OPEN COMMUNITY MANUFACTURING

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ABSTRACT

In the current competitive economic environment, start-up companies struggle to accomplish production tasks alone. Digitisation helps to solve most product or service customisation challenges with open co-creation platforms and toolkits. The concept of Open Community Manufacturing (OCM) systems is introduced. OCM uses open design platforms to create value at the base of the pyramid, by empowering incubators through distributed manufacturing systems. OCM systems embrace new ways of technology transfer, ideas and risks, so as to create the most collaborative environment possible. This research study evaluated several open design platforms, projects and toolkits that can be used as social innovation support system to develop distributed manufacturing entrepreneurs. It was found that economic value can be created using open design, simply due to mass collaboration where people are living, experiencing and expressing gradually more within digitally enabled social- and peer networks in distributed communities. OCM finds synergy amongst various stakeholders in order to mobilise developing communities. This allows products to be manufactured economically in smaller, more flexible quantities for the customised demand.

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1 BACKGROUND AND MOTIVATION

Poverty remains an issue of the modern world. Despite that South Africa (SA) is the most developed country in Africa, there are still regions suffering from severe poverty. More than half of the working population belongs to the so-called base of the pyramid (BoP). In order to comply with tighter legislation, Broad-Based Black Economic Empowerment (B-BBEE) policies and to receive tax benefits, several stakeholders attempt to address this issue with passive social responsibility programs.

Poverty can not only be addressed by programs that adhere to and support sustainable business conduct, growth plans and the Millennium Development Goals. Therefore, it is critical to find a synergy amongst various stakeholders and that actions are orchestrated to support the development goals. The call for systems and strategies to mobilize the target population and to ensure distributed value creation even in isolated regions remains unanswered.

In addition to this, the recent financial crisis that shivered the global economy caused an economic bear run even in developing nations. These conditions make it really hard to foresee that traditional Technology Transfer (TT) actions (e.g., foreign Greenfield investments) will be enough to radically accelerate economic growth.

Since the industrial revolution in the eighteenth century manufacturing has been considered to be the main engine of economic growth and development. It contributes to the quality of life of individuals, to growth of wealth in a nation as well as power and position of a state. Manufacturing is the backbone of modern industrialized society, as it always has been cornerstone of the world’s economy. Having a strong manufacturing base is important to any society or community, because it stimulates all the other sectors of the economy. Therefore, manufacturing deserves strong and continuous endeavour of all actors in a modern society to ensure prosperity, better life and sustainable development. Few in SA doubt the essential need to grow the manufacturing sector of the country. Some universities and non-profit organizations even invested in community factories (e.g., FabLabs and BURN design lab) to encourage manufacturing movement. Still, there is a shortage of new concepts which would fast-track the development of this sector.

Small and medium-sized enterprises suffer from the shortage in skills (know-how), appropriate technology and the lack of a collective support system. This leads to inefficient value creation, a high degree of energy (resources) wasted in production processes and frightening pollution. The ability to co-create value independently (even in socially- and geographically isolated regions), together with improved teaching capabilities can open numerous possibilities for developing countries. These statements highlighted some of well-known challenges and facts, which affect development in SA.

In order to find innovative systems to alleviate poverty in SA, this contribution proposes the concept of open community manufacturing as a new technology transfer mechanism. It is based on principles of value co-creation, networking, open design, and ubiquitous manufacturing. This approach is defined with a model and demonstrated in two case studies. These case studies illustrate low- and high technology products.

