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# Ethical manufacturing: What value can a public health ethics framework add?

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## **Abstract**

*Manufacturing is impacting both the public's health and the environment. This impact has far-reaching consequences. These consequences raise, among others, ethical questions as manufacturing impacts people's health, habitat, safety, and security. It also impacts the environment, water, energy, sustainable livelihoods, and more. In addition, workers' rights, sustainable resourcing, and waste reduction are also ethical matters relevant to ethical manufacturing.*

*Ethical manufacturing depends on more than ISO standards alone. Ethics is the decision between what is morally good or bad, whilst standards refer to compliance and meeting quality criteria. Norm and principle-based guidelines are needed to protect vulnerable communities, secure sustainable environments, and affordable and accessible products, and promote social cohesion. A Christian ethics perspective is used to provide guidelines for the intersection between manufacturing and public health.*

*This article examines the intersection of Christian ethics and ethical manufacturing, focusing on the relationship between manufacturing and public health. It explores how the dignity of both workers (as producers) and the public (as consumers) can be enhanced through proposed guidelines that arise from this intersection.*

*A 3D case study will be used as illustrative support to contribute to a public health ethics framework that promotes ethical manufacturing.*

## **Opsomming**

### ***Etiese vervaardiging: Watter waarde kan 'n publieke gesondheid etiek raamwerk toevoeg?***

*Vervaardiging beïnvloed die publiek se gesondheid en die omgewing en het verreikende gevolge. Hierdie gevolge is onder meer eties van aard. Vrae oor die impak van vervaardiging op mense se gesondheid, hulle woonplek, veiligheid en sekuriteit kan gevra word. Dit het ook 'n impak op die omgewing, water, energie, volhoubare leefruimtes en meer. In aansluiting hierby, gaan dit ook oor werkers se regte, volhoubare hulpbronne, die vermindering van vermorsing en ander vrae relevant tot etiese vervaardiging.*

*Etiese vervaardiging gaan oor meer as net ISO standaarde. Etiek is die keuse tussen wat moreel reg of verkeerd is, terwyl standaarde verwys na nakoming en kwaliteitskriteria. Norm- en beginsel-gebaseerde riglyne is nodig om brose gemeenskappe te beskerm, 'n volhoubare omgewing, bekostigbare en toeganklike produkte, en sosiale samehorigheid te verseker. 'n Christelike etiek perspektief is gebruik om riglyne te formuleer vir die samehang tussen vervaardiging en publieke gesondheid.*

*Hierdie artikel ondersoek die betekenis van 'n Christelike etiek vir vervaardiging in samehang met publieke gesondheid. Dit bestudeer hoe die voorgestelde riglyne die waardigheid van werkers (as produseerders) en die publiek (as verbruikers) kan bevorder.*

*'n 3D gevallestudie word gebruik ter illustrasie van 'n publieke gesondheidsraamwerk wat etiese vervaardiging kan bevorder.*

### **Keywords:**

Ethics, manufacturing, ethical manufacturing, public health

### **Kernwoorde:**

Etiek, vervaardiging, etiese vervaardiging en publieke gesondheid

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## 1. Introduction

Manufacturing, regardless of the product type, is impacting the health of the public and the environment, either positively or negatively. From an ethical perspective, several questions can be raised. Leading ethical questions on the impact manufacturing has on *people* relate to health, habitat, safety, security, and the *environment*, including pollution, water, energy, sustainable livelihoods, and more. In addition, workers' rights, sustainable resourcing, and waste reduction are also ethical matters relevant to ethical manufacturing. In ethical manufacturing, humans and the environment cannot be separated from one another.

The importance of ethical manufacturing is evident from the World Health Organization's (WHO) Compendium and the United Nations' (UN) guidance on health and the environment. The link between humans and the environment in manufacturing is supported by the updated sections in this document on *nature* and *health*, among others. In this updated section, the dependence of health and well-being on the natural environment and biodiversity is confirmed. Biodiversity and functional ecosystems are important in preventing infectious diseases, including those that give rise to pandemics, and supporting mental health (WHO, 2024). The conclusion is expected: *Manufacturing impacts the lives, health, and habitat of people*. This awareness is also evident in the WHO's Compendium of Innovative Health Technologies for low-resource settings (2022). This compendium confirms the potential of health technologies to improve the quality of life and health outcomes. The latest compendium edition focuses on health technologies supportive of the COVID-19 responses and other health priorities. The compendium emphasises key concepts including patient and staff safety, human rights, and environmental sustainability. Consequently, ethics plays a significant role in evaluating technological evidence. The use of technology can raise ethical dilemmas regarding its application, the research conducted to support its use, and the allocation of resources (WHO, 2022).

