Beyond Birth: Exploring the Complexities & Potential Misuse of Artificial Womb Technology

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***Abstract*— Artificial Womb Technology (AWT) promises revolutionary advancements in infertility treatments and neonatal care for premature infants. This paper conducts an examination of AWT's ethical, legal, social, environmental, economic, and cybersecurity implications. Methodologically, it integrates an extensive review of existing literature with a theoretical analysis of potential misuse patterns. The ethical discussion addresses concern about the commodification of human life, parental rights, and the disruption of natural birth processes. Legal challenges focus on the necessity for new regulations to govern usage, consent, and responsibility. Social implications highlight the potential impact on family dynamics and the risk of worsening existing inequalities, while the environmental considerations are centered on the resource demands, overpopulation and waste associated with AWT. Economically, AWT introduces new market opportunities while also raising concerns about commercialization and profit-driven misuse. Cybersecurity emerges as a critical, overlooked issue due to the sensitive nature of the data involved and the severe consequences of potential breaches. The theoretical analysis highlights the historical misuse patterns in digital health technologies, reinforcing the urgent need for stringent guidelines and policies to ensure the responsible implementation of AWT.**

Keywords—artificial womb technology, cybersecurity, ectogenesis, ethics

I. INTRODUCTION

Artificial Womb Technology (AWT) stands at the frontier of neonatal care and human reproduction, with the potential to transform how we approach premature births and infertility. Imagine a world where a fetus can develop entirely outside the mother's womb, nurtured in a highly controlled, artificial environment. This groundbreaking technology not only promises to save countless premature infants but also offers new hope for those struggling with infertility.

AWT enables the growth of a fetus outside the mother's physical womb by creating an environment for extracorporeal pregnancy. By simulating a womb-like surrounding of amniotic fluid in a temperature-controlled habitat, with an interface resembling an umbilical cord through which nutrition and oxygen are provided, this technology provides a revolutionary alternative to traditional pregnancy [1].

The concept, known as ectogenesis, which was first introduced by the biologist J.B.S Haldane in 1924, has recently been realized on lamb foetuses by researchers at the Children's Hospital of Philadelphia in 2017 [2]. Termed "biobag", the system included a bag equipped with fluid and machinery to give oxygen and nutrients, mimicking a womb, and was successful in sustaining a lamb fetus for 4 weeks (see Figure 1).

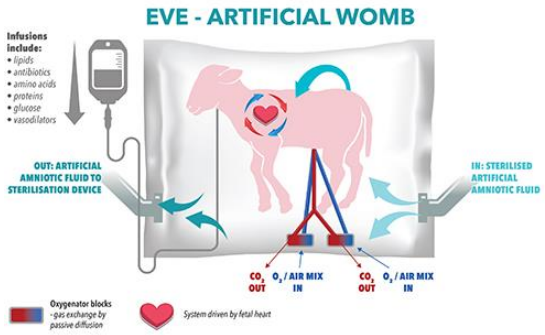

Fig.1, Artificial Womb of Lamb Fetus, [38]

While this breakthrough may seem like a cause for celebration, it entails a serious spectrum of dilemmas ranging from ethical to legal to social. Moreover, a forgotten issue that arises and is highly relevant in this digital age is cybersecurity. Given the AI and data-centric nature of AWT, cyber risk has become a prominent issue in this field.

The purpose of this paper is to explore the multifaceted implications of AWT, emphasizing its ethical, legal, social, and cybersecurity aspects. Understanding these dimensions is crucial as we advance towards potentially integrating this technology into medical practice. This topic is important because AWT not only represents a significant leap in medical technology but also challenges existing frameworks of bioethics, law, and social norms. The research objectives of this paper are:

1- To examine the ethical, legal, & social considerations surrounding the use of AWT.
2- To analyze the potential social and environmental consequences of widespread AWT adoption.
3- To identify and evaluate cybersecurity risks associated with the AI and data-centric nature of AWT, and propose mitigation strategies.

This paper is structured as follows: Section 2 reviews existing views on the ethics of AWT, Section 3 discusses its potential consequences, Section 4 examines the cyber risks and preparations associated with AWT, and Section 5 provides a theoretical analysis.

II. Literature Review

The concept of Ectogenesis has brought about numerous arguments, both offensive and defensive, regarding ethics, social views, and legality. In this section, existing work on the views towards AWT will be explored.

A. Ethical Concerns & Social Implications

Firstly, in [3], the author sheds light on the fact that viewing AWT as an "innovative treatment" instead of investigative research is ethically and clinically wrong. The former term draws AWT to be an alternative to newborn intensive care (NIC) technology, which is false because its beneficial outcomes are still unconfirmed and unknown. The socio-ethical consequences of mis-defining AWT and not seeing it as research will overlook the need to answer questions about the status and rights of the gestate (i.e., is it a fetus or preterm infant? Do they have rights to be protected?), risk and benefits assessment (i.e., exposing vulnerable subjects to risks without clear benefits), informed consent, and therapeutic misconception (i.e., parents may misunderstand AWT as an experimental, not standard, treatment, highlighting the importance of clear communication during the consent process). Moreover, proper research design (like randomization and blinding), validity, and clinical equipoise is difficult to execute in AWT trials due to the novel, uncertain, and potentially evolving nature of the technology, as well as due to the medically fragile and vulnerable nature of the research subjects (i.e., the fetus). The study effectively highlights the importance of ethical clarity and precision in the terminology used for AWT. While the author calls for a careful and ethical approach to its development and testing through clinical trials, no detailed plan or alternative solution or recommendation is delved into.

