# GLOBAL ACADEMIC RESEARCH INSTITUTE

COLOMBO, SRI LANKA

## GARI International Journal of Multidisciplinary Research

ISSN 2659-2193

**Volume: 07 | Issue: 04**

On 31st December 2021

http://www.research.lk



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GARI Publisher | Digital Fashion | Volume: 07 | Issue: 04

Article ID: IN/GARI/ICATFD/2021/203 | Pages: 73-86 (14)

ISSN 2659-2193 | Edit: GARI Editorial Team

Received: 17.10.2021 | Publish: 31.12.2021

# SYNC: THE PHYGITAL T-SHIRT. A TEST CASE FOR DECENTRALIZED FASHION CUSTOMIZATION UTILIZING BLOCKCHAIN TECHNOLOGY AND LOCAL PRODUCTION

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## *ABSTRACT*

The phygital NFT climate t-shirt test case proposes a new fashion pipeline emerging from digital spaces, local production, and physical fashion. The test case discusses advanced garment tools and processes for interactive 3D garment design, the processes which utilise blockchain technology to create an NFT from the garment design, the additional NFTs which include parametric sewing patterns, and local construction processes, which together create a global lingua franca for practicing fashion localism. The test case furthermore discusses the ecological footprints of the tools and processes involved at each step to address climate impact directly from the garment design stage. The non-fungible token or NFT is an opportunity within the global pandemic for initial testing of decentralized fashion production. Utilizing parametric patterns developed in Rhinoceros 3D CAD software, an interactive 3D design and digital files were produced and analyzed. The 3D virtual garment was then minted on the Tezos blockchain (which uses a proof-of-stake consensus algorithm), via the experimental Hic et Nunc website. The collectors of the NFT were sent a second token minted on the same blockchain. The secondary token contained the layouts for 6 sizes of the t-shirt formatted for digital textile printing. Once the size is chosen, the layout is sent to regional textile printers and then constructed by local tailors within one's home village or city. The methodology of the phygital fashion process diverges from tradition to reconnect consumers with production processes both globally and locally, acknowledging the ecological footprints along the way.

Keywords: Digital Fashion, Non-Fungible Token, Decentralized, Blockchain, Customization

## *INTRODUCTION*

This paper discusses and demonstrates a new phygital fashion process emerging from digital processes, local production, and physical fashion. The test case of the Phygital T-Shirt demonstrates the use of advanced garment tools for interactive 3D fashion design, blockchain fashion design and production distribution and local construction processes. These digital processes when used in a multi-method approach create a new process for practicing fashion localism. The paper further discusses the methodology and workflows of the phygital fashion process diverging from current industry practices to reconnect consumers with production processes both globally and locally, acknowledging the ecological footprints along the way.

The main motivation for developing this process stems from the many issues of industrialized fashion. The global fashion carbon footprint ranges from 8-10% of global greenhouse gas emissions annually, ranges are used as the exact amount of the problem is unknown (Quantis, 2020) making fashion a classic wicked problem.

Complexities and contradictory solutions arise leading to rebound effects exacerbating existing fashion industry problems. It is important to understand that the implementation of single measures (e.g. circular design) will not make the apparel sector sustainable in the long term (Quantis, 2018). Experimentation with multi-method and agile systems to change the linear fashion supply chain alongside use of sustainable design, materials, direct to garment printing and local production may be more effective at decreasing fashion's footprint. Long term habitable planet goals require an 80% reduction in GHG emissions by 2050 with the understanding that different improvement measures must be applied in parallel (Rockstrom et al., 2009).

**Approach**

The test case presented implements several approaches which were key to guide the development of the Phygital T-shirt. The first approach describes the principles of phygital degrowth as a hybrid design workflow for creating both digital fashion assets and production data. The second approach describes the benefits of blockchain technology for distributing design and production data. The third approach describes the direct to garment and local production workflow. These approaches work in concert to shape the Phygital T-Shirt.