Ethical manufacturing is far-reaching with unintended consequences. To cite one example: Banda and co-authors convincingly argued in support of the role of local manufacturing to enhance the safety of workers. The COVID-19 pandemic hampered this initiative. At the same time, the pandemic confirmed

the vulnerability of local communities to compete with what is available on the international market. Economic vulnerability is a reality that cannot be ignored. Another consequence was the relatively low African contribution to health-led research and contribution, which, as a result, weakens the rightful leadership role in global health matters (Banda, Mugwagwa & Wanjala, 2021).

Michaels and Monforton (2005) raise another related matter, namely that the clash between “manufacture uncertainty” and “junk science” cannot be ignored. In the former, the validity of scientific evidence is questioned by opponents of public health and environmental regulations. In the latter, it is used to downplay research that threatens powerful interests. Their commentary is sound: *Scientific evidence should be available to ensure that the health of the public and the environment is protected.*

From the above comments, three matters are evident:

- *Firstly*, manufacturing is important for human advancement.
- *Secondly*, manufacturing is more than product development, as it depends on nature for its material, has human needs as an outcome, and influences nature as a provider of materials.
- *Thirdly*, ethical manufacturing and the ethics of manufacturing should not be treated as interchangeable. The first concept refers to how products are manufactured, and the second to what the principles and values for manufacturing are.

Against this background, it is somewhat surprising that there is limited research available on the intersection of Christian ethics and manufacturing. This observation is based on an internet search of “Christian ethics and manufacturing”. A limited body of scholarly research is available. From what is available, a summative view created through a Google search of Christian ethics in manufacturing focuses on applying biblical principles, such as honesty, fairness, stewardship, and the Golden Rule, to all aspects of production and business practices. This involves valuing the common good and social justice by ensuring fair treatment of workers, minimising environmental harm, and engaging in transparent business dealings with customers and competitors. Leaders are encouraged to be servant-minded, compassionate, and to demonstrate integrity, prioritising ethical conduct and God’s values over solely profit-driven motives.

A comprehensive overview of the scope of Christian ethics by Reed, Forster, Von Sinner, Conradie, Hausteijn, Heide, Méndez-Montoya & Lumã Vaai

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(2024) emphasises that emerging ethical challenges, particularly those impacting marginalised communities and the environment, should be more thoroughly considered within Christian ethics. The value of Christian ethics is further highlighted in the work of Melé and Fontrodona (2017), who note that the Bible addresses concepts such as human dignity (derived from being created in the image of God), stewardship (the responsibility we have toward the earth), and the Golden Rule (treating others as one would like to be treated). These principles are not only relevant to the Christian faith but are also found in broader contexts. For example, the preamble of the UN's Universal Declaration of Human Rights refers to "human dignity", and the Golden Rule is often referenced in business ethics literature. Additionally, the concept of "servant leadership", grounded in Matthew 20:27-28, serves as another example. The authors argue that the application of Christian ethics to social and economic life has deep roots, originating from the very beginnings of Christianity as a continuation of Jewish moral teachings, both in intellectual thought and in practice.

Fourie (2012) offers another important perspective by stating that Christian ethics can be viewed from two angles: ethics practised by Christians and ethics applicable to Christians. These two perspectives represent the practitioners and audiences of Christian ethics. By implication, the church remains the primary practitioner of Christian ethics and continues to express this deeply Christian conviction. This does not mean that Christian ethics is confined to this context alone, but that it holds significant value for a broader society, as evidenced by the Roman Catholic social teachings and Protestant social ethics, both aiming for a just society. This provides a basis for practitioners of Christian ethics to engage with a wider audience, including the manufacturing sector. On another note, the view that the Church itself embodies the social ethic is widely accepted and exemplifies how the Church can embody Christian ethics (De Villiers, 2003).

