



The Role of Educational Action Research of Recycling Process to the Green Technologies, Environment Engineering, and Circular Economies

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Abstract: Recycling process in waste management reduces the cost of waste handling, minimizes cost of raw materials and processing, and simplifies supply chain management. It introduces 3D printing design and circular economies and significantly impacts green technologies and environment engineering in terms of waste management and materials processing. Educational action research play crucial role in communicating designer, stakeholder, consumer, and distributed in end-to-end recycling process. It fosters the entities across value chain and accelerates the modernization of waste management processes.

KEYWORDS: education, action research, recycling, circular economy, environment engineering

I. INTRODUCTION

Recycling process is taken place when product becomes out of service and unable to perform expected functions, and either discard or reprocessing is necessary, to change the product's state. The scope of recycling process covers the typology and facilities of the waste collecting sites, the filtering algorithm and facilities to separate materials of waste, the techniques in reprocessing and assembly of materials and parts, and new supply chain distribution that effectively move product into market and change product's states status to "in use". In the following paragraphs, educational methodology, context of education such as resource management, 3D printing, and recycling processes are introduced.

2-1. Educational action research methodology

As indicated in earlier paragraph, this study involved multi-entities in interoperability of systematical analysis, and each entity need education, communication and action to collaborate in recycling process. The methodology being employed is the educational action research which is a qualitative research methodology. The aim of educational action research is to solve a current practical problem while adding to the body of knowledge.

Typically, it is an iterative research process applying existing theory to solve a practical problem, learning from experience and then adding to the body of knowledge by modifying existing theory.

2-2. Industrial ecology of resource management

Keep the product, with a state's status of "out of service", as close to "in use" as possible.

A key principle of industrial ecology considers sources and sinks of natural resources, and promotes a regenerative use of resources where consumption shall not exceed regeneration rate. Hence, increasing manufacturing efficiency through process efficiency and recycling can be the key in improving sustainability. The closed loop recycling process is demonstrated in figure 1.

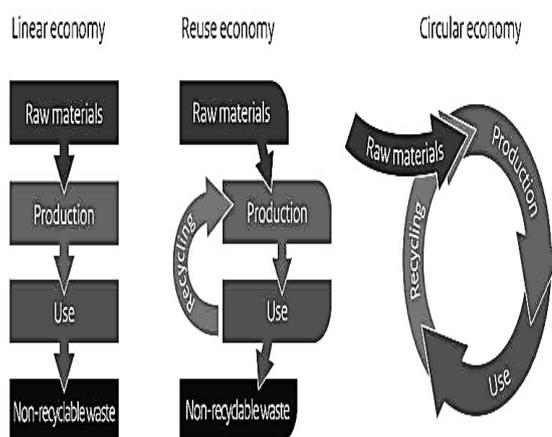


Figure 1. Comparison of conventional linear, reuse and circular economy

2-3. Recycling process

Recycling process involved in comprehensive analysis of waste collecting topology and facility, maintenance, sorting and transportation, recycled materials fabrication, and supply chain distribution. The modernization of recycling process takes all these actors into consideration and seeks optimization of economic benefits through circular economy evaluation. The evaluation tunes the process design based on the balancing of multi-entities' value chain, to ensure the feasibility and communication are in place and educational action research is commonly launched, to streamline and shed light on recycling process.

Reducing material waste in process and recycling are both advantages to circular economies (Royal Academy of Engineering, 2013), hence industrial ecology encourages the formation of synergies across industrial sectors, and view waste as an abundant and free resource.

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II. LITERATURE REVIEW

Linkage between green technologies, environment engineering and circular economies became pervasive in these few decades. It widely involved in multi-entities, and the scope is so huge that requires an effective education and communication to derive a common practice.

Educational action research refers to the education provided by environment engineering experts, by applying educational theory, to derive a single view of recycle process, supported by concept of sustainability, to achieve circular economies. The milestones of educational action research basically cover some typical cases as followed, which relies on education to move toward realization.

The concept of resource management and minimizing raw materials consumption was first introduced by Sacharen (2014), and Wigan (2014). Followed by the concept of higher resource efficiency, circular economies was introduced to apply disciplines of sustainability in new age of waste management.