The physical and digital worlds of fashion design combine creating phygital fashion, or fashion that exists both digitally in the metaverse and physically in the real world. The metaverse are the perceived three-dimensional (3D) virtual spaces created and shared virtually and in augmented realities. The creation of 3D digital fashion has led to the virtual self-expression via one's unique online personalities. Digital fashion can be created in the physical world once the digital design has been translated into a functional sewing pattern and constructed. The process from digital fashion to physical fashion can be customized and changed rapidly, creating an agile system valuing customized fashion pieces via advanced garment tools (AGTs) (Bigger, 2019). Degrowth movements are often seen as opposing capitalist growth, and can be applied to enrich the value of physical fashion. The increase in customized fashion value could decrease the consumption of fast fashion, reducing production volume and directly decreasing the carbon footprint of the fashion industry. Phygital degrowth can be viewed as a movement using the combined physical and digital fashion worlds to decrease fashion consumption in order to halt capitalist growth decreasing negative environmental impact. Because of the nature of both digital and physical carbon footprints, such a movement must work in tandem cautiously, aware of rebound effects from both realities

The decentralization of fashion is necessary for the industry to pivot towards the rapid decrease of climate impact. Decentralization is the process of redistributing or transferring the power of decisions from one authority to a group. The fashion industry's top 20 companies account for 97% of the economic garment profit, and are referred to as 'super winners,' 12 of the 20 companies have been in the 'super winners' category for a decade (McKinsey & Company, 2018). In order to decrease fashion's carbon footprint, a shift from large enterprise mass production models to decentralized locally produced fashion could decrease overstock waste, chemical use/effluents and transport emissions. Advanced garment tools, including blockchain technologies, provide a unique opportunity for transition of power and transparency from 20 to millions of small and medium size enterprises. Partnerships between fashion designers, patternmakers, and sewists can also include consumer groups that are sufficiently invested and interested in the development of content from the creators. Such a collective could be run as a Decentralized Autonomous Organization (DAO) (Chohan et al., 2017). which would allow it to make decisions about the kind of content desired without any centralized authority to manage decision making.

Direct to garment printing uses garment layout patterns to print textile designs directly onto the textile for single or multiple garments. Digital printing allows the printing of less than a meter of textile and is thus an ideal technology for customization and degrowth fashion movements. The process of using digital printing in place of large batch dyed textile order can drastically reduce water effluents from production and user care lifecycles. When consumers practice localism they choose how and where their garment is constructed utilizing local talent and craftsmanship.

The consumer effort to turn away from the instant gratification of an online order arriving the next day to a few weeks for a customized, digitally printed and locally produced garment is a challenge to the consumer's mindset and values. The transition away from mass production supply chains to local production has the possibility to eliminate shipping emissions, unethical labor practices, garment return rate, and fit issues

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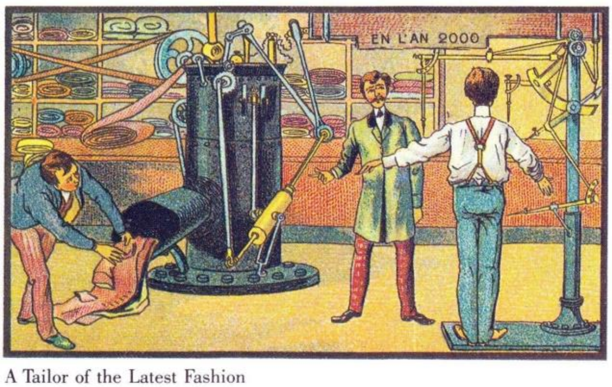


Figure 1. A Tailor in the Latest Fashion by artist Jean-Marc Côté (Côté, 1900)

Background and Related Work

Digital fashion was envisioned in the year 1900 by artist Jean-Marc Côté in his series "France in the year 2000." The images were printed and enclosed in cigarette and cigar boxes around the time of the 1900 World Exhibition in Paris. The image shows two machines, one measuring a man standing straight with arms to his sides and the other machine producing a suit jacket. The artist's vision became reality in the early 1990s with some of the earliest adopters, the United States menswear brand Brooks Brothers, using body scanning devices and even trademarking the phrase 'digital tailor' in 2001. Digital tailoring is the process of using computational devices to take body measurements and create sewing patterns, including the use of body scanning devices. Computer aided design (CAD) systems originally focused on fit and patterning issues within the industry only later to be used for digital fashion design.