2 SUSTAINABLE DEVELOPMENT AS INNOVATION DRIVER

A balanced sustainable development framework will ensure that a country’s geographic area is utilised effectively, the country’s people are healthy, skilled and educated; the infrastructure is sufficient and that there are abundant employment opportunities within respected governance systems. Considering that sustainable development entails meeting the needs of the present without compromising the ability of future generations to meet their own needs - this concept has become a real innovation driver to grow the formal economy.
2.1 Base of the pyramid (BoP)

The base of the pyramid represents the largest (4 billion), but poorest (live on less than US$ 2.50 per day) socio-economic group [1]. These are the people that should receive basic needs and basic services to survive. The BoP was first introduced in the work by Prahalad et al. [2] attempting to raise awareness of the world economic pyramid and the vastly untapped market. Since then, there have been considerable attempts toward developing economically viable initiatives to serve the BoP.

In theory, organizations targeting this segment operate under the proposition of mutual value creation, which suggests that creating more value for the BoP creates more value for the venture [1]. In other words, in order to grow the formal economy, stakeholders need to help create value inside the informal economy as shown in figure 1 by investing in education, infrastructure, skill-, supplier- and enterprise development programs.

![Diagram showing the relationship between the BoP and the formal market.](image)

**Figure 1:** Creating more value for the BoP, creates more markets for organisations investing its SEED funding into social innovation programs (Adapted from [1])

The poor at the base of the corporate ladder primarily transact in an informal market economy, due to the cost, complexity and unfamiliarity of transitioning to the formal economy [1]. In order to address the BoP issues, a more in-depth understanding of this environment is needed. One must keep in mind that the BoP significantly differs from formal business environments as follows:

- customers have a low and irregular income
- markets can be located in extreme geographic locations (e.g. poor physical and informational infrastructure)
- competition is weak or may be too strong for start-up entrepreneurs to enter the market
- lack of support system (e.g. suppliers, distributors)
- corruption is embedded in the society
- formal institutional (e.g. legal enforcement) environment is usually weak
the informal institutional environment has strong ties within the community and;
the informal economy is often in conflict with formal institutions

These are just a few, but noteworthy characteristics of the BoP which require significantly different approaches and business models as we know them from the developed (formal) world. Among other, one has to consider the following principles [3]:

- products are to be produced in small sizes with strong local adaptation (flexibility)
- distribution must take into account frequent, small purchases and hard-to-reach areas
- transactions must consider little reliance on contractors
- transactions have strong reliance on informal tie and;
- important to obtain local recognition and legitimacy

Knowing that manufacturing deserves a strong and continuous endeavour to ensure sustainable development, the BoP must be considered not only as a potential market, but also as a producer. According to London et al. [4] BoP producers, which are operating in the informal sector, generate goods for sale (e.g. agricultural products and handcrafts). The challenge is that it is sold almost exclusively in local, informal markets. Also, due to the lack of an industrial culture, one must be aware that there is no adequate knowledge, skills, and resources for manufacturing in the BoP.

Still, there is evidence of undergoing activities related to BoP development. Some case studies [5] show what types of innovation are best to reinforce the value propositions to address low-income consumers’ problems. Other work [6] proposes community desired products to meet the needs of the BoP. Khan [7] proposes a new learning method for BoP people. Therefore, there exists opportunities for introducing the manufacturing of low-tech products in BoP communities.

2.2 Technology transfer

As the lack of knowledge, skills, resources and infrastructure are universally recognised; technology transfer (TT) becomes a key mechanism for introducing manufacturing to the BoP. Several definitions of technology and its transfer in literature exist, with a recent overview given by Wahab et al. [8]. For the purpose of this research we use the following definition of TT: “Technology transfer is the movement or flow of technical knowledge, data, designs, prototypes, materials, inventions, software, and/or trade secrets from one organization to another organization or from one purpose to another purpose” [9].

According to Tahmooresnejad et al. [10] companies are the driving force of TT and need to prepare their infrastructure and human skills to be successful. Government’s role is to support organisations with policies to accelerate localization and aid them in developing their new products based on transferred technology.