In addition to treating infertility, AWT can be misused for purposes like "sex selection," which is illegal in most countries. Haldane envisioned ectogenesis as a tool for controlled breeding and feature extraction, not just infertility treatment. In sexist cultures, this could lead to a surplus of male births. Another misuse is its proposed use as a solution for abortion, as discussed in [4]. Horn argues this is flawed because AWT doesn't protect bodily autonomy—the ability to make personal decisions backed by necessary resources. Additionally, it could marginalize low-income women, particularly women of colour, who already struggle with access to reproductive care due to high costs and complexity. Reproductive autonomy requires a supportive social environment, not just technological solutions. In other words, transferring a fetus to an artificial womb alone without supporting the pregnant person's broader needs (inadequate workplace maternity policies, healthcare access, social support, financial support, etc.) doesn't solve the core issues and renders the process unfeasible. Furthermore, fetal viability (i.e., ability to survive outside uterus) is a socially and legally created notion; lowering viability requirements might be abused to further restrict access to abortion without considering the socioeconomic effects and the realities of providing for children after birth. More importantly, ectogenesis doesn't eliminate the need for human care, raising the question of who will care for the child if the original parents choose not to. Shared parental rights and obligations could further complicate personal autonomy and relational dynamics, causing unwanted entanglements. Ectogenesis fails to address the broader social, economic, and relational factors tied to reproductive rights and autonomy. While potential risk mitigation strategies are not directly explored, the study examines reproductive autonomy and the broader societal context associated with AWT, often overlooked in technology-focused discussions.

To add to Horn's concerns, substituting abortion with AWT can cause a surplus of unwanted babies who will be placed in foster homes, contributing to the already existing issue of children-filled foster care systems, receiving no attention in some and facing abuse in others. In 2017 alone, there were over 2,500,000 children in such systems worldwide [5]. The use of AWT for abortion purposes will not only contribute to that number but may also increase the world's population, furthering issues of overconsumption, resource scarcity, and ecological degradation. While some may claim that such an argument is "far-fetched", all evidence points towards the opposite. With an expectation of the world population exceeding ten billion, high fertility rates contribute to depletion of resources (including economic ones) and prevent sustainability and development [6]. This will be delved deeper into in the coming section.

The complex social aspects of implementing AWT are also explored in [1]. The author notes that AWT could promote gender equality by allowing men to become single fathers without needing a female partner or surrogate. However, acceptance of such use of AWT is likely to be low due to traditional societal norms regarding reproductive roles. [8] also believes that ectogenesis could enable men to procreate without women, reinforcing male gendered supremacy. Additionally, [7] argues that promoting "gender equality" through AWT must address not only gender inequality but also social inequalities within genders, such as those affecting ethnic minorities, disabled individuals, and the socioeconomically disadvantaged. Ignoring these broader social inequalities could lead to ectogenesis reinforcing existing disparities. These studies collectively analyse AWT's impact on gender equality with a multi-dimensional approach. While they offer valuable insights, their reliance on hypothetical scenarios over empirical evidence may limit practical application. Nonetheless, these works highlight the importance of a comprehensive approach to understanding AWT's intersection with social structures and norms.

From a political perspective, [9] believes that modern arguments about ectogenesis focus too much on the technology itself, overlooking its revolutionary potential. The real significance of ectogenesis lies in its ability to challenge and confront social institutions that restrict women's freedom and equality. For ectogenesis defences to be genuinely liberating, they need to adopt a political stance similar to the "Wages for Housework" movement of the 1970s. This movement not only demanded acknowledgment of reproductive labour but also sought to highlight women's roles in the home, workplace, and community. Similarly, arguments for ectogenesis should emphasize the need for greater access to social and medical services, better working conditions, and a real redistribution of parental duties. Without considering the broader social context, defences of ectogenesis risk maintaining the status quo.