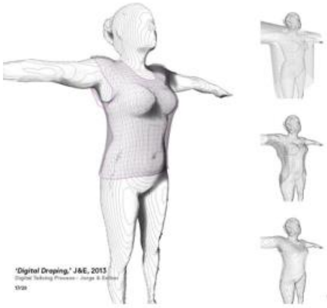


Fig. 2a Jorge & Esther Digital Tailoring & Draping (Jorge & Esther, 2013)

Fig. 2b Nervous System & Body Labs 4D Kinematics dress image (Nervous System, 2014)

There are several examples of early digital fashion workflows. Early systems of digital fashion include Jorge & Esther's Digital Tailoring (fig.2a) with textile simulation (Jorge & Esther, 2013) and Nervous System and Body Labs 4D printed Kinematics dress in 2014 (fig.2b) (Nervous System, 2014). Digital fashion brand Fabricant in 2019 became known for their digital fashion designs walking in mid air, without bodies inside the garments, creating a new way for digital fashion to catch mainstream attention (Larosse, 2021). CAD systems for digital fashion creation are well suited for 2D pattern drafting, but for 3d garment design and textile draping there are limited options. These include CAD software focused on animation and which employ varying algorithms to approximate textiles for animation. Digital fashion designs can be used in gaming, virtual worlds and marketing. For Côté's vision to become a reality, specific algorithms are needed to ensure the deformation of the virtual 3D garment textile is precise enough for the creation of the garment sewing pattern.

Digital fashion assets are typically 3D creations sold as non-fungible tokens using decentralized apps via blockchain in exchange for cryptocurrency.

Conceptually, a blockchain is a collection of transaction records linked together via secure cryptographic algorithms. Once recorded, blockchain data cannot be altered. Blockchain transactions can be used to track the trade of tokens from one entity to another. A token can be "fungible" or alterable, or non-fungible which means it is immutable. On a blockchain a fungible token might be the currency, since it can be exchanged for something else with a similar value just like gold or the Euro can be exchanged for other goods. A non-fungible token (NFT) has no predefined value, so it cannot be directly exchanged for another NFT without some mediation that decides if the exchange is valid. An NFT derives its value by that which it represents, like a certain picture, video, or garment pattern. Technically an NFT is a record which links to a digital asset. The digital asset is typically not stored on the blockchain itself, but on the Interplanetary File System (IPFS), a decentralized and globally distributed file storage network. NFTs are a tradable digital asset, and can be collected by exchanging cryptocurrency for the NFT. Certain blockchains support smart contracts which are programs that are stored on the blockchain. Smart contracts can be used to execute

specific actions when called upon, for example, a smart contract could be called upon the collection of an NFT which manages the splitting of the royalties between multiple entities involved in the creation of the NFT media. Smart contracts enable further decentralization in this collaborative scenario. Phygital fashion can operate in a decentralized manner, offering a transparent and collaborative environment for all of the different stakeholders by making use of currently available blockchain technology.

One example is Saint Fame, formed in November 2019, claiming to have been the first DAO fashion house via the Ethereum blockchain (Saint Fame, 2019). Saint Fame produced an experiment in "speculative fashion," of a long sleeve black t-shirt designed by Matt Vernon. Eight hours of the designer's time were purchased using their own cryptocurrency and the final design approved via vote from the Saint Fame DAO. A DAO is an important aspect of the decentralization of fashion, phygital degrowth and decreasing fashion's carbon footprint. Accountability for fashion design and production decisions can be traced back to the DAO's voting, increasing the understanding of what is important to the DAO's stakeholders. Another example on Ethereum blockchain is Digitalax's Global Designer Network DAO formed in 2021 and specifically for fashion items that 'only exist in their digital environment.'(Digitalax, 2021). Other platforms for digital fashion have hosted many fashion houses' first forays into digital fashion from Stella McCartney to Karl Langerfield. Footwear is also among popular use cases for phygital fashion and NFT uses. Sneaker design firm RTFKT's NFTs can also be used as a token to get a free physical version of the shoe, but one in 20 customers do not redeem that token (Reuters 2021). The early adoption of consuming digital fashion items and not physical items shows a potential for degrowth, if digital footprints are taken into account.