Amesse et al. [11] define two phases of TT: (1) innovation process or technology creation, and (2) reproduction or technology diffusion. The authors also distinguish if these processes are performed within one organization or between organizations. On this basis they define four contexts of traditional TT methods and point out a need for new ways of TT for knowledge based economy.
In the last decade we have witnessed some new emerging approaches to technology creation and transfer. Collective organizational forms emerged such as industrial clusters and networks. Nowadays, the innovation process is even totally opened to global communities in which everybody can participate. The Google Android development and marketing platform is a good example. Everybody can access and use existing design tools and solutions on this platform and co-create even more solutions.

Table 1 shows technology transfer contexts in a systematic manner. The left four quadrants (denoted with I - IV) are adopted from Amesse et al. [11] and represent the traditional technology transfer methods. The right four quadrants (V - VIII) represent the novel technology transfer methods.

Table 1: Eight contexts of technology transfer

<table>
<thead>
<tr>
<th>Traditional technology transfer methods</th>
<th>Novel technology transfer methods</th>
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<tbody>
<tr>
<td>Within organization</td>
<td>Between organizations</td>
</tr>
<tr>
<td>Creating technology</td>
<td>Reproducing and diffusing technology</td>
</tr>
<tr>
<td>I MANAGING INNOVATION</td>
<td>III TRANSFERRING TO DIVISION OR SUBSIDIARIES</td>
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<td>II CONTRACTING OUT R&amp;D AND OUTSOURCING</td>
<td>IV BUYING OR SELLING PROVEN TECHNOLOGIES</td>
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<td>V COLLABORATION &amp; OPEN INNOVATION</td>
<td>VI OPEN DESIGN &amp; CO-CREATION</td>
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<td>VI OPEN DESIGN &amp; CO-CREATION</td>
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Traditionally, TT is considered as a closed system. The creation of technology is performed either within an organization and the main concern is innovation management (I), or between two or more organizations and where the technology creation is contracted or outsourced (II). If reproduction and diffusion of technology is performed within an organization, it is performed as transfer of technology to a division or subsidiary of the organization (III). If reproduction and diffusion of technology is performed to a third party, it is usually executed through buy/sell arrangements and carried out in one of the established forms, such as licensing, turnkey installation, or build-operate-transfer (IV). In all cases knowledge is well protected either through non-disclosure measures or intellectual property rights.

The novel TT methods are more open than the traditional ones. One reason for this lies in the development of information and communication technologies, which enable collaboration in virtual, geographically distributed teams. In such environments, the creation of technologies is performed through collaboration and based on open innovation principles (V).

The next approach to technology creation, which we are facing recently, is the principle of open design performed in open communities. The Internet was the enabler for this approach. It started with the open source software movement and was recently extended to open hardware design. The principles of open design enable co-creation of value through participation of anybody from the global community (VI).

Within clusters and networks the suitable forms for diffusion of technologies are business alliances and partnerships (VII), such as joint ventures and public-private-partnerships. These forms are especially suitable for big technological investments.

The issue of reproduction and diffusion of technologies in open communities is new and not adequately formalized yet. Certainly it is an issue of adoption and adaptation of technology.
2.3 Open ‘X’ for Manufacturing

Openness is a feature which has played a vital role in production engineering over the last three decades. Several concepts have been developed which tend to be open. In order to point out their character, it contains the word ‘Open’ in their titles. We shall denote these concepts with Open ‘X’.

It all started with the issue of connectivity in the early days of computer networking. The International Standard Organization (ISO) recognized a need for standards for communication among different systems in a network and initiated work on the Open Systems Interconnection (OSI). According to [12] the term “open” was chosen to emphasize that by conforming to OSI standards, a system would be open to communication with any other system obeying the same standards anywhere in the world. The resulting ISO 7498 standard (accepted in 1983) opened a way to integration of systems, such as CAD/CAM and Computer Integrated Manufacturing (CIM).