B. *Technical & Legal Concerns*

In [7], the abortion argument is addressed further by noting that AWT is very different from early-stage abortion and involves more risk as it requires carrying the fetus for around 22 weeks before it can be surgically removed from the woman. This violates the woman's autonomy and can eventually deny people the choice to not have children. Regarding surgical risk, [7] also highlights how the incision done in the uterus to extract the fetus is likely to be riskier than the one done in Caesareans because the uterus is not as stretched as it would be during a term pregnancy, the incision will be made early in the pregnancy, which increases the risk of uterine rupture, incorrect placental implantation, and other complications down the road. Moreover, if ectogenesis exceeds the limit of viability, meaning that more or maybe all babies become viable, this could increase pressure on expectant mothers to have fetal removals instead of fetal therapy. The author also compares and contrasts similar concepts like surrogacy, Uterus transplants (UTx), and adoption. Surrogacy poses liability and risk of coercion of surrogate, UTx has safety risks and may worsen black market organ trade, and adoption can be expensive. However, all of these dangers are not mitigated by AWT. Coercion of women, surgical risk, production of fetus' for the black market, and high costs are all highly probable issues with AWT implementation. Moreover, the author examines the challenge of being able to test ectogenesis on humans in the future, as no amount of animal testing results can be sufficient enough to safely guarantee AWT's application on humans. Important issues about the possibility of direct implantation of an embryo into an ectogenetic incubator for full gestation—also known as complete ectogenesis—are also brought up by the author. This strategy aims to advance human embryo cultivation as well as the capacity to care for preterm babies, with the ultimate goal of facilitating the conduct of a whole pregnancy outside of the human body. The use of spare IVF embryos is suggested, though most countries currently adhere to the 14-day rule, which prohibits the in vitro growth of embryos beyond 14 days post-fertilization. While scientific developments may prompt reconsideration of this rule, the mere possibility of extending the in vitro period does not imply that it is ethically acceptable.

In addressing legal issues with AWT, various contract frameworks are evaluated in [1] for agreements between intended parents and clinics. At-will employment contracts are unsuitable due to their termination flexibility, while adoption contracts do not apply as AWT facilities cannot be natural parents. Goods contracts are also inadequate as embryos and fetuses are not property. Service contracts, on the other hand, where clinics provide gestational services for payment, are deemed most appropriate. These contracts establish intended parents as legal guardians from the start, avoiding issues seen in surrogacy where parental rights may be contested. However, challenges may still arise, such as disputes over legal status in jurisdictions with differing laws on artificial reproduction. Adding to the legality of the procedure, the issue of who has the final say in significant decisions, such as terminating the process, is not only complex but also highly subjective. In contemporary society, it is generally accepted that the mother, who bears the child, has primary authority over pregnancy decisions. However, with AWT eliminating traditional "child-bearing" characteristics, this authority may no longer solely rest with the mother. Resolving potential disputes through mutual agreement between both parents is overly simplistic. The lack of clear legal precedence in this area highlights the need for new legal frameworks to ensure fair decision-making. A proposed solution is to use currently existing legal approaches like mediation or arbitration by a neutral third party to resolve disputes. Another one is to treat such cases akin to that of custody-assigning divorce cases. However, the traditional basis for primary custody involves physical care and bonding with the child, which is absent in the case of a fetus in an artificial womb. Hence, due to the unique aspects of the process, to create new legislative and judicial frameworks specific to cases of AWT is a necessity to prevent unfair or immoral actions and decision-making. Furthermore, the legal framework must address the cybersecurity risks associated with AWT, which will be further discussed in the coming section.

III. OVERLOOKED ISSUE: CYBERSECURITY IN AWT

One of the critical issues that may come as an afterthought in the development and deployment of AWT is cybersecurity. Digital Health technologies are some of the most susceptible systems to cyberattacks due to the wealth, sensitivity, and confidentiality of the data they hold. Yet, funding on cybersecurity measures does not hold a major part of healthcare organizations' budgets, as seen in Figure 2.

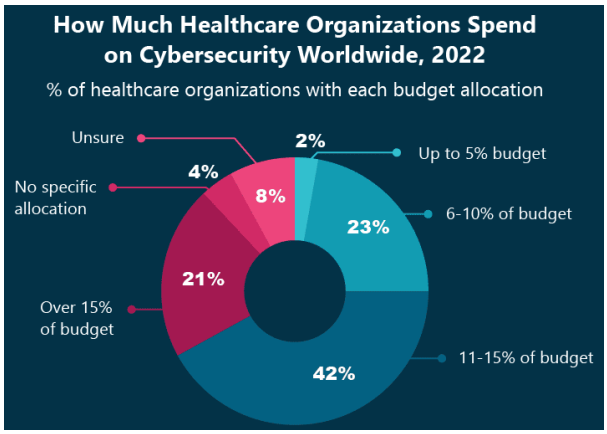

Fig. 2, Healthcare Organizations ' Budget Spending on Cybersecurity, [39]

Artificial wombs, like any other AI-based technology, would likely collect and store large amounts of data about the developing fetus. Thus, cybersecurity and the potential for cyber breaches in AWT are of paramount importance, given that such systems involve the significant responsibility of ensuring the life and development of a fetus. Any compromise in the security of these systems could have far-reaching and severe consequences, far surpassing those associated with breaches in other computer systems. The stakes are uniquely high because the integrity and safety of the developing fetus depend directly on the reliable operation of these advanced technological environments.