This article will explore the intersection of Christian ethics with ethical manufacturing within the context of the relationship between manufacturing and public health. It will examine how the dignity of both workers (producers) and consumers (the public) can be enhanced through the proposed guidelines arising from this intersection.

The next paragraph will attend to the central focus and argument of the article.

## 2. Central focus and argument

Ethical manufacturing and ethics in manufacturing depend on more than ISO standards only. The purpose of ISO manufacturing standards is to secure *compliance* with the standard of manufacturing. However, value or norm-based guidelines are required to protect vulnerable communities, secure sustainable environments, and affordable and accessible products, and promote social cohesion. Such guidelines should be required by the relevant manufacturing standard.

Although the debate on ethical manufacturing and ethics in manufacturing is not new, a perspective from public health on this debate can identify matters often overlooked in ethical manufacturing and the ethics of manufacturing. Manufacturing will be delineated to focus especially on additive manufacturing.

The importance of public health is emphasised in, among others, the *New Public Health Order for Africa* (2021). This approach to public health is built on five pillars, namely strong public health institutions, access to life-saving medicines and equipment, addressing health threats through public health interventions, resources in support of health, and strong partnerships (African Union and Africa Centre for Disease Control, 2021). Taken from these pillars, the preventative support from public health action is beyond argument.

These matters will be considered within the domain of Christian ethics. Reed, Forster, Von Sinner, Conradie, Haustein, Heide, Méndez-Montoya & Lumã-Vaai (2023) identified several important characteristics of Christian ethics:

- A lived experience of discipleship,
- Faith seeking practical wisdom, and
- A focus on marginalised voices and the impact of socioeconomic inequalities, climate change, and conflict on ethical decision-making

Christian ethics holds significant value for those who wish to align their daily lives with Biblical principles and values, which have evolved through tradition. It is also an academic discipline that addresses ethical issues and dilemmas.

Various methodologies can be employed to approach Christian ethics, enriching our understanding of the field. These methodologies include:

- Historical approaches, which examine how power dynamics and cultural changes influence Christian ethics.
- Theory-practical methods, which explore how beliefs shape actions in specific contexts.
- Socio-anthropological approaches, which analyse the lived experiences of Christians and their communal practices.

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- Philosophical methods, which focus on logical coherence and the ethical implications of Christian doctrine.

The Bible serves as a foundational text for understanding Christian ethics and requires careful interpretation and application. Reading the entire Bible is vital for grasping its diverse moral teachings and avoiding selective interpretations. Narrative readings highlight the importance of the biblical truth in shaping ethical understanding within the faith community.

Christian ethics is further enriched by examining a variety of historical and ecumenical perspectives, revealing both commonalities and differences. The study of these diverse perspectives fosters mutual understanding and dialogue within the Christian community. Engaging with the Bible involves descriptive, synthetic, hermeneutical, and pragmatic tasks that inform ethical decision-making. Most would agree that the Bible is an essential source for formulating beliefs (*doctrines*) and for contemplating practice (*ethics*).

Characterised by its evangelical nature, practical application, and commitment to the marginalised, Christian ethics emphasises the importance of lived experience and the embodiment of ethical principles in daily life. This approach is context-specific, addressing global issues such as climate change, inequality, and social justice.

For the article's focus and arguments to emerge, an appropriate methodology should be identified.

### 3. Methodology

This article is based on *concept, descriptive, and document* analyses in manufacturing and in public health.

From these analyses, an *integrated framework* will be constructed to illustrate how a public health approach can assist in addressing ethical challenges in additive manufacturing as an example within manufacturing. The application of the framework will be narrowed down to *additive manufacturing for elderly care*. From this application, the guidelines will be identified as relevant to the article's focus and discussion.

The discussions in this article are relevant to the fast-growing medical product development through 3D printing.

## 4. Concept and descriptive analysis

### 4.1 *The domains of ethics and manufacturing*

Ethics is the science of values and norms, relevant to people's lives and interactions with themselves, others, communities, and the environment. The going interpretation of ethics is the choice between good and bad, what should be done and what should not be done.