In the beginning of the nineties a new open initiative was put forward in manufacturing. This time the machine tool controllers (CNC) became a target for being opened up (e.g. LinuxCNC). The CNC controllers offered at that time by a few vendors were closed systems. These closed systems did not allow any adaptation and blocked further development. In order to overcome this situation, Open Architecture Control (OAC) was proposed as a concept for easy implementation and integration of customer-specific controls by means of open interfaces and configuration methods in a vendor neutral, standardized environment [13].

The idea of open architecture was recently extended to Open Architecture Products (OAP) - a new class of products comprising a fixed platform and modules that can be added and swapped. According to Koren et al. [14], customers can adapt OAP’s to their needs by integrating modules into the platform. Manufacturers will produce these platforms, while new small companies and customers will develop the modules, thus increasing employment and causing the economy to flourish.

Most software producers consider source code as valuable intellectual property and make it unavailable. The concept of open source software (OSS) is different. OSS programs give any interested party access to the source code, leading to a distributed innovation platform in which users actively participate in the product’s development thus enabling co-creation of value [15].

Recently, there are initiatives to also provide open source hardware under the similar propositions as are valid in the OSS community (e.g. Open Source Ecology). The idea here is not only to provide license free product documentation to be downloaded for a do-it-yourself (DIY) realization, but also to enable uploading of new design solutions open to communities.

The open source and open hardware concepts are today considered as one concept called Open Design (OD). OD initiatives can be divided into toolkits (e.g. 3DVIA Cloud, Autodesk 123D), projects (e.g. SketchChair, Wikispeed and OpenStructures), education and learning (e.g. Tinkercad) and enterprises (e.g. Local Motors, Arduino and Bug Labs).

The challenge with manufacturing is that in addition to knowledge, equipment and tools are needed to implement the designed solutions. Three solutions can be seen for addressing this issue: (1) rapid, digital manufacturing (e.g. 3D printing), (2) mini factories (e.g. FabLabs)
and (3) distributed manufacturing systems composed of various advanced workshops providing professional manufacturing services.

Another concept under the Open ‘X’ framework is open innovation (OI). One of recent OI definition states that: ‘the use of purposive inflows and outflows of knowledge to accelerate internal innovation and to expand the markets for external use of innovation, respectively’ [16]. The basic principle of open innovation is opening up the innovation process through (1) collaboration and co-creation of different actors, and (2) opening innovation outcomes to broader public. Based on this definition, all the above mentioned Open ‘X’ concepts fit into OI. Pisano et al. [17] explained that OI models can function in the following environments:

- Organisation posts a problem and anyone can submit a solution, while the organisation chooses the best solution
- Organisation chooses participants, posts problem and selects best solution
- A flat network where all peers are equal and anyone can post a problem, or deliver a solution
- Private network of peers that jointly chooses problems, and jointly reaches solutions

OI models that emerged in recent years include idea competitions, customer immersion, collaborative product development and platforming.

2.4 Industrial clusters

“An industrial cluster is an entity characterized by a social community of people and a population of economic agents localized in close proximity in a specific geographic region. Within an industrial cluster, a significant part of both the social community and the economic agents work together in economically linked activities, sharing and nurturing a common stock of product, technology and organizational knowledge in order to generate superior products and services in the marketplace” [18].

This definition stresses the geographic proximity of cluster partners which, perhaps, is the main distinction between a cluster and a network. In other words, a cluster is a regional network. Industrial clusters support collaboration and cooperation among partners [19]. They provide a sound basis for competitiveness, innovativeness, agility and adaptiveness by enabling the interconnected partners to (1) form long-term business coalitions, (2) share information, knowledge, resources, competencies and risks, (3) develop mutual understanding and trust, (4) jointly react to business opportunities, and (5) gain synergetic effects by collaboration and cooperation. Thus, they combine good characteristics of large companies with the advantages of SME’s and introduce new possibilities and potentials for innovation. Innovation is usually one of the strongest motivation factors for establishment of a cluster. Successful clusters consist of entities from the industry, public bodies, finance, media, universities and formal and informal networks.