Similar to other medical devices like pacemakers, insulin pumps, and life support systems, AWT must have robust security measures to protect the following aspects:

A. Data Privacy & Protection

It is anticipated that artificial wombs would gather and retain large volumes of private medical data, including genetic data, developmental milestones, and other health parameters of the growing fetus. Safeguarding this data is crucial as unauthorized access could lead to severe privacy violations and misuse. Sensitive data may be used for illegal research, identity theft, or genetic discrimination, among other nefarious activities. Protecting the confidentiality and integrity of this important data requires strong encryption, safe data storage options, and strict access restrictions. This need ties back to the ethical concerns of AWT, highlighting the imperative to protect individual privacy and prevent potential misuse of sensitive information.

B. System's Integrity & Safety

The integrity of both the software and hardware components of artificial wombs is important for the safe and effective development of the fetus. Cyberattacks that compromise these systems can have catastrophic consequences. For instance, a ransomware attack could lock users out of the system, potentially demanding payment to restore access, which could disrupt the continuous care necessary for fetal development. In addition, malicious software could alter critical parameters, which could lead to developmental abnormalities or even the loss of the fetus. Implementing rigorous security protocols, regular system updates, and real-time monitoring can help mitigate these risks and ensure the system's reliability and safety. This concern is directly related to the legal and ethical responsibilities of ensuring the highest standards of care in medical technologies.

C. Unauthorized Access and Control

There is a serious possibility that an unauthorized person may gain control over the environment of the artificial womb. Such control might put the growth of the fetus at risk by enabling malicious actors to interfere with vital life-support systems including oxygen levels, nutrition delivery, and temperature regulation. Unauthorized access might not only result in immediate harm but could also have long-term health implications for the child. This issue raises significant legal concerns regarding liability and accountability in the event of a security breach. To prevent similar cyberattacks in AWT, strong authentication procedures, multi-factor authentication, and access logs should be put in place to make sure that only authorized individuals are able to administer and keep an eye on these vital systems.

D. Communication Networks

Artificial wombs connected to hospital networks or the internet for remote monitoring and control introduce vulnerabilities to network-based attacks. These communication channels must be secured against interception, eavesdropping, and data manipulation to protect the integrity and confidentiality of the transmitted data. Network security measures, such as end-to-end encryption, secure communication protocols, and firewalls, are essential to defend against cyber threats. Ensuring the reliability and security of these communication networks is imperative to maintaining the continuous and safe operation of artificial wombs. This aspect emphasizes the economic impact of investing in robust cybersecurity measures to prevent costly breaches and ensure public trust in AWT.

Nonetheless, despite all the mentioned protective security measures placed, cyber-risks are never eliminated, as seen with current computer systems, including ones used in healthcare. A recent example of this was in 2019 when Medtronic, a well-known manufacturer of cardiac devices, revealed vulnerabilities in several of their devices including insulin pumps (MiniMed), implantable defibrillators, and pacemakers. Unauthorized users or attackers could wirelessly connect to the pumps and change their settings, which might result in the delivery of too much or too little insulin. Moreover, in 2023, another cyber breach was reported in Medtronic's Paceart Optima System, which is in charge of gathering and organizing data from patients' cardiac equipment [26]. Additionally, in 2016, Johnson & Johnson disclosed the use of unencrypted communication in their OneTouch Ping system, which can lead to spoofing attacks and administering unauthorized insulin injections [27].

IV. METHODOLOGY

The topic of the complexities and potential misuse of Artificial Womb Technology (AWT) was researched using a systematic literature review design. This design was employed to identify, select, and critically evaluate previous studies on the topic in a reproducible and explicit manner. The literature was systematically searched, and critically appraised, and each study was synthesized individually. Ethical considerations included acknowledging contributors, declaring conflicts of interest, ensuring data confidentiality, obtaining informed consent from participants, and protecting children.

The systematic literature review design is scientific, providing evidence-backed results and conclusions. It identifies knowledge gaps and aids future studies. The methodology relied on electronic sources from online databases, with searches including quotations and reference lists. Google Scholar was initially used to find samples of articles, followed by searches for peer-reviewed and primary source articles using broader search terms.

Key search terms included Artificial Womb Technology (AWT), Dangerous Sex Selection & Inequity in AWT, Environmental & Economic Harm by AWT, and Complexities & Potential Misuse of AWT. The literature review identified critical areas such as care for preterm babies, cybersecurity risks, ethical governance, mother-fetal connection, and potential misuse of AWT. Boolean logic and keyword synonyms were used to enhance the search strategy across databases like Taylor and Francis Online, Oxford Academic, ProQuest, and PubMed. Various synonyms of phrases and keywords were also considered, as recommended by [41]. For example, "connection" was replaced with bond, "artificial womb technology" was replaced with reproductive technologies, and "complexities" was replaced with challenges. By combining terms with 'OR' and 'AND' commands, relevant articles were identified, ensuring a focused and comprehensive search.

An inclusion and exclusion criterion was used in selecting the relevant studies. A critical appraisal skills program (CASP) worksheet was used to review the articles. Omission was done manually to ensure that the literature review was relevant. Only studies with valid methodologies were

consulted. The studies were required to clearly focus on the research questions. Any paper that did not have a clearly formulated research question was omitted. Papers that clearly answered the research question in their abstract, introduction and final paragraph were considered. In addition, a number of criteria were used in the analysis of sources, as recommended by [42]. The materials were required to be in line with the study topic, peer-reviewed primary sources were highly preferred, and articles whose theme was similar to that of the research were considered.