From the other side, action education and communication of associated entities between manufacture, designer, consumers, stakeholder, and distributor was proposed by Birtchnell et al. (2013); Janssen, Blankers, Moolenburgh and Posthumus (2014); Petrick and Simpson (2013), and Rayna and Striukova (2014) to emphasize the importance of education across mass customization.

To streamline the recycling process and fasten the impacts to circular economies, people's habit of daily life need be changed, which means; the environment engineering experts need to educate multi-entities of the end-to-end process, to balance their viewpoints of value, to optimize the value-chain, and to communicate across multi-entities, to achieve a consensus.

Cohen, Sargeant and Somers (2014) proposed simplicity, such as reducing assembly in long process, and recycling semi-product instead of raw materials, are all the means in achieving sustainability through less complexity of recycling. Meanwhile, they proposed to reduce conceptual barrier between producer and investor, and collaborative manufacturing, to streamline niche markets.

III. MODERNIZATION OF RECYCLING PROCESS

Recycling process covers the collecting, maintenance, disassembly, sorting, transportation, filtering, materials processing, manufacturing, and distribution in an end-to-end process. Within the long process, 3D printing plays crucial role as it redefine the design, manufacture and supply chain management in the modernization of recycling process.

3D printing and additive manufacturing (AM) can be similar in semantics as additive manufacturing has been a general concept and 3D printing is just a modern terminology. Both terminologies reference the process of building parts by joining material layer by layer from CAD data and opposed to a traditional manufacturing process, such as machinery or die casting which are generally termed as subtracting process built by subtracting material from a block of material. 3D printing and AM can be used regardless of the form, shape, and combination of different materials, hence flexibility is one of the advantages 3D printing and AM has committed.

3D printing has a wide range of usage at all levels. We can use 3D printing to create almost everything we wish. The

main usage can be either commercial or aesthetic design or construction, but it is also possible to be used in medical treatments, such as tissue and organ fabrication, and even used in archeology for the purpose of cultural preservation. Rapid prototyping technology allows it to fabricate 3-dimensional models instantly with help of CAD (computer aided design). Researchers in Cornell University developed "hydrocolloid printing" to apply 3D printing technology into food industry.

3D printing manufactures 3-dimensional products from recycled materials, by means of software and automated devices. Plastic, ceramic and metals are commonly used as materials with flexibility of combination. Product design is the key of unique value, and the cost of machines has been decreasing continuously, from initial price ranged from few thousands to few hundred dollars, although the price may vary depending on the quality of machine.

3-1. Education in educational action research

Education and skills development in relation to 3D printing for circular economy can be considered from several perspectives: 3D printing understanding and awareness, skill development and policy making. In an optimistic scenario, transitioning to 3D printing will lead to many more benefits for sustainability as many of 3D printing's characteristics align with sustainability and circularity concepts (Ford and Despeisse, 2016). These concepts adopted an industry perspective on sustainability, often disregarding the role of individuals and culture in achieving more efficient use of natural resources and closed-loop circulation of materials.

3-2. Modernization of design process for recycling

Due to the unique capability in dealing with complex share, the fundamental differentiators of 3D printing over conventional manufacturing are that; 3D printing usually produces a product through one machine by using layer-by-layer method, while conventional manufacturing fabricates products through different machines by using parts-by-parts method. Each component part in conventional process may be produced through different machine at different plant, and finally assembled before distributed to retailers.

Rapid prototyping is one of the objectives of 3D printing umbrella in producing prototype model of CAD techniques. Most of rapid prototyping is used as miniature before production, which is the end result of 3D printing. 3D printing printing/additive manufacturing is the process, and rapid prototyping is the end result.

3D printing boom in this decade as the materials can be easily recycled and repossessed in fabrication process. (Wohlers, 2014) anticipated that the global market size for 3D printing will grow from 3 billion USD in 2013 to 13 billion USD by 2018, and surpass 21 billion USD by the year 2020. Gartner reports similar numbers, forecasting the market to reach a size of 13 billion USD in 2018 (Basiliere, 2013).

3-3. 3D printing process

3D printing was initially known as "additive manufacturing" in 1980s, when equipment and materials were developed. The technology was invented by Japanese inventor Hideo Kodama in 1981. 3D modeling has been used to develop mathematical representation of surfaces of objects in three dimensions by CAD-based software.