Blockchain technology enables a host of new economic models by decentralizing the validation of each transaction to a network of nodes which process a block of transitions and update the chain with the new block. How each blockchain decides which node gets to process the transaction depends on the blockchain consensus mechanism. A consensus mechanism allows a distributed system to agree on the status of the blockchain in a secure yet trustless manner. Consensus mechanisms (also known as consensus algorithms or consensus protocols) are widely used in distributed database systems. New consensus mechanisms have been developed specifically for blockchain technologies. While there are many consensus mechanisms in operation, we will discuss Proof of Work and Proof of Stake as they are used in the blockchains most relevant to the themes of this paper.

In a blockchain which uses a Proof of Work (PoW) consensus mechanism, the network nodes compete to process the next block of transactions by attempting to solve a complex math problem. Nodes with more computation power, typically using many high end GPUs, can solve these problems faster at the cost of high energy consumption. Bitcoin and Ethereum are blockchains which use PoW consensus mechanisms. In a blockchain which uses a Proof of Stake (PoS) consensus mechanism, nodes can participate in processing blocks of transactions if they stake a certain amount of currency. Nodes that have a higher stake have a higher chance of being chosen to process the next block. Different blockchains will have different rules for node selection. While PoS does incentivise those that can stake more currency, it does so without the energy cost of PoW. Tezos and Cardano are blockchains which use PoS consensus mechanisms.

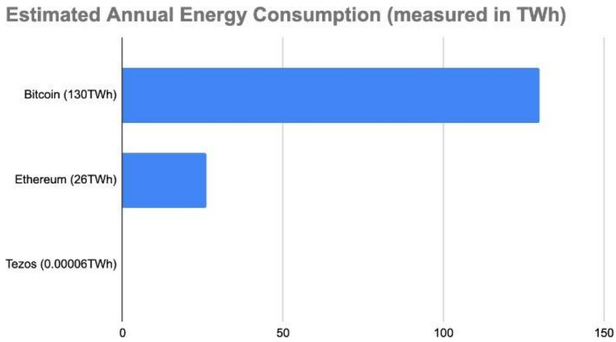


Fig. 3 Estimated annual energy consumption of Bitcoin, Ethereum and Tezos Blockchains (Wiki.tezosagora.org, 2021)

Comparing the energy consumption of different blockchains is not a straightforward task, especially since the very nature of these systems is running as a decentralized and distributed network where the hardware for each node can vary significantly, as can the cost of energy from one country to the next. The University of Cambridge maintains the Cambridge Bitcoin Electricity Consumption Index which tracks the overall energy consumption of the Bitcoin network since January 2017. The index provides a comprehensive statistical analysis of the energy consumption while at the same time acknowledging the limitations of such an analysis through a series of assumptions such as assuming the energy cost is the same across the world, that nodes are always running the most efficient hardware, etc. In figure 3 the energy consumption of Bitcoin, Ethereum, and Tezos blockchains were compared. The result shows that Ethereum and Bitcon (both PoW blockchains) require orders of magnitude more energy to operate than Tezos (a PoS blockchain). Again, this comparison is not without its limitations but the overall trend is that Proof of Work blockchains consume more energy.

Energy consumption and carbon footprint have been a key factor in blockchain adoption for certain use cases, like art and other collectible NFTs. In February of 2021, Joanie Lemercier, a French artist and environmental activist published an article where they outline the benefits of using blockchain technology and NFTs for publishing and selling art as well as the environmental issue with Proof of Work blockchains (Lemercier, 2021). Artist Memo Atken in the same time frame created a public NFT calculator, in which one could input the address of the NFT and it would calculate the carbon footprint of the piece (Atken, 2021). Both of these resources changed the landscape of NFTs, exposing the carbon footprint readily and early in the 2021 NFT boom. The transition of understanding the carbon footprint of using advanced technologies occurred in months instead of years. The knowledge of different types of blockchain environmental impact is public knowledge, making it unreasonable to mint fashion on carbon expensive PoW blockchains.