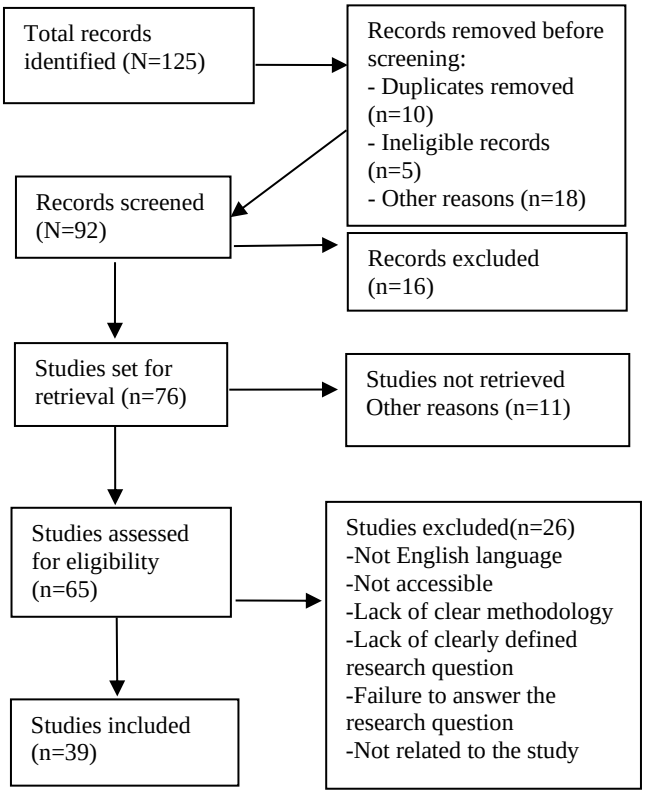

Fig.3, PRISMA Flow Diagram

The table below summarizes the most critical and representative studies included in the systematic review.

TABLE 1 OVERVIEW OF KEY REVIEWED STUDIES

Study Name	***Authors***	***Methods***	***Key Results***
Artificial Womb Technology: A Roadmap to a changing Medico-Legal Landscape	Sampa Karmakar Singh et al.	Examination of bioethical, legal, religious, and social issues related to AWT.	Analyzes bioethical issues, including potential misuses like human trafficking, genetic modifications, cheap labor, organ harvesting, and unethical scientific experiments. Emphasizes the need for a strong ethical framework before implementing AWT.
Artificial Womb Technology and Clinical translation: Innovative Treatment or Medical research	Elizabeth Chloe Romanis	Ethical analysis of AWT terminology and implications.	Ethical concerns about mis-defining AWT, risk and benefits assessment, and need for clear communication during consent process. Calls for careful approach but lacks detailed recommendations.
Ectogenesis is for Feminists	Claire Horn	Socio-ethical analysis of AWT and reproductive autonomy.	Critiques AWT's potential misuse for sex selection and abortion, highlights socioeconomic impacts, and emphasizes the need for supportive social environment.
Fertilisation in Artificial Womb Legal and Bioethical Issues	George G. Tumanishvili and Marco Poli.	Exploration of AWT's impact on gender equality and exploring potential legal contractual resolutions to deal with the AWT process.	AWT's potential to promote gender equality and the risk of reinforcing gendered supremacy; emphasizes the need for addressing broader social inequalities. Service contracts implementation are most suitable to avoid parental rights issues.
The path toward ectogenesis: looking beyond the technical challenges.	Seppe Segers	Technical and legal analysis of AWT, comparison with surrogacy and UTx.	Discusses surgical risks, potential coercion of women into AWT, and legal frameworks for AWT. Highlights the need for new legal frameworks.
Transparency, consent and trust in the use of customers' data by an online genetic testing company: an Exploratory survey among 23andMe users.	Aviad E. Raz et al.	Political analysis of AWT's potential for social change.	Argues for AWT's role in challenging social institutions and promoting better access to services, drawing parallels with the "Wages for Housework" movement. Highlights the need for more focus on the revolutionary aspect of AWT over the technological one.

V. Discussion

The consequences of AWT utilization pose serious concerns from a biological, social, environmental, and economic perspective. In this section, the different aspects will be discussed.