The typical technology used in 3D printing is fused deposition modeling (FDM).

In FDM technology of 3D printing, filament is extruded through a heated nozzle, and additive method is applied, that the material is sprayed layer after layer, into the designed shapes. FDM has been recognized as one of the fastest technologies, to accomplish parts in a few days, and freedom of shaping is FDM's advantage.

3-4. ICT-supported Standardization

The modernization of recycling process relies on computerization of process automation to realize waste collection, 3D printing, recycling processing, supply chain re-distribution.

Shipping and logistic costs could be minimized when products are built geographically close to their intended markets. With the proposed information heuristic underpinning the adoption of 3D printing in circular economy settings, essential data can be fed into "design for environment" methodologies (Telenko et al. 2008). Additionally, information can be provided to end-users and consumers directly to enable environmentally responsible decision making.

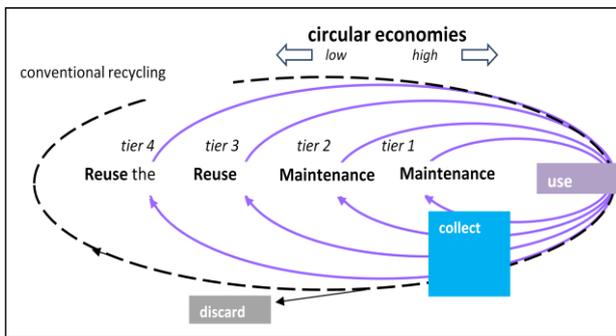
3-5. Modernization of distributed manufacturing

Processing and assembly activities can be limited and very short supply chains are enabled, with an added side-effect of simplifying the measurement of resource consumption without having to consider long and complex supply chains (Baumers et al., 2013).

Cut supply chain to further reduce cost and time. Manufacturing components in different physical locations and then managing the supply chain to bring them together for final assembly of a product is also considered a form of distributed manufacturing.

Figure 2. Recycling classification and advantages to circular economies

3-6. Customers need innovation



Customers demand high degree of customization in full lifecycle meanwhile; high quality and competitive price are also key factors before 3D printing and other modern technologies can be massively launched into market. The use of 3D printing technologies for distributed/home fabrication holds great potential for business model innovation (Rayna and Striukova, 2016), a transformation which would involve a major shift from a manufacturer- to a consumer-centric business model (Bogers et al., 2016).

3-7. Design for environment:

3D printing can facilitate combinations of circular economy enabling business models with consumer-manufacturer interactions working towards the goal of maximizing energy and material efficiency. As indicated in figure 2, the conventional recycling process does not gain any significant impact to environment protection and economies as well instead, tier 1 and tier 2 (maintenance) achieve most favorable circular economies, and both tier 3 and tier 4 are typical examples within modernization of recycling process that achieve circular economies.

IV. DISCUSSION

To envision the impact factors within the modernization of recycling process, metrics of process evaluation, supply chain management, and business modeling are introduced to shed light on transformation impacts.

4-1. Mathematical model for recycling processes

Before investigating the key processes of metrics of recycling process, a few terminologies are introduced to leverage the facilities and nodes to the processes. The main facilities and nodes being used in recycling processes are;

- Collection sites (CS) such as kerbsides, civil amenity sites or other bring sites
- Data processing unit (DPU) to collect data for governance purpose
- Material recovery facility (MRF)
- Waste transfer stations (TS)
- Final destinations (FD) of recycled materials

Waste will be collected at CS, so the waste can be transported to a TS or directly to a MRF. At TS, general waste and recyclable materials are bulked up before being transported to a MRF for further treatment.

After processing at a MRF, the waste stream will be sent to other MRF, or TS for further processing, or to FD for recycling. According to the source information, 97% of the recovered products are within the comingled waste stream and sorted out at MRF.

If TS has capacity to sort the waste and the accuracy pass certain level of threshold, then MRF can be distributed to different location as the waste sorted at TS, can be transported to the exact MRF for further processing. However, if TS is lack of capacity to pre-screen the type of waste, it is recommended the distance between MRFs shall be minimized to eliminate transportation between MRFs.