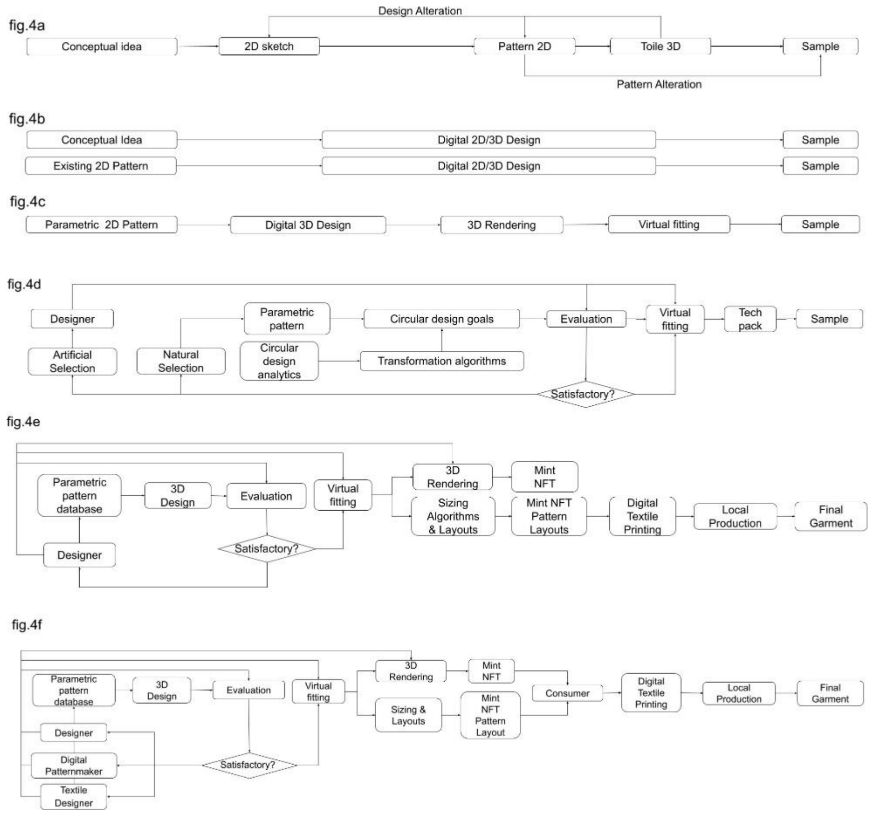


Figure 4. Fashion Design Workflows. Fig.4a shows the traditional fashion design process of conceptual idea, sketch, pattern, toile, and sample developed by Timo Rissanen in 2007 (in McQuillan 2020). Fig.4b shows two versions of the transition from Rissanen's 2D workflow to a 3D CAD workflow for the zero-waste fashion method (in McQuillan 2020). Fig. 4c shows the 3D interactive fashion design process including rendering and virtual fitting processes.

Fig.4d is the generative garment design workflow for inclusion of circular analytics data via multi-objective optimization (Bigger, 2021). Fig 4e is the phygital fashion design to production workflow. Fig. 4f is the proposed workflow for collaborative phygital fashion design to production which includes the consumer within the workflow.

## *METHODOLOGY & WORKFLOW*

The methodology and workflow to create the SYNC Phygital T-Shirt are discussed and illustrated via figure 4. Fig. 4a shows the traditional fashion design process of conceptual idea, sketch, pattern, toile, and sample developed by Timo Rissanen in 2007 (in McQuillan, 2020). Fig. 4b shows two versions of the transition from Rissanen's 2D workflow to a 3D CAD workflow for the zero-waste fashion method featuring the hybridization of the multiple iterative steps of 2D sketching, 3D draping, 2D pattern cutting, and 3D sample into a single 2D/3D design process (McMillian, 2020). In fig. 4c we introduce the two additional stages of 3D rendering and virtual fitting to create a 3D interactive fashion design workflow. The generative garment design workflow (Bigger, 2021) in fig. 4d shows a generative evaluation process formulated to include circular design optimization. The generative evaluation process and use of parametric patterns is mimicked in the phygital t-shirt design process.