Based on the above observation, an industrial cluster may be the best organizational form to support the proposed OCM concept. In the cluster an important role could be played by incubators. Incubators, or more specifically business incubators, are programs which support entrepreneurial or start-up companies via various business support resources and services as shown in figure 2. Young entrepreneurs enrol at these incubators to develop skills. The Department of Public Enterprises (DPE) established a Competitive Supplier Development Program (CSDP), which involves procuring in such a way as to increase the competitiveness, capacity and capability of the local supply base. This program also helps to develop enterprises and sustainable suppliers using these incubators in the clusters.
There are currently approximately 60 privately- and publicly-funded incubators in South Africa. The Department of Trade and Industry (the dti) currently supports publicly-funded incubators via the Small Enterprise Development Agency’s Technology Programme, and also has very ambitious plans to establish an additional 250 incubators directly by 2015 under its recently-launched Incubator Support Programme (ISP). These incubators are currently covering industries like chemicals, furniture manufacturing, stainless steel processing, mining and agricultural tooling, construction, jewellery, agro-processing and renewable energy.

3 OPEN COMMUNITY MANUFACTURING MODEL

Considering the Sustainable Development challenges, an innovative development model called Open Community Manufacturing is proposed as shown in figure 3. The model is based on (1) continuous technology transfer based on the Open ‘X’ principles, (2) mobilization of communities belonging to the base of the pyramid (BoP), (3) co-creation of value through development of low-tech products and educational services desired in communities, (4) transfer of technology and knowledge to spin-out micro enterprises based either on profit or socio-economic principles, (5) interconnection of stakeholders and other interested parties in an industrial cluster, and (6) achieving synergies among individual supporting initiatives provided by the government and public agencies.

The Open Community Manufacturing concept was developed to help grow the formal economy, while not interfering with existent technology transfer mechanisms. The core objective is to mobilize the ‘sleeping’ BoP communities to help grow the formal market. The OCM value chain also integrates the skill development incubators into a collective support system. The concept uses open design to eliminate the Intellectual Property (IP) barrier and to virtually connect people to develop low-tech and self-replicating high-tech products. This value chain is divided into five core phases – community needs analysis, open design, advanced manufacturing, assembly processes and the incubation of future entrepreneurs. The process is usually driven and managed by volunteers.
OCM integrates the knowledge and skills of various global universities and volunteers to solve social challenges. After identifying and understanding the community’s needs better, volunteers can either develop their own; or search for possible solutions on the various open design platforms. These possible solutions are then improved through co-creation by students as part of their practical/lectures for various engineering subjects in a Learning Factory. The volunteers then select the best solution from this collection of solutions and identify incubators or workshops that can do the advance manufacturing processes. The winning design is then sent to be manufactured.

The various components are then transported from the incubators to the community as a kit for final assembly. It is important that the community do the final assemble; as it transfers skills and shows the community how to maintain (repair) their innovative solutions. These skilled people can later assist the local municipalities. In order to ensure sustainability (independence), future work will focus on the creation of entrepreneurs with these OCM developed products. These products can include value creating brick, briquette or charcoal making machines, recycling and water filtration technologies or; mini-modular factories in containers as examples. After volunteering for two months to complete an OCM challenge, the program offers the foreign students the opportunity to explore the country, before implementing (assembling) the solutions in the community.

In this cluster designers transform their social developing ideas into physical products, by virtually collaborating with the volunteers and manufacturing specialists. Universities participate by integrating the OCM challenge into their curriculum similar to the learning factory concept. This helps to educate and prepare university students with industrial & social challenges on the platform through collaborative learning. Start-up manufacturers participates and help generate fair work opportunities by creating value through manufacturing of quality products to meet the social demands. At the same time incubators are supported in this cluster to help start-up SMME’s with the specialist knowledge on the platform. The OCM development challenge also ensures that social investments are made with a sustainable impact in people, partnerships, infrastructure and technology.
4 CASE STUDIES