At zone i , facility (MRF or TS) j is established with cost M_j of MRF setup fee (of total number of facilities: m)
 M_j : MRF facility j setup fee including land cost
 f_j : binary (1/0) possibility that facility j is setup
 $s_{i,j}$: binary (1/0) possibility that facility j serves for i zone
 $l_{i,j}$: location (google map azimuth) of facility j (MRF or TS) associated with waste collection site of zone i

$d_{i,j}$: distance (km) for the original waste site i to travel from facility $j-1$ to j

d_i : distance (km) between the original waste site i and FD (direct distance between source and sink)

w_i : weight (ton) of recycle materials of original waste site i

w_j : weight (ton) of recycle materials of the intermediate sites (TS/MRF) of j step and FD

c_{ij} : unit cost of transportation (USD/ton-km) for the original waste site i to travel from facility $j-1$ to j

e_{ij} : gas emission caused by transportation (l/ton) for the original waste site i to travel from facility $j-1$ to j

t_i : type of materials (t_i : type at source, t_j : type at intermediate sites and sink)

Δt : time duration

M_j cost reference: <https://www.baltimoresun.com/news/maryland/baltimore-county/cockeysville/ph-tt-recycle-facility-1127-20131119-story.html> (Baltimore MRF cost \$23 million)

Our objective is to achieve $\min (\sum_{i=1}^n f_i * M_i + \sum_{j=1}^m (f_i * s_{i,j}) * (c_{ij} + e_{ij}) * (w_{i,j} * d_{i,j}))$

1. We seek max i and min j values (maximize distributed TS/MRF sites, and minimize steps)

2. $\forall i (c_{ij} + e_{ij})$ can be replaced by $(1+\gamma) * c_{ij}$ ($\gamma > 0$ denotes the compared weight to transportation cost)

Our constraints are;

1. In initial state:

$d_{i,1}=0$ (at waste collection site)

2. In direct connect:

$d_i \leq \sum_{j=1}^m d_{i,j}$ (when $m=3$ $d_i = \sum_{j=1}^m d_{i,j}$)

this happens when no further TS or MRF is required between source-MRF-FD

3. All sites are direct connect:

$\sum_{i=1}^n d_i \leq \sum_{i=1}^n \sum_{j=1}^m d_{i,j}$

($m=2 \forall i \sum_{i=1}^n d_i = \sum_{i=1}^n \sum_{j=1}^m d_{i,j}$)

this happens when the above scenario applied to all waste sites

4. Source = (interm. + sink)

$\sum_{i=1}^n w_i(t_i, \Delta t) = \sum_{j=1}^m w_j(t_j, \Delta t)$

5. Policy based (example): $m \leq 5$ and $d_i \leq 100\text{km}$ individually.

To eliminate CO2 emission, this guarantees the transfer steps and distance between source and sink be limited to a maximum of 3 and maximum of 100km individually.

4-2. Local manufacturing

Circular economy has been focused on local manufacturing and the minimization of environmental supply chain footprint will require efficient 3D printing supply chains allowing for distributed manufacturing configurations minimizing downstream logistics (Cotteleer and Joyce, 2014).

This implies that networked production planning, scheduling and manufacturing execution functionality must be established to underpin 3D printing.

Analysis of technology roadmaps and public technology strategies relating to 3D printing at the national level reveals the complexity of the challenges facing policymakers. Nations are taking very different approaches to the development of 3D printing skills, and integrating them into other aspects of policies through diverse structures.

4-3. Supply chain management

In general a supply chain consists of suppliers, manufactures, logistics, retail, consumers and recycling companies. As indicated in the trend, when centralized manufacture was turned into distributed manufacture, SCM's position was changed from a cost driver into a value driver which implies the position of SCM has been shifted from product-based process into an intermediate process that sustain customers' satisfaction. In recent years, SCM for 3D printing has even been transformed into a service-based mediator that shortens the gap between materials supplier, manufacture and end-users. This transformation brings-in huge impacts and opportunities of customization in design, time-to-market, and flexibility in distribution. However, the barrier in reaching a smooth operation can be also huge, which cannot be neglected.

4-3. Product customization

Customization means tailoring the products according to each customer's needs. It is flexible to meet individual needs and allow customers to get involved in design and customization based on their preferences, which make the supply chain more agile and flexible to react to changes in the marketplace.