A. Mother-fetal Connection

AWT poses challenges by diminishing the crucial mother-fetal bond essential for fetal health. Research highlights the significance of hormonal exchanges, sensory experiences, and the mother's voice and heartbeat in fetal development [10-15]. These factors, integral to the natural uterine environment, provide essential biochemical signals supporting organ development and stress management, aspects that AWT may struggle to replicate fully. Hormonal changes during pregnancy, such as oxytocin release, play a pivotal role in labor and emotional bonding [16]. AWT's potential to mitigate fetal exposure to stress hormones doesn't negate the developmental benefits of the natural hormonal milieu. Furthermore, the argument that this bonding experience has been inconsistent across studies is easily refuted by the fact that inconsistencies in research can arise due to differences in research methodologies, measures, and populations used. Hence, they do not negate the overall trend seen across many studies, especially longitudinal ones. With thorough methodologies, a clear pattern tends to be drawn supporting the connection between prenatal emotions and post-natal behavior. Moreover, multiple studies demonstrate that women who have strong recollections and involvement in maternal experiences during pregnancy exhibit enhanced and more positive maternal behaviour after birth [20-22], as well as how these processes are biologically driven via neuroendocrinological evidence [17, 18, 19]. AWT's proposed benefits in allowing maternal work or minimizing physical changes disregard the profound influence of maternal experiences on bonding and subsequent maternal behaviour. What many authors label as “burdensome” in defence of ectogenesis is, in essence, a fundamental part of motherhood. Naturally, a woman who has her fetus developing in a device, removed from her, is unlikely to develop a strong emotional connection to the fetus and may also become preoccupied with other activities, potentially forgetting about the fetus.

B. Dangerous Sex Selection & Inequity

The ability to control breeding using AWT raises significant ethical concerns, reminiscent of historical eugenics movements [23]. It risks discrimination based on gender, race, and physical features, perpetuating harmful stereotypes and worsening social inequalities under the guise of "positive eugenics." The subjective nature of genetic advantages complicates this issue, potentially leading to coerced reproductive decisions. Genetic preferences vary across societies, and AWT's potential to reduce genetic diversity could impact human adaptability and resilience.

Furthermore, socioeconomic disparities may limit access to AWT, with only the wealthy affording this technology, further dividing society. Marginalized groups, such as racial minorities and those in impoverished areas, could face greater access restrictions, solidifying existing inequities (e.g., black women are 50% less likely to be examined for infertility compared to white women [24]). Restricted access could exacerbate societal prejudice, stigmatizing unplanned pregnancies and those unable to afford artificial wombs. This is already seen in IVF, where the probability of black and Hispanic women receiving infertility treatment was found to be 70% less than that of white women [45,46,47,48,49,50]. Societal views on parenting may also shift, favouring technological reproduction over natural pregnancies, which can place unrealistic expectations on women.

Ethical principles of justice demand that new medical innovations be accessible to all, not just the wealthy. Governments and policymakers must regulate access to prevent escalating social and economic disparities. Without equitable access, reproductive freedom could become a privilege rather than a fundamental human right, raising serious justice issues. Additionally, global inequities could worsen if underdeveloped nations struggle to access this technology, leading to significant variations in reproductive health outcomes across national boundaries.

C. Environmental & Economical Harm

As previously mentioned, AWT's impacts on the economy and environment, though seemingly long-term, are still significant and potentially dangerous. By potentially increasing birth rates and reducing the physical limitations of traditional pregnancy, AWT could exacerbate urbanization and strain resources like food, water, and energy, as shown in figure 4. This increased demand may lead to agricultural expansion, deforestation, soil erosion, and heightened greenhouse gas emissions, further contributing to climate change. AWT's environmental footprint presents the need for careful consideration of its broader ecological implications and the potential economic burdens associated with its development and maintenance.

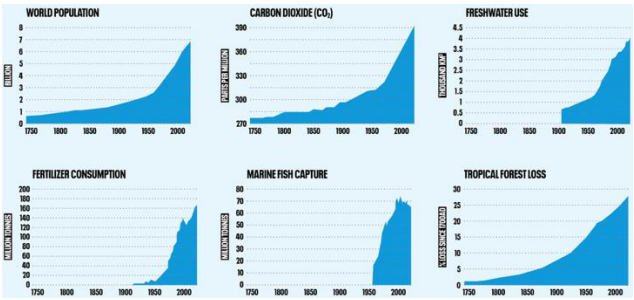

Fig. 4, Population Effect on Environmental Aspects [25]

Economically, the development and maintenance of artificial wombs may strain healthcare systems and increase costs, potentially limiting access to affluent individuals and exacerbating economic inequalities. While AWT could enable women to continue working without maternity breaks, it may also impact productivity and the value placed on childcare support and maternity leave. Moreover, substantial investments in AWT could divert resources from essential social services like housing, education, and conventional maternal and child health programs, compromising long-term sustainability and equity by undermining initiatives to address underlying social and economic problems that fuel reproductive difficulties.

VI. Theoretical Analysis

Theory: Artificial Womb Technology (AWT) will be used for purposes other than infertility treatment and saving premature babies, leading to negative societal, ethical, and cyber implications.

Over the years, the risk of technological misuse and deviation from its intended purpose in digital health technologies has become evident, and Artificial Womb Technology is no exception, potentially facing the same trajectory. In this section, the historical and contemporary examples and patterns of such misutilizations will be explored.