4.1 OCM development and manufacturing of a low-tech product

In order to validate the value chain, a low-tech product was manufactured using the OCM platform illustrated in figure 4. Two volunteers from the University of Kassel (Germany) helped to drive the Open Innovation process. Firstly, the community needs of a selected community (Kokstad) were analysed by working closely with various stakeholders in the area (e.g. MCCDO non-profit organization and social workers). It was then decided to develop a stove that could be manufactured by the MSI incubator and assembled by the Kokstad community. The volunteers selected an applicable stove from an open design platform as starting point. The challenge was divided into tasks with clear definitions and the necessary resources were identified. A practical was prepared by the German volunteers for the University of Johannesburg’s bachelors Mechanical Engineering Science students as illustrated in figure 3.

As part of a practical, the open design solution development process was divided into four steps: product planning, digital collaborative design, rapid prototyping and refinement. The various requirements of the possible solution and potential risks were communicated to the students as design criteria for the practical. A continuous exchange of information between the community, the volunteers and the Universities was needed to effectively adapt the product to the desired needs of the Kokstad community.

Figure 4: The Open Community Manufacturing development challenge platform used to drive the open design phase of the OCM process

Figure 5: Using open design as part of a University practical to involve students to develop community desired solutions
All the possible solutions were uploaded (published) on the OCM Development challenge platform to ensure continuous knowledge management in the form of a database for duplication in other communities. Thereafter, possible solutions were identified by the volunteers. Rapid prototyping was used inside the Learning Factory as final criteria, before sending the design to the skill development incubators to be manufactured. Only then the selected components were manufactured inside the MSI incubator as shown in Figure 6b. The volunteers worked closely with the MSI incubator to bridge the gap between the design and manufacturing steps; and also to ensure TT to both parties.

![Image of FabLab technologies](image)

**Figure 6:** Using FabLab technologies to rapid prototype the student open designed a) product that was then b) produced using c) advanced manufacturing processes inside the d) MSI incubator in Middelburg

The manufactured components were then transported as a kit to the community for final assembly. Final assembly was done inside the selected community to ensure skills transfer. Doing assembly this way also helps to ensure that the people in the community can do maintenance on the manufactured products. None of these designs or manufactured products was sold for a profit.

### 4.2 Mini mobile robot RoboComp

The mini mobile robot RoboComp is a robotic platform developed at University of Ljubljana for the purpose of the traditional Summer School on Mechatronics. The event is organized annually for third year Bachelor students in Mechanical engineering, with the objective to promote Mechatronics. Using the open microcontroller (e.g. Arduino) students could develop and manufacture their own robots in three weeks. Besides the open design solution they have access to a FabLab (e.g. 3D printer, desktop milling machine and water jet machine). These robots are then used in a competition organized at the end of the Summer school to test the engineering designs. It was found that the students were very excited and motivated to participate on a voluntary basis. They also showed a lot of creativity. Figure 7 shows a robotic kit and an assembled mobile robot.
Based on the positive experiences of the three successive Summer schools, the RoboComp action is seen as a comprehensive learning tool to raise technological awareness. Such an event can also help to create a manufacturing culture in BoP communities. The main mission of RoboComp action is to accelerate the transition of basic research concepts performed within the academic environment, into working aspects for the manufacturing industry while educating prospective engineers in the process.

5 CONCLUSION

This contribution introduced the concept of Open Community Manufacturing systems as a new technology transfer mechanism. The concepts of Openness and the BoP were discussed within the context of sustainable development. Several successful open design platforms, projects and toolkits and education packages were reviewed. Both the design and manufacturing of low-technology and high-technology products was evaluated as case studies. Future work will focus on the refinement of the quality management systems for the OCM product development value chain and the sustainable implementation (acceptance) of these products in the community. It will also be interesting to understand the effects of OCM on external stakeholder’s production stability and supply chains for formal economies.

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