This further impacts supply chain as product can be fabricated in one step instead of multi-steps, with final assembly through the consolidation of components. End-users have opportunities to get involved in design and customization with potential opportunity to reduce cost being spent in inventory, stock, logistic, supply chain and distribution.

From product design perspective, customers have opportunities to be involved in the whole life cycle of 3D printing processes.

Apart from those large-scale 3D printing organizations, evidence reveals that 3D printing has enabled distributed small scale manufactures to establish feasible business models without demanding much upfront capital investment, thus technology has opportunities to reshape the regulation of competition in the sectors. From customization perspective, it has been highly recognized that the significant advantages that 3D printing will bring-in are the freedom of complexity and variety, which makes 3D printing a perfect fit for those applications that require a high degree of customization or a high degree of complexity in their shape. Evidence already prove that many companies shared significant benefits from those best possible applications, such as direct manufacturing of highly customized products, tooling or prototyping in the development process.

4-4. Cost evaluation

From cost perspective, 3D printing technologies enable manufacturing companies for a high degree of design flexibility at lower cost. It causes high impacts to those products require mass customization without any significant loss of efficiency. 3D printing's additive nature is different as subtractive fabrication, the materials efficiency is higher than other technologies in achieving cost saving. Hence, 3D printing has potential to initiate a change in the underlying assumptions about supply chain sustainability.

4-5. Initial setup

From the perspective of initial setup, space required for production has been one of key factors for mass production.

Space for 3D printing is relatively small and the efficiency of production volume over space occupied is much higher than the conventional manufacturing. By consolidating all parts into final product can happen in one place, 3D printing enables manufacture to significantly reduce supply chain complexity, which makes the entire supply chain more agile and resilient.

4-6. Data management

Application-specific data must be fed into manufacturing design and design validation processes preceding 3D printing operations (Mellor et al., 2014).

Only the incorporation of such data will yield the benefits obtainable from products differentiated to particular applications, for example resulting from optimization-based design methodologies (Aremu et al., 2013).

Moreover, advanced predictive design methodologies can be employed to anticipate future use-cases, which will extend the usefulness horizon even further. It is probable that the complementarity between 3D printing and the supporting data structure will spawn products influenced by the information heuristic itself, thereby giving the rise to the concept of "Things-of-the-Internet".

From data management perspective, a digitized supply chain management becomes possible, as the manufacture can easily control the products by using a single source of data repository for global access.

A shortened lead-time, reduced inventory, logistics and distribution are all 3D printing can offers. This aspect opens a variety of opportunities in the decentralization of supply chain and shifts it to a highly distributed system.

From the perspective of enhancement scenario, 3D printing and its pilot production serve as supplemental solutions to mass customization to aim the exact customers' requirements and prevent risks from product defects or dissatisfaction. A combination of 3D printing and conventional mass production can supplement each other and commit a better control of supply chain, inventory, time-to-market, and shortage.

4-7. Successful factors and business model

Shorter lead time, design flexibility, users-involved customization, and lower costs are key factors 3D printing became a trend.

Through decades, evidence revealed that 3D printing offers flexibility in design, customization in production, collaboration in end-to-end process, personalization in user experience (UX), innovation in business, and cost saving in supply chain.

Furthermore, in its nature of digitized data and additive printing, the design and change become easier as it can be modified and shaped as demands.

As the space for technical improvement is huge, the potential to use 3D printing as a direct production is gradually being realized in some pilot sectors such as aerospace, construction, pharmaceuticals, and automotive are in blossom in this decade. UX and personalization are critical to the medical instruments such as implants, artificial arms and orthodontics, and customer goods.

3D printing is specially suitable for such applications when compared with conventional manufacture. Hence, the future development in technologies, milestones, and applications need be carefully planned. From the other side, business innovation can be critical in various stages of maturity, to

drive technologies and new applications continue to be launched in future development. The plan is outlined in details as followed;

4-8. Lead time and design flexibility

In recent decade, the lead time became critical as market competition became high, and time-to-market gradually became crucial particularly for those newly announced design and products. Under such circumstance, there is no time allowed for manual design and translation into machine control languages. Supported by CAD technologies, 3D printing works perfectly on lead time saving, as it cuts time between idea and product.