The SYNC Phygital t-shirt workflow is shown in fig. 4e, beginning with a parametric pattern from GenCloth's unisex t-shirt parametric block/sloper (Gencloth, 2020). Parametric patterns are formed from scripted algorithms in Grasshopper3D and have variable values set for design attributes such as silhouette, hem lengths, as well as sizing. The pattern visualizes various design modifications to the garment or block/sloper which depend on several geometric rules such as dynamic seam lines altering silhouette, textile variables, fit, or construction rules (Bigger, 2021). Pattern modifications were made to the algorithm to the armscye, neckline and sleeve to transform to the dolman sleeve design. The textile design of the dolman sleeves, of various words regarding sustainability, was created to visually mimic a solid color sleeve style without using a secondary bulk dyed fabric during the evaluation phase to decrease the effluents of the t-shirt. The textile design was created in a separate 2D Rhino file and applied to the sleeves and the neckband and the front and back text were placed. The next stage uses the file in two different subsequent processes, one of the 3D rendering and on for the production files. For the production files the parametric patterns adjusted their sizing algorithms for six different size layouts. The size layout adheres to textile print dimensions for digital textile printing of the design.

The 3D rendering process involves a stitching algorithm created in Grasshopper3D and applied to the parametric pattern. Then a digital textile draping algorithm is applied to the pattern geometry via the Kangaroo physics engine integrated into Rhino3D. From Rhino, the model was exported as an FBX file, a format accepted by Adobe's Mixamo software. Mixamo automates the rigging of an anthropomorphic 3d model in order to then animate the 3d model. Rigging is a term used for the simple skeletal structure associated with a 3d model for the purposes of animating it. For Mixamo to accept and automate the rigging of the 3d model, the software must be able to identify a basic anthropomorphic figure with limbs, joints, and a head. Due to this, the 3d model prepared in Rhino included the body as well as the garment because Mixamo cannot properly identify all of the necessary features with only the garment 3d model. Importing this composite model is successful, and Mixamo is able to automatically apply a rigging structure ready for animation. Once the automatic rigging is complete, one can apply a wide range of predefined motion cycles to the generated rigging skeleton, which in turn animates the 3d model. After the animation cycle has been chosen in Mixamo, the model is ready to be downloaded as an FBX to preserve the geometry, generated rigging, and animation data.

The final 3d model should be in the GLB file format which is an open format developed by the Khronos Group and is the binary version of the glTF format, or Graphics Language Transfer Format. This format supports all of the features necessary to display 3d models on the web, including animation and a standard physically based material definition. It is also the format used in the modelviewer web component which will be used to display the garment on the browser. In order to prepare the final model, the FBX exported from Mixamo is imported into the Three.js Editor. Three.js is an open source JavaScript library for WebGL and has an example editor which allows a user to import and export various supported file formats, among them, FBX. Once the model is imported, we delete the body mesh, as we are interested in keeping only the animated garment. Once deleted, we can check the final 3d model to ensure it is lit and animated in the desired manner. The model can then be exported as a GLB which will contain the geometry, materials, textures, lighting, and animation data.

Hic Et Nunc (HEN) is a decentralized application (dapp) which allows its users to create and manage decentralized digital assets. A dapp is an interface by which a user can interact with a blockchain. HEN was initiated early 2021 and developed by Rafael Lima, a Brazilian developer and is currently maintained by him and a community of contributors. The HEN user interface (UI) on hicetnunc.xyz is an interface to a smart contract on the proof of stake Tezos blockchain which includes functions to create or mint a digital asset and offer the asset for sale (also known as swapping on HEN). When a user creates a digital asset, they create an NFT with transaction data stored on the blockchain, and associated metadata and media are stored on the Interplanetary File System (IPFS). Users can create NFTs from a variety of media formats, including scalable vector graphics (svg), 3d models (glb), pdf, and html/javascript assets as well as more common media formats such as jpg, mp4, mp3, etc. HEN was chosen for this test case because it was the most developed NFT marketplace on Tezos at the time, providing a wide range of supported media types which were necessary for the project. HEN also has an active community of developers, artists, and collectors which provide a direct audience for the project.

To create a new digital asset as an NFT is called 'minting'. Through this process one defines the media, metadata, number of editions, and royalties associated with this new NFT. The metadata includes the NFT title, description, and tags. At the time of minting one must also specify the number of editions of this particular NFT as well as the royalties that will be awarded to the NFT creator upon each sale of the asset. The royalties can be from 10-25% and ensure the creator receives a portion of the secondary sales. Once this information is defined and completed via the minting UI, the creator initiates a call to the HicEtNunc smart contract, which in turn, makes a request to the creator's wallet to confirm the request and pay the fees for minting.