Raymakers and De Dijn assist with the ethical conceptual understanding that is useful for our discussion. Raymakers (2016) states the universally accepted norms that people can live up to regardless of their ethical orientation. This is contrary to ethical relativism, which denies norms that are intersubjective and universal. The importance of this comment is that there are basic principles that all people can live up to. Respect, responsibility, trustworthiness, value of life, do not harm, can be listed as relevant principles here. Another useful perspective on ethics is offered by De Dijn (2003). He comments that one of the benefits of applied ethics is the support of moral responsibility towards a fast-changing society. Applied to manufacturing, the conclusion is that ethical manufacturing gives evidence that values and norms are applied during the manufacturing process. This differs from ethics for manufacturing, where the question is what values and norms are required in the manufacturing process. The following comments will further guide this conceptual clarification.

The Industrial Machinery Digest (2021) defines ethical manufacturing as “a holistic approach to the manufacturing process that focuses on good health for all involved”. The product maintains sustainable standards. Both process and product have a positive impact on communities.

Jhaver (2024) describes ethical manufacturing as many practices ensuring the well-being of workers, the environment, and communities. He continues to say that these practices include fair labour, responsible sourcing, and sustainable practices. Apart from a competitive advantage, ethical manufacturing's focus is on operations that take the well-being of the workforce and the impact on the environment into consideration. Two actions are important from his perspective: *opportunity* and *responsibility*.

When we turn to what values and norms for manufacturing are needed, applicable values and norms are respect for and protection of people and the environment, safe and affordable products, responsible sourcing of materials, fair trade, and supply-chain management. These categories can be further unpacked, for example, in the domain of ergonomics, respect for

people encompasses workers and consumers; workers' rights and safety should be assured (ergonomics in the workplace), and consumers' safety and needs (consumer ergonomics) should be considered. The crux of the matter is that a suite of ethical lenses in ethics (such as consequentialism, deontology, and virtue ethics) will put people and the environment first. The first dictum in ethics is simply *no harm*. The required ethics for manufacturing will depend very much on ethical views from, but not limited to, *engineering ethics, business ethics, human rights ethics, bioethics, and environmental ethics*. Each of these applied ethical perspectives will contribute to identifying relevant norms and values for manufacturing. The following perspectives illustrate this comment.

**Engineering ethics:** Gwynne-Evans, Chetty and Junaid (2021) remind us of the balancing act between the “powerful knowledge” of the engineer, with risk and humanity. In essence, the old question of whether one should do what one can do. This question confirms that engineering ethics is more than just the application of technology, as it should take people and their operating context into consideration (Lategan, 2024). Harris, Pritchard and Rabins (2005) correctly remark that standards and operating procedures are sometimes not enough, especially if people are not well equipped to deal with the standards and operating procedures. They continue to support the concept of *responsible care* as a concept that meets the obligations in standard operating procedures and responsibilities. In manufacturing complex products, the individual operator/production line worker is seldom aware of the magnitude of abilities the final product may have, and further considering the impact the product may have. The responsibility of ethical manufacturing, therefore, lies with the systems designer and integrator, more so than with the individual production line worker.

Medical devices and procedures witnessed a blow in their development thanks to technological development. As a result, something like biotechnology contributed to a mirth of ethical questions, as living nature is controlled by a mechanistic view (Lajul, 2021). Global South countries, such as in Africa, raise biotechnology ethical and geographical questions, which is further evidence that ethical challenges are not stand-alone challenges in the context of manufacturing (Lajul, 2021). *Bio-printing* is a good example of how manufacturing can impact humanity and lives. Even if it is possible to do so, bioprinting interfering with life essentials cannot be approved in any way (Lategan & Van der Merwe, 2023). Another problem with ethics and research about technology and ethics is that when reporting on their interaction, the focus is more on *intent* than on the *effect* on patients. This finding is based

on a scoping review of 250 studies on how the relation to health technologies and ethics is described in the literature (Steerling, Houston, Gietzen, Ogilvie, De Ruiter & Nygren, 2022).