For a designer, the design work simply move idea into a draft sketch which can be completed in a couple hours, and 3D printing software automatically calculate the attributes of multi-layers and other attributes of products' characteristics. Once the software calculation is completed, the design work is done and prototyping process is ready.

So 3D printing process can finish the product life cycle within 1-2 days, this can be a significant differentiator to the conventional design.

The other factor that 3D printing impacts lead time is the time needed for redesign and adjustment is significantly cut as well. Prototyping for mass production happens when manufacturing large quantity of goods, and compared to conventional design, 3D printing is much easier for design change.

Compared to 3D printing's role in lead time saving, the inherent design flexibility is much more important. Conventional design has focused on rules and manufacturability of step to step process, as deviation causes defects in assembly and any step may impact the overall feasibility.

The constraints set by design rules are mandatory however, much of the designer's concept was unable to be fully represented in final products furthermore, the design methods became rigid and creativity stunted due to the limitation of creativity and legacy of the processes.

4-9. Cost saving and less complexity

Similar to the other advantages 3D printing has achieved such as lead time saving and design flexibility, consequently these advantages reduces manufacturing costs through a variety of tactical factors such as waiver of tooling, machining, assembly and associated labor cost, details of description are listed as below;

In the nature of subtracting manufacture, tooling is inevitable in conventional design. Tooling involves casting to steel tooling for injection molding, which is part of design to get molded part out of the tool, by using a floating interior. Lots of constraints adhered to tooling process which limits the pattern and complexity of product design, and this can be one of the reasons 3D printing became a game changer as it doesn't need tooling.

In the nature of additive manufacture, 3D printing logically divides parts by identifying each part's special function or shape however, the layer-by-layer printing doesn't handle each part separately, and thus 3D printing doesn't require tooling to perform complex design and manufacture.

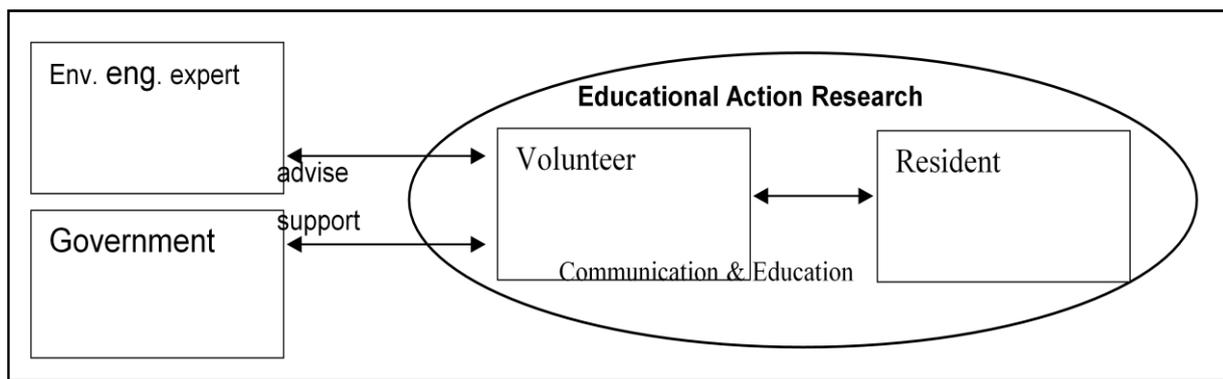
By avoiding tooling cost and labor, the saving is significant. Rolling and machining produce interior floating part which can take lots of time and effort, which are not required in 3D printing. Even though 3D printing require supporting materials and surface polishing work which applied to conventional manufacture, the saving in tooling and machining is huge, and assembly can be even a significant saving as it reduce labor in parts consolidation and integration, as there is no need to divide the design and manufacture by-parts, and no assembly work is necessary. Furthermore, it reduce labor through process automation. In conventional design, machining requires manual control of the software code to work on each part however, this is fully automated in 3D printing as system automatically read the file and print line-by-line without any human interaction. Unlike conventional manufacturing methods, there is no direct relationship between product complexity and manufacturing costs: the complexity of the product design does not drive complexity for tooling or assembly labor. The decrease in the number of parts as well as fewer assembly steps result in a significant reduction of production costs as compared to conventional manufacturing methods. Even

requirements of free moving parts (e.g. ball and socket joint) can be met by printing a single monolithic structure that does not have to be assembled. Integrating an assembly into a single part can also result in fewer subcontractors in the supply chain and thus reduced coordination costs. Hence, 3D printing is especially suitable for product portfolios characterized by a high mix of variants and a low volume per variant.