These fees include a storage fee to store the transaction on the blockchain and can vary depending on the demand of the network, but at the time of writing are approximately 0.30€ per transaction. Once the request to mint has been accepted by the creator in the wallet interface, the HicEtNunc smart contract finalizes the minting process and the NFT eventually appears in the creator's profile page on the HicEtNunc UI.

While the NFT has been created or 'minted' it is not yet available for collection by others. At this point, the NFT could be sent by the creator to another address via the creator's wallet, or the creator could offer this NFT for collection. Offering the NFT for collecting by others is called 'swapping' and is also done via the HicEtNunc UI. When swapping, the creator chooses the number of editions to make available and the cost of each edition. The cost is specified in tez, the Tezos cryptocurrency. Once the number of editions and price is chosen, the creator initiates a call on the HicEtNunc smart contract to swap the asset from the creator's wallet over to HicEtNunc, where they will be made available for collecting by other interested parties.

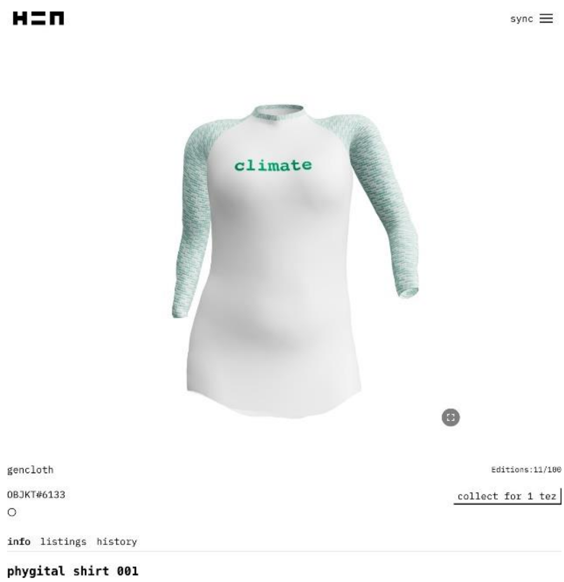


Fig. 5 The Phygital T-Shirt listing on HicEtNunc platform

For the Phygital T-Shirt we minted an NFT of the animated interactive 3d garment with 100 editions and the minimum royalty at 10% (fig.5). There was a second NFT created of the 2D garment pattern in six sizes, to be transferred to the collectors of the 3d Garment NFT. This second NFT is a multipage PDF, of the 2D garment patterns, ready for digital textile printing (fig.6). 20 editions of the NFT were swapped at 1 tez each and eventually 6 were collected

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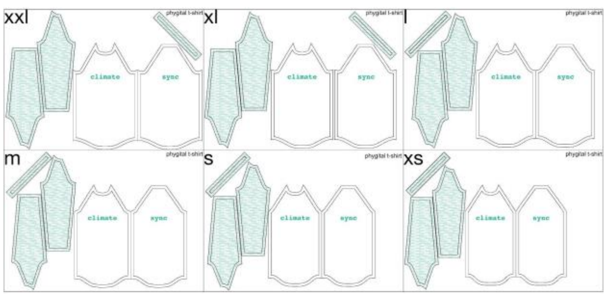


Fig. 6 The Phygital T-Shirt sewing pattern layouts

The 2D garment patterns in the chosen size were uploaded to the digital textile print shop, Spoonflower in Berlin, Germany. This service was chosen both for proximity (EU) and for the variety of fabrics available. Organic cotton knit textile, 142 cm wide and 215g per sq meter, was chosen for the t-shirt. It is certified organic cotton by Global Organic Textile Standards (GOTS) and estimated shrinkage is 2-4% in length and 6-8% in width (Spoonflower, 2021). The phygital tee design was placed in center to be printed on 51.13 inch x 36.01 inch at 328 pixels/inch. Digital textile printing is environmentally beneficial, reducing the water usage from dyeing textiles by 95% and the power usage by 75% (Fashion Marketer, 2014). The ability of digital textile printers to print any yardage amount, is an example of an advanced technology for bespoke local production. The fabric and pattern printed (fig. 7) was received and pre-washed on a low energy cotton cycle prior to construction. The sewing of the garment was done locally on a domestic machine and construction leisurely completed

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Fig. 7 The digitally printed Phygital T-Shirt cotton knit

**Challenges and Future Works**

Phygital fashion faces digital and physical challenges in design, production, and environmental footprints. Fashion design can transition from the top-down system of the fashion industry to a collaborative customization event, in which the co-creators can share in creation and royalties from the sales and resales of the physical garment and digital files. Collaborative on-chain contracts create a decentralized and transparent environment for subsequent garment economies.