**Business ethics:** The complexity of ethics for manufacturing is further highlighted by core principles in business ethics, such as employer and employee, market value and profit margins, and end-user, customer, and consumer. The complexity deepens in emerging economies, vulnerable communities, and job creation in developing markets. Whilst all products should meet the required ISO standards, be affordable, and make a difference, ethical challenges are emerging from stakeholders' needs, customisation, and the green environment. A business ethics perspective reminds us of the role of globalisation and sustainability (Verstraeten & Liedekerke, 2010) and securing the future of the next generation (Crane & Matten, 2004).

**Human rights ethics:** This ethical view further contributes to sustainable manufacturing and ethical behaviour. A guiding document from the Australian Human Rights Commission (2024) underlines that whatever the business, it should not harm humans. Matters such as workers' rights, consumer rights, and product safety are essential. In this Commission's discussion, respect for the "cultural environment" is also emphasised.

**Environmental ethics:** Recent developments in environmental ethics include concepts such as *green living* and the *green economy*. The significance of a healthy environment is well illustrated by the move toward planetary health. Planetary health's relevance is that human health is situated in human systems and that humans live within natural systems (Horton & Lo, 2015).

Joseph L. Badaracco (1998) raised another matter that is relevant to our discussion, although his comment was directed at business ethics. Often, he says, it is not about "issues of right versus wrong" but "conflicts of right versus right". Choosing the "right" ethics means that context and consequences are other key concepts that should be considered when ethics in manufacturing is discussed.

Having said it all, ethics in manufacturing is influenced by various ethical views and frameworks. When these views and frameworks are integrated, five specific aspects can be identified, namely:

- Human, to which health is linked,
- The environment, to which sustainability is linked,
- The product, to which materials, safety, and affordability are linked,
- Knowledge to which the profession, labour, and skill are linked, and
- Technology, to which enhancement is linked.

In bringing ethical manufacturing and ethics in manufacturing together, **responsible care** can be identified as a key concept. Based on this, we can state that responsible manufacturing will protect consumers' and producers' rights; contribute to sustainable environments, quality and healthy living, and assure the quality and affordability of products.

Responsible care is a concept that is deeply rooted in Christian ethics. It provides a framework for responsible action through principles such as the Law of Christ, which emphasises love for God and one's neighbours, stewardship of creation and resources, the sanctity of life, and a commitment to honesty and integrity. This ethical system guides Christians in caring for others, the environment, and their communities by reflecting Christ's love, promoting justice, and acting with empathy and compassion.

In his discussion of an ethic of responsibility, De Villiers (2003) highlights the importance of understanding both *role* responsibilities and *moral* responsibilities. He argues that these two types of responsibilities should not be viewed in isolation from one another. Furthermore, he makes the point that role responsibility should not be reduced solely to functionality. De Villiers emphasises the idea of "prospective responsibility", which involves looking towards the future to prevent harm to both humans and nature. This perspective is a moral orientation that transcends mere functional risk management. He asserts that a Christian ethics of responsibility carries an additional obligation: to assess the present and future consequences of our actions from a moral standpoint. As De Villiers (2003:36) states: "A Christian Ethics of Responsibility has an extra obligation to insist that present and future consequences of actions taken today should also be assessed from a moral perspective."

## **4.2 Public health**

The general understanding of public health is the government's interventions and steering of the public health systems to promote the quality of health and living (Lategan & Van Zyl, 2018).

Harvard University's T.C. Chan School of Public Health (2024) follows a broad-based description of public health, namely that "public health is the science of protecting and improving the health of populations – from neighbourhoods to cities to countries to world regions". Rhodes and Bryant's (2024) definition confirms five actions for public health, namely *prevention, promotion, prolong, control, and organise*. All these actions aim to improve health and the quality of life. According to Fareed, Hussain and Khan (2023), one of the goals of public health is to "create environments that support good

health". Another aspect of public health is to uphold *health equity* and protect *vulnerable groups*.

From these observations, it is confirmed that prevention is core to public health. In addition, *health equity, sustainable social and natural environments, and protection of the vulnerable* are important pointers for public health.

The relevance of public health for manufacturing is well illustrated by Fiachra O'Brolcháin, Gordijn, Byrne & Dune's (2021) discussion of the "*biologicalisation of manufacturing*". This concept refers to the convergence of engineering and biology. It also refers to how technology is using materials and principles from nature to establish a sustainable economy. Technology and biology can create new processes, materials, and products that could benefit health, such as *algae* for diabetic chronic wounds, *silk proteins*, and *food production*. Medical devices can benefit from batteries that are energy efficient and biofuels based on organic materials. Although the outcome has good intentions (sustainable economy, new treatments), there are often unintended ethical consequences, for example, waste, economic expenditure, and over-exploitation of ecological systems during the manufacturing process.