A. Analysis of Misuse Patterns

a) Commercialization

After being created with the intention of improving health outcomes, many digital health technologies have been commercialized, putting profit ahead of patient care. This pattern is evident in the way businesses employ health technology for profit rather than for the good of the patient or sell patient data. Profit-driven behavior frequently results in technological abuse and ethical compromises. The case of Google's Project Nightingale [28], where Google partnered with Ascension (one of the biggest U.S.-based health systems) to collect and analyze patient health data without patient consent, shows the commercialization of health data and prioritization of profit over patient care. Another example involves direct-to-consumer genetic testing technology, which was first marketed as empowering people with knowledge about their ancestry and health but ended up being misused by many companies to sell genetic data to third parties. In 2018, the genetic testing company 23andMe sold millions of consumers' genetic information to the multinational pharmaceutical company GlaxoSmithKline without getting their explicit consent regarding selling the data to another company [29].

The commercialization of in vitro fertilization (IVF) services has led to the rise of "fertility tourism," where individuals travel to countries with fewer regulations for IVF treatments. Some parents go so far as to use IVF specifically to create and select twin embryos so they can have twins artificially. The financial burden experienced by desperate parents due to the sensationalized marketing of IVF as a result of its commercialization is staggering and, more importantly, has been proven deceitful with many parents around the world. With profit maximization being the end goal of many IVF clinics, it's only natural that aggressive marketing tactics downplay these hardships, creating false hopes and expectations among prospective parents. Furthermore, through Preimplantation Genetic Diagnosis (PGD) with IVF, some parents select embryos with specific genetic traits like eye colour or intelligence. Out of around 1000 people, a study showed that 21% and 14% were in favour of using PGD for sex selection and physical traits, respectively [30]. This already-existing sentiment can be further facilitated and exacerbated by AWT, leading to misuse of the technology. In addition to their apparent genetic superiority or particular physical characteristics, donor eggs and sperm have also been sought after for non-medicinal purposes. This has created a market in which donors are chosen based on desired characteristics, often mimicking a business deal.

Pre-natal genetic testing, which is done to inform if the fetus has any aneuploidies (down syndrome, Edwards, etc.), has been abused by parents to abort babies based on their gender. Private institutions in the UK, for instance, offer expecting parents the chance to know the baby's gender for around 200 pounds, and multiple women have been aborting or being forced to do so due to dissatisfaction with the gender, causing the labour party to call for a ban on blood screening for sex-selective abortions [31]. Whether forced to or not, aborting a fetus for not being the desired gender is wrong in all aspects, both ethical and legal.

Surrogacy is another example of an infertility alternative that has become so commercialized that a new term, 'commercial surrogacy,' had to be coined to distinguish it from traditional surrogacy, where women are not financially compensated for carrying the child. Figure 5 illustrates the anticipated market growth for surrogacy. The concern then with such growth is the misuse of surrogacy where women are being paid to carry a child for intended parents who may not have medical infertility issues, but simply choose surrogacy for convenience purposes or to avoid pregnancy-related changes to their bodies. Even more troubling is the exploitation and trafficking of surrogate mothers and their children, a direct consequence of the commercialization of surrogacy, which operates as a multi-billion-dollar industry driven by profit and demand [33].

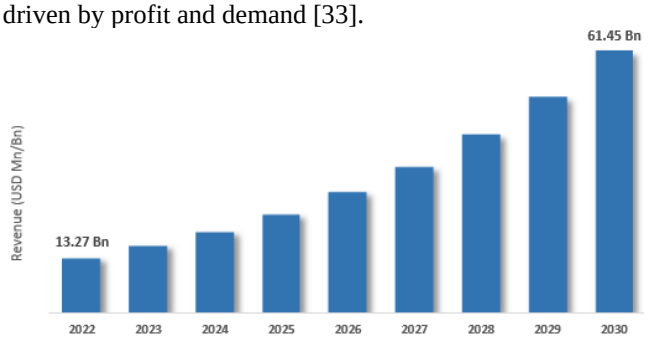

Fig. 5, Global Surrogacy Market 2030, [32]

Hence, a clear pattern emerges with reproductive technologies and alternatives veering towards misuse over time. It is evident that although AWT holds promise for treating infertility or saving prematurely born babies, it could also be commercialized and misused for non-medical purposes. There is a risk that AWT could be used for cosmetic or convenience purposes, such as creating designer babies (i.e., infants with selectively chosen genetic characteristics), thus prioritizing appearance or profit over ethical considerations and medical necessity, and worsening social inequality and previously discussed ethical dilemmas.

b) Bias & Inequality

Digital health innovations, despite promising improved diagnostic accuracy and efficiency, have exacerbated pre-existing prejudices and disparities in healthcare. AI diagnostic systems, for instance, can perpetuate biases present in their training data, impacting patient treatments directly. In healthcare, this widespread issue in AI systems poses a direct threat to patients' lives and treatments. In skin cancer diagnosis, significant biases were found in 21 public image datasets, with limited representation of darker skin tones and ethnic diversity [34]. Of over 106,950 photos, only 2,436 included skin type information, with minimal

representation from African, African-Caribbean, and South Asian origins. Similar biases have been observed in AI tools predicting patient care needs, where prioritization favored white patients over others, leading to disparities in access to necessary care [35]. Ethnic women of Hispanic, Black, and Asian backgrounds often receive less accurate diagnostic results from AI-powered tools [36], highlighting pervasive inequalities in healthcare AI.