This empowers the involved constituency of stakeholders (fig. 4f); textile print artist, digital patternmaker, fashion designer, generative analysis system, and consumer in new and dynamic ways. Transitions in industry are not without critique, and the NFT movement has been met with volatile reactions. The argument for DAO to revolutionize the production industry can be found similarly in historical movements, such as the recent maker movement, however could be considered less reliant on physical maker spaces.

Currently customized digital fashion faces challenges in the creation of reliable 2D sewing construction patterns from a 3D model. Animation software which includes textile simulation uses mathematics and physics which approximate fabric behavior in exchange for better performance. Using such software results in imprecisions which make the developed 2D patterns unusable for reliable physical construction. Additional algorithms are needed to ensure that pattern properties such as surface area and border length are preserved when developing the 2D pattern from the 3D model. Integrating sizing systems, vanity sizing or ease allowance into the pattern design algorithm all create variables for the possibility of fit challenges.

Furthermore, the construction of the generated garment from the 2D pattern relies on the creation of a fashion production lingua franca, or visual guide, transforming sewing languages so that anyone in the world would be able to follow specific methodology denoted for the garment design production. Further challenges are faced when regional textile printers use different textiles and local talent uses different construction methodologies for one design, creating regional customized fashion.

Collaboratively customized phygital fashion could help prevent the creation of obsolete stock which contributes to the 45 million megatons of clothing disposed annually, 75% of which is landfilled or incinerated (Ellen MacArthur Foundation, 2017). While the physical side of phygital fashion remains exploratory, the process of collecting NFT fashion could be a prevention method for the fashion waste created from compulsive buying behavior. Social media trends such as outfit of the day denoted by the hashtag #OOTD promotes wear-it-once behavior where a proof-of-stake NFT fashion garment could fulfil the need for social media expression without the physical product footprint. “A t-shirt used once and then discarded to a landfill has 100 times greater production-burden environmental impact than a t-shirt used 100 times before being discarded”(Laitala et al., 2018). The caution for such future fashion workflows remains in understanding the carbon footprint prior to production and consumption. A standard cotton t-shirt has a lifetime carbon footprint of 4.3 kg of $CO_2$ (Kirchain et al., 2015), therefore digital processes need to account for the additional digital carbon costs. In reviewing 18,000 CryptoArt NFTs, Memo Atken found the average NFT on PoW chains have a footprint of around 340 kWh, 211 Kg$CO_2$ (Atken, 2021). A single edition NFT can use many blockchain transactions; minting, swapping and collecting. Therefore a mass produced linear phygital t-shirt could carry a $CO_2$ footprint far larger than 4.3 kg of carbon emissions. The Sync phygital t-shirt omits factory and shipping emissions with local production, however is reliant on the agricultural emissions of the source of textile the direct to garment print entity has provided. The phygital methodology of production needs clearer understanding of the carbon emissions lost and gained to evaluate these new processes.

## *CONCLUSION*

The phygital NFT t-shirt test case proposes a fashion pipeline for the next generation of conscious consumers. We have discussed the rapid need for advanced garment technologies, decentralization for degrowth and local production to collaborate as new systems for a climate focused fashion industry. Blockchain technologies are already being used for digital fashion in several use cases including digital fashion NFTs and we demonstrate their use could also support the design, production, and distribution of physical garments. We have discussed and reviewed common fashion and digital fashion design to production workflows, introducing both 3D interactive fashion and phygital fashion workflows. We’ve also discussed that the specifics of the blockchain technology (PoW vs PoS) are important to ensure the phygital fashion process maintains the smallest carbon footprint possible. There are still challenges to overcome, such as the technical necessities of available digital fashion software tools and wider acceptance by consumers of crypto economic systems. We demonstrate a process which dramatically sidesteps fashion’s wicked problem as it relates to climate impact and consumer behavior with the hopes that such a process can be further developed to meet the needs of the next generation fashion industry.

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