Based on these comments, three core values identified for this discussion are *prevention, protection, and promotion of health and vulnerable communities*.

From these analyses and descriptions emerges a framework that can be used in additive manufacturing.

## 5. An ethical framework for additive manufacturing

In the discussion so far, four core observations are:

- *Responsible care* is required in the manufacturing process, as manufacturing impacts on people and the environment.
- *Public health* has a meaningful role to play in manufacturing as it supports the *quality of health and living* through interventions that prevent harm and disease, protect vulnerable communities, and promote equitable health.
- Ethics' role is to *identify relevant norms or principles* for the situation, to steer between right and wrong activities and behaviour, and to guide when decisions between conflicting good behaviour may arise.
- Ethics, public health, technology, and manufacturing emerge into *transdisciplinary studies* and provide multi-phased perspectives for dealing with conflicting matters during the manufacturing process and beyond.

These observations lead to six dimensions, namely (a) goals, (b) values, (c) norms/principles, (d) ethical view, (e) ethical guidelines and (f) ethical evaluation. The contribution of these dimensions to one another is evident and is based on evaluation criteria. These criteria are *relational* and *public health* criteria. The *functional criteria* are analysis, consideration, and interpretation. The *public health criteria* are quality of health and living, health equity, and vulnerability. These dimensions and criteria will form the basis of the framework. The following explanations provide evidence in support of the framework.

If the *goal* of additive manufacturing is to enhance cost-effectiveness, reduce time, and customise medical devices, then the goal should be supported by *values, norms/principles*.

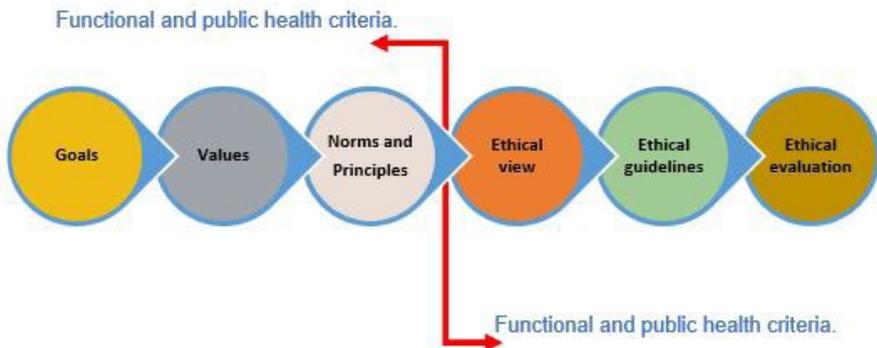
**Values** can be explained as those qualities that no action or activity can go without.

**Norms and principles** can be defined as the value-based actions required to accomplish a task (norm) and the belief systems underpinning the actions (principles).

**Ethics** is *different* from morality in that ethics are norm- and principle-based, whilst morality is an individual orientation to questions regarding right and wrong. Within ethics, there are descriptive, normative, and applied ethics. Ethics systems are evaluated, based on ethical lenses such as consequentialism, deontology, and virtue ethics. Choosing the relevant ethics system is therefore important within manufacturing.

**Ethical guidelines** are derived from the analysis, consideration, and interpretation of the goals, values, norms, principles, and ethical views. These guidelines can be further evaluated against the guidelines provided by Beauchamp and Childress (2013) for *bioethics* and Goldman (2023) for the *ethical supply chain*. Although Beauchamp and Childress identified their principles for bioethics, these guidelines can be regarded as the backbone for all research involving humans. These guidelines are beneficiary, non-maleficence, justice, and autonomy. Goldman defines the ethical supply chain that calls on corporate social responsibility. From here, products are produced and services provided that treat workers and the environment ethically. Human rights and environmental considerations will be part of social responsibility. These principles and *the ethical value chain* can be regarded as the basis for the ethical evaluation.