4-8. Educational action research

As indicated in figure 3, environment engineering experts shall initiate strategy and evaluation with associated organization of government, to lead the construction of process.

Meanwhile, facilities such as recycling collecting pot, recycling factory, and transportation are all the factors need extensive evaluation. From the other side, educational facilitators need to work closely with volunteers of society, to guide residents in transformation process.



Experiential Research (Action Research)

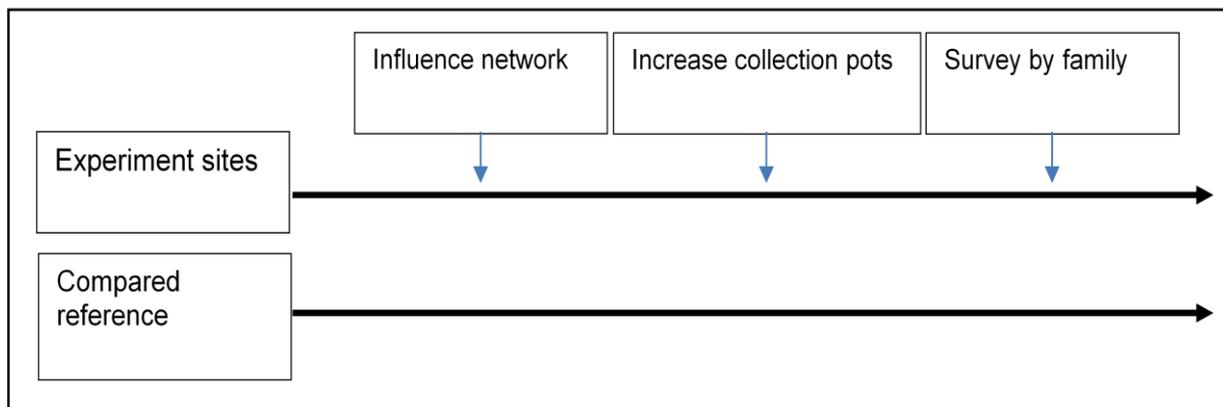


Figure 3. Multi-entities' interoperability within educational action research

Educational action research has been a key factor in maintaining consensus and effective interoperability across multi-entities within designer, stakeholder, consumer, and distributed in end-to-end recycling process. First, the consumers' concept needs a change as consumers need to understand the invisible values are hidden inside the waste. Recycling play key role in waste management as it recycles the value and protect environment. Second, the stakeholders need to be involved in the recycle process of their products,

and build the recycling process to fabricate products through recycling route. The third, government need to reevaluate the waste collecting topology, the supply chain and connectivity between source channel and products channel.

V. CONCLUSIONS

Waste management, green technologies and circular economies are the major topics in environment engineering of this decade. To protect our living environment, and to recycle the waste in a closed loop, modernization of recycling process has been studied and a comprehensive analysis has shed light on key factors that can streamline the transformation at minimum risk. Through the studies, education research action is proposed to interoperate multi-entities of consumer, designer, manufacturer, stakeholder and distributor in an balanced value chain, and the education facilitator of environment engineering expert is expected to take the lead to drive the transformation through interoperable education.

Modernization of recycling process in waste management reduces the cost of waste handlings, minimizes cost of raw materials and processing, and simplifies supply chain management. It introduces 3D printing design and circular economies and significantly impacts green technologies and environment engineering in terms of waste management and materials processing. Educational action research play crucial role in communicating designer, stakeholder, consumer, and distributed in end-to-end recycling process. It fosters the entities across value chain and accelerates the modernization of waste management processes. 3D printing technology offers a general capacity to fabricate products with a high complexity of shape which is very difficult to produce by using conventional manufacturing techniques. In addition, 3D printing has better control of fabrication process to adjust internal structure; it offers capacity of less materials loss, and weight control.

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