Therefore, like other AI-based technologies, AWT systems may exhibit biases if trained on non-representative data. This can result in unequal or inaccurate treatment across demographic groups, potentially increasing health risks for underrepresented populations. For instance, if an AI system monitoring fetal development in artificial wombs is predominantly trained on data from white populations, it may inaccurately identify complications for fetuses of African, Asian, or Hispanic descent. Fetal growth restriction (FGR), which varies across ethnicities, illustrates this issue, where measurements based on white population data may inaccurately flag normal conditions for fetuses of Asian descent as potential FGR cases [37]. Such errors could lead to unnecessary stress, medical interventions, and premature deliveries. Moreover, combining AWT with genetic editing could perpetuate discrimination by selecting for traits associated with specific racial or ethnic groups, further exacerbating social injustices.

c) Privacy and Security concerns

Significant privacy risks are brought about by digital health technologies, particularly by their misutilization. A common example is health applications, which monitor and enhance wellbeing, often take use of user data for profit. Businesses frequently gather a great deal of personal health data and then, without explicit user authorization, share it with advertising and other third parties, putting profit ahead of user privacy and moral principles. In 2018, the fitness app Strava heat map function unintentionally disclosed the locations of covert military installations, posing serious security dangers [40]. Premom, an ovulation tracking app which takes in over thousands of users' pregnancy, menstrual cycle and fertility data, violated Health Breach Notification Rule (HBNR) by not only disclosing sensitive users' data to third parties, but also failed to notify users of the breach. The responsible corporation consistently misled users by falsely assuring in its privacy policies that it wouldn't share their health data with third parties without consent. It also claimed any collected data was non-identifiable and solely used for internal analytics or advertising. However, they neglected to adequately mitigate privacy risks from third-party automated tracking tools (SDKs) [43].

Prescription Drug Monitoring Programs (PDMPs) are another technology that have been misused by authorities, posing not only privacy risks, but ethical and legal concerns as well. Initially designed to monitor opioid prescriptions and mitigate the opioid crisis, PDMPs have expanded considerably, which led to the incorporation of PDMP data with criminal justice records, a practice that offers no discernible benefit to healthcare providers [44]. It does, however, lead to fear of legal repercussions (patients may avoid visiting healthcare providers or being honest about their conditions if they suspect their information could be used against them in a legal context), erosion of the doctor-patient relationship resulting from distrust, potential misuse of data beyond its intended scope (individuals might be unfairly targeted for drug offenses based on their prescription history, even in the absence of criminal behaviour), lack of contextual understanding leading to misinterpretations, discrimination and bias (vulnerable populations, including individuals from low-income backgrounds and communities of colour, may be disproportionately targeted), and profound legal and ethical concerns surrounding patient autonomy and confidentiality (as law enforcement can access patient data without their consent).

These examples show that despite the presence of rules, regulations, and cyber-protective measures, digital health technologies continue to be misused – by both attackers and their owners, often for profit. The fate of AWT may not be any different from these past reproductive and digital health technologies.

VII. Conclusion

Artificial Womb Technology (AWT) represents a ground-breaking innovation with immense potential to revolutionize reproductive healthcare by offering solutions for infertility and improving outcomes for premature babies. However, the ethical, social, legal, economic, environmental, and cybersecurity challenges associated with its development and implementation cannot be overlooked.

From ethical dilemmas surrounding the nature of parenthood and the potential for misuse in creating designer babies to concerns about privacy, security vulnerabilities, and exacerbating social inequalities, AWT demands careful consideration and regulation. The commercialization of reproductive technologies in the past has shown a tendency to prioritize profit over ethical considerations, leading to exploitation and societal division. AWT, if not ethically governed and regulated, could follow a similar path, risking further inequities and ethical dilemmas in healthcare.

Moreover, cybersecurity risks underscore the critical need for robust protective measures to safeguard sensitive data and ensure the integrity and safety of fetal development in artificial womb environments. Recent incidents with digital health technologies highlight the vulnerabilities even in well-intentioned systems, emphasizing the importance of proactive cybersecurity strategies in AWT.

In conclusion, while AWT holds promise for medical advancements, its ethical implementation and responsible regulation are paramount. Addressing these complex issues in AWT requires interdisciplinary collaboration among policymakers, healthcare professionals, ethicists, and technologists to develop frameworks that prioritize patient safety, equity, privacy, and societal well-being, just as with all other AI-based systems. Moreover, the role of policymakers and legal bodies is of utmost importance in the implementation of AWT, as it should not be taken lightly. It must be governed strictly to determine who can use it and under what circumstances, ensuring it is applied based on *genuine* need and does not end up being misused or exploited for other non-medical reasons, as IVF and previously discussed reproductive technologies have been. By doing so, the potential of AWT can be harnessed while mitigating its risks, ensuring that future generations benefit from this transformative technology in a fair and equitable manner.

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