The alignment between goals, values, norms/principles, ethical views, ethical guidelines, and ethical evaluation can be illustrated via the circle process in Figure 1.



**Figure 1: Framework for Ethical Manufacturing**

The application of this framework will be discussed from a 3D case perspective.

## 6. Case perspective and application

The case for this article is taken from 3D printing aimed at elderly people.

*Additive manufacturing* for elderly people can benefit their healthcare and -cure through products and 3D images of potential diseases. Ma, Gu, Wang, Bi, Liu, Zhang, Yang & Zhang (2023) attended to the advantages and disadvantages for elderly people and patients. The breakthroughs are many. The author refers to 3D-printed ageing disease models, implants, drug delivery systems, dysphagia diets, and auxiliary devices that can be used for both investigation and treatment. Of note is that within the domain of neurological diseases, 3D printing is limited in the treatment and research relevant to these diseases. Apart from the limitation, there are ethical risks that have not been resolved yet.

The advantage of additive manufacturing is that complexity is free. Improved designs are possible, and topology optimisation allows the designer to develop lightweight structures, which is not possible with conventional manufacturing. Material reapplication is also possible. Where subtractive manufacturing removes material from a billet, additive manufacturing grows the part using only the material required. Less waste of energy and material supports the ethical guidelines framework.

New material applications contribute towards new challenges. In additive manufacturing, material is “welded” together, which may result in new, often unknown, or untested material properties that have not been researched yet. Such unknowns may cause ethical risks. Designers and manufacturers need to consider the dimensions of the proposed framework regarding the risk of transgression.

Product development for use by a specific population sector requires ethical consideration by the developer organisation. Amongst others, ergonomics is a science that addresses both manufacturing and consumer risk. Ergonomics is the science of human-machine interaction. During the production process, industrial ergonomics principles should protect the human operator from harm in the manufacturing environment. Similarly, consumer ergonomics principles should protect the consumer of the product against harm from the product. In both cases, the human operator or consumer may be unaware of the harm that can be caused by the product.

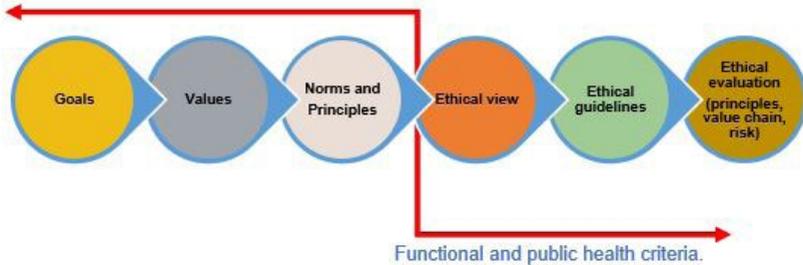
Consider toxicology as an ergonomics factor that may cause harm. In the case of materials traditionally used safely in conventional manufacturing, but now used in additive manufacturing, may have unknown toxicological properties. During manufacturing, the machine operator may be exposed to fume particles generated. The consumer may be exposed to cytotoxic materials used for implants, and particles dislodged to enter the bloodstream, amongst other examples. The elderly consumer may have a higher dependency on customised products for which additive manufacturing is ideal. But has ethical manufacturing been considered for this use case?

Industrial ergonomics is the science of proactively quantifying and qualifying for possible harm to operators in the workplace. The focus is on the public health of the working population. Similarly, consumer ergonomics aims to prevent harm to consumers and focuses on public health. In our case, the vulnerable ageing population depends on the customisation that additive manufacturing offers; therefore, the focus of ethical manufacturing in additive manufacturing.

When this case is compared to the framework in Figure 1, these dimensions are relevant to arrive at ethical guidelines. However, the case confirms that the functional and public health criteria should be evident across these dimensions, but also within the dimensions. The added meaning of this observation is that each dimension should be subjected to analysis, consideration, and interpretation, but each dimension should be subjected

to the same scrutiny as the next dimension. These dimensions should be analysed, considered, and interpreted as a unity. The case also suggests that **risk** should be part of analysis, consideration, and interpretation, and as a part of the ethical evaluation itself. Figure 2 presents the update of the framework.

Functional and public health criteria.



