado, F.A. Sustainability Indicators for the Assessment of Eco-Industrial Parks: Classification and Criteria for Selection. *J. Clean. Prod.* **2016**, *133*, 99–116. [CrossRef]
10. Dinis-Carvalho, J.; Guimaraes, L.; Sousa, R.M.; Leao, C.P. Waste Identification Diagram and Value Stream Mapping A Comparative Analysis. *Int. J. Lean Six Sigma* **2019**, *10*, 767–783. [CrossRef]
11. Iacovidou, E.; Millward-Hopkins, J.; Busch, J.; Purnell, P.; Velis, C.A.; Zwirner, O.; Brown, A.; Hahladakis, J.N. A Pathway to Circular Economy: Developing a Conceptual Framework for Complex Value Assessment of Resources Recovered from Waste. *J. Clean. Prod.* **2017**, *168*, 1279–1288. [CrossRef]
12. Walmsley, T.G.; Ong, B.H.Y.; Klemeš, J.J.; Tan, R.R.; Varbanov, P.S. Circular Integration of Processes, Industries, and Economies. *Renew. Sustain. Energy Rev.* **2019**, *107*, 507–515. [CrossRef]
13. Saladini, F.; Gopalakrishnan, V.; Bastianoni, S.; Bakshi, B.R. Synergies between Industry and Nature—An Emergy Evaluation of a Biodiesel Production System Integrated with Ecological Systems. *Ecosyst. Serv.* **2018**, *30*, 257–266. [CrossRef]
14. Hossain, M.U.; Poon, C.S.; Wong, M.Y.K.; Khine, A. Techno-Environmental Feasibility of Wood Waste Derived Fuel for Cement Production. *J. Clean. Prod.* **2019**, *230*, 663–671. [CrossRef]
15. Velenturf, A.P.M. Promoting Industrial Symbiosis: Empirical Observations of Low-Carbon Innovations in the Humber Region, UK. *J. Clean. Prod.* **2016**, *128*, 116–130. [CrossRef]
16. Henry, M.; Bauwens, T.; Hekkert, M.; Kirchherr, J. A Typology of Circular Start-Ups: Analysis of 128 Circular Business Models. *J. Clean. Prod.* **2020**, *245*, 118528. [CrossRef]
17. Fan, Y.; Fang, C. Circular Economy Development in China-Current Situation, Evaluation and Policy Implications. *Environ. Impact Assess. Rev.* **2020**, *84*, 106441. [CrossRef]
18. Hartley, K.; van Santen, R.; Kirchherr, J. Policies for Transitioning towards a Circular Economy: Expectations from the European Union (EU). *Resour. Conserv. Recycl.* **2020**, *155*, 104634. [CrossRef]
19. Jiao, W.; Boons, F. Policy Durability of Circular Economy in China: A Process Analysis of Policy Translation. *Resour. Conserv. Recycl.* **2017**, *117*, 12–24. [CrossRef]
20. Choi, P.K. A Need for Co-Evolution between Technological Innovations and Social Innovations. *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 54. [CrossRef]
21. Tolstykh, T.; Gamidullaeva, L.; Shmeleva, N. Elaboration of a Mechanism for Sustainable Enterprise Development in Innovation Ecosystems. *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 95. [CrossRef]
22. Liu, Z.; Stephens, V. Exploring Innovation Ecosystem from the Perspective of Sustainability: Towards a Conceptual Framework. *J. Open Innov. Technol. Mark. Complex.* **2019**, *5*, 48. [CrossRef]
23. Svirina, A.; Zabbarova, A.; Oganisjana, K. Implementing Open Innovation Concept in Social Business. *J. Open Innov. Technol. Mark. Complex.* **2016**, *2*. [CrossRef]
24. Egbetokun, A.; Oluwadare, A.J.; Ajao, B.F.; Jegede, O.O. Innovation Systems Research: An Agenda for Developing Countries. *J. Open Innov. Technol. Mark. Complex.* **2017**, *3*. [CrossRef]