**Figure 2: Framework for Ethical Manufacturing**

The usefulness of this framework for 3D printing is illustrated in the following way:

**Table 1: Matrix to use Framework for Ethical Manufacturing**

Dimension	Evaluation of dimensions per dimension, between dimensions, and as a unity (E1)	Public health criteria	Ethical Evaluation (E2)
Goal	<ul style="list-style-type: none"> <li>▪ Analysis</li> <li>▪ Consideration</li> <li>▪ Interpretation</li> <li>▪ Risk</li> </ul>	<ul style="list-style-type: none"> <li>▪ Quality of health</li> <li>▪ Quality of life</li> <li>▪ Health Equity</li> <li>▪ Vulnerability</li> </ul>	
Values	<ul style="list-style-type: none"> <li>▪ Qualities to action an activity</li> </ul>		
Norms & Principles	<ul style="list-style-type: none"> <li>▪ Value-based actions</li> <li>▪ Belief systems</li> </ul>		

Dimension	Evaluation of dimensions per dimension, between dimensions, and as a unity (E1)	Public health criteria	Ethical Evaluation (E2)
Ethical view	<ul style="list-style-type: none"> <li>▪ Descriptive ethics</li> <li>▪ Normative ethics</li> <li>▪ Applied ethics with consequentialism</li> <li>▪ deontology</li> <li>▪ virtue ethics</li> </ul>		
Ethical guidelines	Based on E1 and six dimensions		
Ethical evaluation			<ul style="list-style-type: none"> <li>▪ Bioethics principles</li> <li>▪ Supply chain</li> <li>▪ Risk</li> </ul>

## 7. Application

The remaining question is the role of Christian ethics in ethical manufacturing and its nexus with public health.

For this question, Fourie (2012:57) offers an important guideline by noting that the Church, as a practitioner of Christian ethics, is not a “powerless adversary”, but rather “a competent dialogue partner”. This implies that Christian ethics is not merely an incidental voice or an opinion; it plays a significant role in constructive interactions that are grounded in critical engagement and can influence the content of these interactions. It is essential to adopt cooperative rather than reactive approaches, although both methods require caution. A reactive approach can lead to being ignored, while an overly cooperative stance may result in being assimilated and losing influence. Achieving this balance is challenging but depends on the Church’s own resources, their application, and a commitment to faithful compromise (Fourie, 2012:58).

Based on the scope of Christian ethics discussed in this article, the following key points can be highlighted to guide ethical manufacturing, considering the core values of human dignity, stewardship, the golden rule and sustainable livelihoods:

- In the manufacturing sector, human dignity must always take precedence. Safety should not only be considered during the manufacturing process, but also for the end-users of the product. Upholding human dignity means that being a manufacturer of a product entails a responsibility, primarily a proactive responsibility, that prioritises consumers over profit and commercial interests.
- People cannot be separated from their environment, which necessitates an ecological ethic.
- A public health ethic grounded in the principles of doing good, avoiding harm, promoting social justice, and respecting autonomy can greatly enhance the quality of health and living.
- Interculturality and cultural diversity require that Christian ethics clearly articulate its contributions to complex issues, including morality, constructive values, and dialogue among different ideologies.
- Responsible care is about human dignity, stewardship, the golden rule, a just society, role and moral responsibilities and prospective responsibilities.
- An eco-technological ethics with the emphasis on care for the environment can be useful for ethical manufacturing. For such an ethic, the emphasis will be on promoting sustainability by considering the full life cycle of technology, ensuring algorithmic fairness, upholding human moral agency, and fostering a responsible relationship with the natural world informed by Scripture and tradition.

A Christian ethics perspective on the discussions in this article calls for critical reflection on how technology affects the environment and human beings, especially their health, which requires responsible development, innovation and application.

## 8. Conclusion

This article presents a framework for ethical manufacturing that can guide the ethical challenges triggered by manufacturing. This framework is based on six dimensions and four evaluation indicators within these dimensions.

Although the debate on ethical manufacturing and ethics in manufacturing is not new, public health strengthens the values of quality health and living that should be embodied in ethical manufacturing and the ethics of manufacturing.

These views are considered from the intersection of Christian ethics with ethical manufacturing within the context of the relationship between manufacturing and public health.

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